Self-healing performance of intelligently building concrete module

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Abstract. Intelligent building concrete module is an important part of parametric construction and its self-repairing performance is the premise condition for ensuring the quality of the building. In this paper, some experiments have been done using fly ash, slag, meta-kaolin and silica fume mixed into cement in order to test several performances, including compressive performance, impermeability and self-healing performance. The results demonstrate: the worst healing effect was fly ash, followed by slag, meta-kaolin and silica fume. In the cement-based materials, the self-repair of the cracks mainly concentrated in the early production of cracks, so paid attention to the protection of the early maintenance is the key for self-repair effect.

Keywords: Smart concrete material; Self-healing performance; Impermeability; Modular construction

1. Introduction

Cementitious materials, especially for the concrete, as the most used in building widely, have its unique features including heterogeneous components and different micro-environments that lead to cracks. The crack problem based-cement material is a quite important for the building, so it has a long history about the research in order to solve the difficulty.

There are two directions about crack treatment, one is a passive way and the other one is active style. For the passive way of repair work, it is a procedure of detecting, monitoring, and repairing through external conditions. The cracks are been detected, at the same time the repair work will be performing and the healing components penetrate into the cracks from the outside in order to fulfill the defects.

The earliest study of self-healing capacities about cementitious materials was in France and at that time scientists began to study the difficult problem using scientific method [1].

Cement-based building materials have several crack types and there will have different methods to deal with the problem in terms of the crack type. Cement-based materials have self-healing capability to block the crack generally, however, the capability is limited, cement-based composite materials become the object of study in this paper because of the self-healing capability of composite materials have a stronger than single cement material.

Using an electrodeposition technique to improve the crack problem of reinforced concrete had identified by Japanese researchers in the late 1980s [2]. Compared to traditional repair methods, the electrodeposition technique method has an obvious advantage by its effectiveness and low price [3]. Homma et al. [4] demonstrated the self-healing mechanisms of concrete materials, producing C-S-H swell to block the cracks in order to heal the concrete materials.
Yang [5] pondered the cracks of concrete from another direction that included influence of some essential environmental elements.

There were many reasons which can lead to the cracks of concrete, from saline water, acid rain and carbon dioxide of exterior elements including to interior causes, involved Reaction mechanism [6].

In conclusion, there are some methods to study the repair problem about concrete cracks, having the passive way and the active way through microencapsulation of intelligent materials, hydration of cement, expansive precipitations, bacterial method, and so on. In this paper, the self-repairing properties of composites are the focus of the study mixing with fly ash, slag, meta-kaolin and silica fume.

2. Experimental

The chemical analysis of cement was listed in Table 1. For Fly ash and Silica fume, their most compositions were SiO$_2$, 54.38% and 94.74%, respectively.

| Composition | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | MgO | SO$_3$ | Na$_2$O | K$_2$O | L.O.I |
|-------------|---------|-------------|-------------|-----|-----|--------|--------|-------|-------|
| Content     | 20.1    | 5.4         | 3.7         | 57.6| 3.4 | 1.2    | 0.4    | 0.6   | 4.2   |

Figure 1. Parametric design type of concrete materials.

All specimens were produced for tests including compression degree, conservation time, admixture, chloride ion penetration to evaluate the capability of self-healing, as be shown in figure 1.

3. Results and discussion

3.1. Strength Recovery effect of different composite admixtures

Figure 2. Effect of different composites on strength recovery.
Cement specimens of already damaged had shown a degree of self-healing effect to some extent under 14 days of standard conservations in fig. 2. The phenomenon illustrates cemented materials specimens had self-healing capability due to Continuous hydration process of unhydrated cement composition result in lots of gel product repair cracks. The hydration products mainly consists of CaCO₃ to block the cracks, which generated by Ca(OH)₂ and CO₂. The worst self-healing effect is the fly ash cement compared to Meta-kaolin specimen, slag specimen and silica fume specimen. The best effect of specimens be measured by compressive equipment is Meta-kaolin composite specimen, about 19.4MP after 7days conservation.

![Figure 3. The rhythm of resistance of chloride ion penetration in concrete specimen.](image)

Different composites impact the Resistance of chloride ion penetration in concrete specimen. From Fig.3, the data shows cement specimens have a weaker capability to resist the penetration of chloride ion than others’ composites, whereas the capability to resist the chloride ion will increase obviously after 14 days conservation. In terms of micro-crack theory, the crack will gradually expand under the action of tensile stress, so the resistance of chloride ion penetration can improve along with the repair of cracks.

3.2. The influence of maintenance time for self-healing capability

As seen in Fig.2 and Fig.3, the self-healing effect of cement-based composite materials has different show. The strength of specimens with 7days maintenance time has obviously reduced than before.

![Figure 4. Effect of curing time on compressive strength](image)
Figure 5. Compressive strength of the specimen.

With the increase of the curing time, the strength of the test specimens increased and became gentle, especially the early strength recovery effect was significant. Fig. 4 presents the specimens of 3 days conservation can be restored to 22.7 MPa, amount to the same age non-pressure compressive strength of 95.38%. The strength of the recovery is gradually stabilized, 28 days of strength back to 25.9 MPa, having the same age of non-pressure compressive strength of 82.75%.

The results of the study are fully explained the cement-based material can be self-healing after be subjected to certain damage, and the self-healing phenomenon is sustained with the increase of the curing age, but the self-healing effect is obvious in the early stage from Fig. 5.

Self-healing effect of cement-based materials is closely related to the hydration process and the hydration products are produced and the cracks inside the specimen are rapidly healed during the early stage of curing. With the deepening of the hydration process, the structure is gradually dense. Because water becomes more and more difficult to enter the cracks of specimen, it is not conducive to play from the healing effect further. Due to the cover of the hydration product, the un-hydrated cement particles are prevented result in the hydration of cement hydration slowed down and cement-based material self-healing progress gradually weakened.

4. Conclusion

The work aims to verify the self-healing of cement-based composite materials. There are some self-healing characteristics for all cement-based materials, but the repair scales are different for them.

A. A small amount of admixture has little effect on the self-repair of cement-based materials.
B. Adding fly ash and other admixtures, the self-healing effect of cement-based materials will be reduced, the worst healing effect is fly ash, followed by slag, meta-kaolin and silica fume.
C. The self-repair of cement-based materials mainly concentrated in the early stage.

5. References

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**Acknowledgments**

The research presented in this paper was supported by Postgraduate Research & Practice Innovation Program of Jiangsu Province (KYCX18_0104).