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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　博士（工学）　氏名　Pattharaphon Chindasiriphan

学 位 論 文 題 名

# Evaluation of Self-healing Ability of Concrete Produced with Supplementary Cementitious Materials and Superabsorbent Polymer

(セメント系混和材と高吸水性樹脂を混入したコンクリートの自己治癒能力の評価)

Concrete is the most common material for civil engineering constructions. Because of its cost-effective and excellent performance, concrete is reported to be the most general man-made construction material on earth with the annual average production amount of 2.5 tons/person. Structures made of concrete will lose their structural integrity and durability as time elapses, especially those intact with severe environments. Concrete structures are susceptible to cracking during their design service life. Cracks are developed with various reasons, such as shrinkage, hazardous chemical ingress, fatigue induced by mechanical loads, freeze and thawing cycles, and thermal effect. A crack is prominent to increase concrete permeability by generating a pathway allowing harmful chemical agents to infiltrate and exacerbate steel rebar corrosion. It has been reported that a large amount of budget is allocated annually for concrete structural maintenance. Still, periodic inspection and comprehensive maintenance are usually overlooked and insufficient especially for large scale structures requiring to the huge amount of capitals and extensive man powers to carry out. This evidence emphasizes that budgetary constraints are now a global issue which jeopardizes their structural integrity and serviceability, including safety of the people. Self-healing concrete incorporated with cementitious materials has been developed as a sustainable innovative product. It achieves sustainable development goals by prolonging service life of structures, which allows construction sector to minimize labor resources and reduce a global carbon footprint. Self-healing concrete exhibits excellent results for crack closure, permeability reduction and recovery of mechanical properties. However, most of the self-healing applications depend upon prolonging moisture source to activate healing mechanism. This study investigates the benefits of using different types of supplementary cementitious materials (SCMs) and superabsorbent polymer (SAP) to promote concrete self-healing ability.

In the first stage, the effects of fly ash, rice husk ash (RHA) and SAP were experimentally investigated their self-healing performance using thirteen mix proportions with varying supplementary cementitious materials and SAP replacement ratio. Fly ash with high calcium oxide content was selected to control an initial swelling of SAP and to enhance rheological properties of SAP containing concrete. Two types of RHA with high amorphous silica content were selected because their possession of highly reactive pozzolanic properties. The cylindrical cement mortar specimens were prepared with a pre-crack of approximately 0.2 mm wide. The pre-cracked specimens were healed either by continuous water immersion or exposure to wet-dry conditions. Self-healing performance was evaluated through the changes in physical properties such as the progressive decrease in water discharge through the pre-crack, crack closure and the recovery of ultrasonic pulse velocity. Whereas physiochemical and microstructure development associated with self-healing activities were investigated using stereomicroscopy, scanning electron microscopy (SEM), thermogravimetric/differential thermal analysis (TG/DTA), and energy-dispersive X-ray spectroscopy (EDS). The results show that permeability recovery is significantly improved with increase in fly ash and SAP replacement ratio. At the early age,

SAP containing specimens showed a significant water-flow reduction through the pre-crack, which was contributed by the sealant effect of swollen SAP. The results suggested that the coupling of fly ash and SAP in combination achieved a maximum crack closure and permeability restoration of 100% at 28 days of healing which was found associated with the development of self-healing materials such as pore-filling ettringite, the precipitation of calcium carbonate and C-S-H. Despite the coupling effects, rice husk ash and SAP showed slightly lower improvement in water-flow reduction, but they exhibited better results on ultrasonic pulse velocity transmitting time recovery compared to that of fly ash containing specimens, which implies that the specimens in RHA series possess higher self-healing ability in terms of compressive strength recovery and microstructure changes associated with autogenous crack repair due to the formation of denser hydrated products such as C-S-H. Specimens showed an inconsistence trend in self-healing performance in wet-dry exposure caused by insufficient water supply. The uncertainty is mitigated through the existence of either RHAs or SAP due to their application to discharge theirs absorbed moisture and liquid providing for unhydrate-particles. Thus, self-healing activities can be continued in low relative humidity and subsequently promotes permeability reduction by the development of permanent self-healing products emerging to seal the crack. In contrast, the usage of SAP is responsible to increase in total porosity through its initial swelling. This evidence suggested that initial swelling should be minimized at a minimal extent. In contrast, RHAs showed lower disadvantage effects on pore structure distribution because mesopores at their ITZ were filled with calcium and the products of pozzolanic reaction.

In the second stage, the experimental program was designed to evaluate the risk-benefit of using fly ash and SAP as self-healing additives, though it has been proven that SAP is an ideal material to be used in self-healing concrete. Despite of its benefits, inclusive of SAP in concrete might come with downside if the mix design is not well implemented. Particularly, the development of SAP pores during their initial swelling which may generate a bypass allowing harmful agents to penetrate concrete. This problem is usually found associated with a disability to control SAP's initial swelling. Owing to pozzolanic reaction, concrete alkalinity is reduced in present of fly ash. In this stage, the experimental program investigated the risk of carbonation of self-healed mortar specimens made with fly ash and SAP. Self-healed specimens (from stage 1) was stored in air for 2 years. Carbonation resistance was assessed using carbonation depth measured by spraying phenolphthalein. Portlandite and calcite contents were determined using thermal analysis. The results showed that the fly ash containing specimens has lower portlandite content than the non-fly ash containing series resulted by the pozzolanic reaction. Although the average surface carbonation depths show no noteworthy systematic difference between the reference and specimens solely mixed with SAP, the presence of SAP accounts for approximately 4% higher in calcite content formation which may be encountered either by the progress of chemical reaction or the accelerating effect due to possession of a suitable relative humidity. In contrast, it is worth mentioning that the carbonation rate is not significant in terms of carbonation depth as none of specimens suffered with a severe carbonation depth confirmed by phenolphthalein spray test. In conclusion, crack closure shows a positive effect on carbonation depth mitigation.