Ideal material properties for capsules or vascular system used in cementitious self-healing materials

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ABSTRACT

Self-healing in cementitious materials, i.e. concrete, has a huge potential towards reducing maintenance and repair costs and increasing the service life of concrete structures. The biggest advantage of self-healing concrete is that small cracks, who provide access to hazardous gasses and liquids, are healed and structural degradation is prevented. Several techniques are trending in the field of self-healing concrete, self-healing using bacteria, self-healing using a vascular system and self-healing using capsules. Focusing on the two latter, an encapsulation material is needed. This paper describes the ideal properties of such an encapsulation material, taking into account as many steps of the life-cycle of the self-healing concrete, i.e. from production until the end of the structure. Such an ideal encapsulation material should be resistant through time to the healing-agent as well as to the cementitious environment. The ideal material should be brittle enough to rupture upon cracking of the (aged) concrete on one hand, and on the other it should be strong enough to survive the concrete mixing and casting process. The properties are not always to be combined by one and the same material, combinations of materials who take up different requirements are possible. In current research glass is most often used as encapsulation material. It's a brittle material which is able to contain the healing agent, but it also suffers from a slow chemical interaction with the alkali-environment, and a very low survival rate when implemented in realistic industrial concrete casting processes. The goal of this study is to investigate the wanted versus the needed properties in order to select other materials than glass or to select other materials to combine with glass.

1. INTRODUCTION

In constructions, concrete is the most commonly used material, although it is susceptible to cracking due to settlements, shrinkage or tensile stresses within the concrete section. These cracks enable hazardous gasses and liquids to penetrate the concrete, causing degradation of the concrete and the steel reinforcement. [1] Degradation of these steel reinforcement entails structural problems, since the reinforcement is responsible for taking up the tensile stresses. Self-healing concrete provides a conceptual answer to avoid problems of reinforced concrete degradation by implementing engineered systems with the ability to heal the cracks. The principle is to store small quantities of a healing agent in the concrete, when a crack propagates through the healing agent container, the healing agent is able to leak out of it and heal the crack. Based on this principle, two autonomous systems can be distinguished, self-healing with a vascular system and self-healing with a capsular system [2]. State of the art research uses glass capsules in concrete[3], [4], [5], but glass has certain disadvantages such as a high production cost, the capsules break when introduced during the mixing or casting process and on the long term unwanted alkali-silica reactions between concrete and glass occur, degrading the properties of the glass capsules and the surrounding concrete. Especially because of the latter, glass is not the ideal material to be used for self-healing concrete and alternative materials should be investigated.

Both a vascular and capsule based self-healing system each have their own advantages. A vascular system, a network of tubes embedded in the concrete, is more suitable for structures subjected to cyclic loadings, where more and bigger cracks may appear. As this techniques can allow for multiple self-healing of cracks. In the capsule system a number of small capsules containing healing agent are introduced into the concrete. This is more suitable to coop with structures where numerous small cracks form due to slowly increased loads. Depending on the length of the capsule, short capsules (<30mm) can only be used once for self-healing, long capsules (>30mm) proofed to be able to be used for multiple healing [6].

2. MATERIALS AND METHODS

With an alternative material, the flaws of glass should be covered, but the advantages of glass should be maintained. Identifying these advantages and flaws gives a list of properties which the ideal material should possess.
In order to contain the healing agent, the **porosity** of the encapsulation material should be kept low. Coating the material in order to seal the surface is a solution which might help to overcome low porosities. Attention should be paid whether this coating reacts with the healing agent or the concrete.
This brings up the next property, ideally there should be **no interaction** between the encapsulation material and healing-agent. Again a coating could be applied to solve this problem.
The encapsulation material should be **brittle** for the crack to be able to open the material so the healing agent can leak out of it and fill the crack in order to seal it.
The encapsulation material will be embedded into the cementitious material, the concrete. When the concrete cracks, the crack should go through the material (i.e. the capsule or tube made out of the material). A **good bond** between the cementitious environment and the encapsulation material is therefore necessary. Otherwise the crack might deflect from the capsule or tube. Towards durability, degrading (often slow) chemical reactions are to be avoided. This happens for example between concrete and glass.
When tubes or capsules are embedded in the concrete the strength of the concrete will be influenced. Ideally the concrete's **strength** is **not degraded** because of the addition of a self-healing mechanism. Ideally the mechanical properties and strength should be comparable to traditional concrete.
Some materials become flexible in contact with water (e.g. starch based materials), since in the production process of concrete, water is added to the mixture the material should be able to **resist** such **humid conditions**

Looking to the problems with glass, the ideal encapsulation material should have **no** or very limited **degradation** in time. Silica based materials are thus unwanted.
Another thing we learn from the problems with glass is that the ideal material should be able to **survive the concrete mixing process**.
The concrete mixture containing capsules should still be workable so that it can be casted.
Economically, in order to be realistic, a **minimal** fabrication **cost** to make capsules or tubes from this material is wanted. The high precision on the dimensions of the tubes makes will cause high prices (e.g. price for 100 glass capsules is about €300/$330).

Table 1 several materials fitted to the desired properties.

	Glass		**Gelatin**		**Mortar, gypsum, Jesmonite, IPC**	
	Good	**Bad**	**Good**	**Bad**	**Good**	**Bad**
Contain agent	X		X			X
No interaction with healing agent	X		X		X	
Adhesion with surrounding cementitious material		X		X	X	
Degradation of capsule in time		X			X	
Brittle behavior	X		X		X	
Influence on concrete strength		X		X	X	
Water resistant	X			X	X	
Resistance to mixture forces		X		X	X	
Capsule fabrication cost		X	X		X	X

From Table 1 the advantages and drawbacks of several commonly used and found materials are displayed if they would be used as encapsulation material. When different materials are combined, they can balance each others drawbacks. For example glass or gelatin capsules can be used in combination with Inorganic Phosphate Cement (IPC), see Figure 1. Several combinations were made with gelatin capsules and mortar, gypsum, Jesmonite and IPC. The capsule fabrication cost is high when using IPC but low when using mortar, gypsum or Jesmonite.
Looking for an alternative for glass, gelatin in combination with mortar, gypsum, Jesmonite and IPC was tested. The main task of the gelatin was to contain the healing agent, where as the task of mortar, gypsum, Jesmonite and IPC was to have a good bonding with concrete and to make them able to survive the mixing process. After making these combinations the capsules were broken by hand.

3. RESULTS

From the combinations, IPC with gelatin proofed to be the best because the interaction and bonding between the materials was good and the capsule could still easily be cracked. Some capsules with this combination were made and introduced to the concrete mixing process with a 100% survival rate, Figure 1 on the right shows one of these capsules that was embedded in a mortar beam and was broken by means of three-point-bending.

Figure 1 (left) a cross section from a gelatin-IPC capsule containing healing agent (right) a gelatin-IPC specimen embedded in a mortar beam which was then broken by three-point-bending.

4. CONCLUSION

Using a list of desired properties, materials other than glass, or materials that can be combined with glass, can be identified. By the research performed in this paper the concept of combining several materials in order to meet the desired properties seems legit. One material can be responsible for containing the healing agent, whereas the other is responsible for the survival during the concrete mixing process.

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