ABSTRACT

論文の内容の要旨

Performance improvement of self-healing concrete
by development of semi-capsulation technique
for functional effective ingredients
（機能的有効成分の準カプセル化技術の開発による自己治癒コンクリートの高性能化）

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In practical civil infrastructures, the crack appearance and water permeation are considered as the main factors facilitating the deterioration process in concrete or reinforced concrete. Especially in case of water-retaining or underground structures, the above problems cause a significant reduction in the functionality, serviceability and also aesthetic appearance.

It has been known for long time that concrete generally has a certain capability of self-healing. According to literature review, the main mechanisms of self-healing in normal concrete at young age are the continued hydration of unreacted cement particles and the calcite formation at cracks. On the other hand, for old (mature) concrete the precipitation of calcium carbonate at crack site is thought to be the dominant process to fill the crack. However, it is necessary to point out that the healing capacity is very limited in the normal concrete and it preferably occurs in a concrete with low water/binder ratios or using huge amount of cement. Moreover, only very small crack, typically whose width is less than 0.1mm, can be healed. Unfortunately, in practice concretes with moderate or high water-cement ratios are commonly used and real crack width could be larger. Therefore, healing of crack in normal concrete in practice is very rare and insignificant.

Cementitious material incorporating some specific mineral and chemical admixtures, in terms of swelling, expansion and precipitation, as partial cement replacement showed a promising crack-healing effect *(Ahn, 2008)*. However, there were some problems when applying these powders to concrete, such as a significant reduction in the workability of fresh concrete and in

self-healing efficiency of hardened concrete. This was due to unavoidable further reactions between the embedded powder, water and other products during the mixing and hardening process of concrete.

To overcome mentioned-above obstacles, the concept of granules having semi-capsulation effect, in which self-healing powder was stored inside by introducing a coating layer of cement compound, was proposed by Koide & Morita 2010. That approach was developed based on a conventional granulation technique used in food/medicine industry. At that moment, granules made by a conventional granulation method did not fulfill the requirements of granules having semi-capsulatopn effect due to immature of technique development and also the lackness of basic design concepts. Therefore, the performance of concrete incorporating those granules was not so good. Moreover, the manufacturing cost of granules was still high and a special granulator was required that further restrained the possibility of applying this technique to construction industry. However, this approach was believed to be a preferable concept to introduce self-healing properties to concrete. It has a potential for long-term preservation of healing capability as long as a crack ruptures embedded granules and is exposed to water. It is necessary to develop a semi-capsulation technique for powder material.

Due to its own advantages and high potential to improve the healing performance and manufacturing cost, self-healing granules having semi-capsulation effect (proposed by Koide & Morita, 2010) were chosen as research approach in this study.

The aim of this research is to improve the self-healing performance of granules in concrete by enhancing the semi-capsulation technique and try to apply this sort of approach to practical construction industry. In order to obtain the above-mentioned target, following objectives should be done:

+ ***Objective 1:*** To propose the basic design concepts of granule having semi-capsulation effect for powder material.

+***Objective 2:*** To enhance the semi-capsulation technique for functional effective ingredients with considerations of simple & cheap granule fabrication.

Based on proposed requirements and design concepts of granules for powder material, several

strategies to select the functional effective ingredients and to improve the granulation technique were proposed.

There was an effort to fabricate various types of granules containing supplementary cementitious materials or Portland cements and other additives with different ratios and techniques. After being manufactured and cured, granules were added to concrete mixture as a partial sand replacement (normally dosage of granules 70kg/m^3 concrete was used). The effects of inclusion of granules on the properties of fresh concrete (such as the workability) and hardened concrete (such as compressive strength) were examined. The water pass test, in which a constant water head of eight centimeters flowing through a static crack of 0.2-0.4mm, was performed to investigate the healing capability of concrete. Healing capability was assessed by observating the reduction of water leakage over time, the closing process of surface crack and chemical analysis of deposited products in the crack.

Based on obtained experimental results, it was found that incorporating granules of the functional ingredients in concrete has no adverse effects on the fresh & hardened properties of concrete such as workability and compressive strength. Moreover, this concrete has a possibility of recovering the water tightness property of cracked concrete, especially in young concrete; and can preserve the healing ability of concrete for a long period of time.

Even though the optimum ratio of effective ingredients of granules still has not been confirmed yet and it was still difficult to verify the self-healing performance in concrete, the requirements and basic design concepts for granules having semi-capsulation effect were established. The basic ideas are that embedded granules should be broken by the penetration of crack and inner self-healing material should be released into crack surface. In order to obtain the above targets, both requirements of coating layer and inner material should be satisfied simultaneously: coating layer should be strong and dense enough; inner material should be effective self-healing agent and weak enough to easily to spread out of the granule.

In order to achieve granules having semi-capsulation effect, it was proposed that the following materials should be used as self-healing ingredients: rapid hardening material should be used to induce an effective coating layer by providing the watertightness property and enough strength to coating layer; inner material should be composed of reactive material (typically self-healing

materials proposed by Ahn,2008) and a water-soluble/water-reducing agent in order to satisfy both healing effect and spreading effect.

Throughout this study, it can be concluded that it is feasible to fabricate finer granules to improve the distribution of granules in concrete matrix and healing capability of concrete with the considerations of simple & cheap granule fabrication. Furthermore, this approach showed a high potential to introduce self-healing concrete to the practical construction due to its feasibility in mass production of granules by using a typical mortar/concrete mixer for granulation process and using fine sand as nuclei for granulation.

Moreover, it is important to bear in mind that both self-healing ingredients of granule (term of chemical effect) and granulation technique (term of physical effect) are of paramount importance to ensure the performance of concrete incorporating granules having semi-capsulation effect.

In order to investigate the potential application of this technique to the construction industry, a field trial was also performed. A ready-mixed concrete were prepared at the plant and transported to construction site by a concrete agitator. Then pre-fabricated self-healing granules were added to drum agitator and mixed with ready-mixed concrete just before casting a portion of slab mock-up.

Based on this experimental investigation, it is expected that the designed concrete possesses an excellent crack self-healing performance, in terms of watertight property recovery and long-term preservation of its capacity. Moreover, there is a promising possibility to broadly apply this concept to practice to improve the durability or functionality, especially in the water retaining and underground structures.