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Review

Tests and methods of evaluating the self-healing efficiency of concrete: A review

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HIGHLIGHTS

- Self-healing admixtures used are supplementary cementing materials, polymers and microorganisms.
- Tests at microstructure level are commonly performed to maximize the reliability of the results.
- Self-healing to successful sealing of the crack width is the key issue.
- Visual observation (microscope, digital imaging and camera photographs) are the primary techniques.

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ABSTRACT

To achieve the extended service life of the concrete material, expansive chemicals and microbial induced calcium carbonate precipitation are used, which induced autonomous healing of cracks in concrete. Various approaches are adopted to develop self-healing cement based materials, where experiments are conducted to establish a new method of self-healing. However, comprehensive evaluations of self-healing efficiency are not performed at the level of macro-, micro- and nano scale. Existing approaches evaluated the self-healing efficiency at the macrostructure level. These are based on the durability criterion of water absorption, chloride and acid resistance. Tests at microstructure level are commonly performed to maximize the reliability of the results. Only few tests are conducted at the nanostructure level. It is worth to review all the available tests and methods on self-healing efficiency assessment of cement based materials to develop innovative experimental strategy. Use of supplementary cementing materials, polymers and microorganisms are the most familiar approaches to achieve effective self-healing. Determining the effect of self-healing to successfully sealing the crack width is the key issue. So far, a crack of maximum size of 0.97 mm is healed. Visual observation based on microscope, digital imaging and camera photographs are the primary techniques to assess the width of the filled cracks. Yet, only couple of researches reported on the healing of crack depths of 32 mm and 27.2 mm. Besides, only one report acknowledged the healing of crack length of 5 mm.

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1. Introduction

Concrete due to availability of its raw materials, affordability, durability and compressive strength is the most widely used construction material. However, a lot of concrete structures including infrastructures inevitably suffer degradation and deterioration over time. This is due to permeation of water which affect the efficiency of the concrete [49]. One of the causes of such deterioration is crack formation at micro and macro levels which create passage for dissolved particles in fluids, unwanted acidic gasses and water ingress. Consequently, these materials and other aggressive substances permeate. Thus, ultimately affect the reinforcement; hence its durability is compromised. Therefore, interaction between concrete and its environment determines its long term performance [12]. In general, water permeation of exposed concrete infrastructure affect durability and also causes corrosion of reinforcing steel bars [9]. Some cracks are not visible and therefore, cannot be accessed. Due to expansion, contraction and permeation of materials, the cracks increase both in size and numbers. For this reason, inspection and maintenance techniques for infrastructure are increasingly drawing attention. Implementation of continuous inspection and maintenance may be difficult especially in the case of large scale infrastructures owing to the huge amount of funds to do it. Some other factors such as location of the damage in the affected structure makes repair difficult. Thus, concept of autonomous repair, otherwise known as self-healing of these dangerous cracks with minimum labour and capital requirements of the affected structures becomes an area of great attraction to researchers. Hence, assessment of self healing efficiency using different approach became attractive due to the requirement of minimum labour and little capital investment. In this regard, self healing efficiency is evaluated using different approach. Self-healing efficiency is the regain in the functionality and desired quality criterion of a cement base material relative to its original form, after healing from crack.

Self-healing materials are those which can restore nearly or all of its original functionality after being damaged, thus, healed completely or partially [27]. Alternatively, self-healing material is that which can detect and autonomically heal damage [13]. In this regard, the healing process proceeds without any manual intervention [26]. Nanotechnology and Biotechnology are relatively the recent advances for the improvement of durability and other concrete properties. The objective of this study is to review all the available approaches for development of self-healing concrete taking into account various tests and methods adopted to evaluate the self-healing efficiency.

2. Literature review of self-healing techniques and measured variable

Cement base materials that have the ability to regain their mechanical properties after crack formation at micro level are the self-healing concrete. Various researchers have studied autogenous self-healing, chemical self-healing and the use of bacteria in the concrete matrix to imitate bone (nature) healing process, thus, produce self-healing concrete material for sustainable development [60]. Expansive materials such as polymers, hollow fibres, mineral admixtures, microencapsulation and microorganisms were used to develop self-healing concrete [88].

According to [73] self-healing could occur naturally by the expansion of hydrated cementitious matrix, calcium carbonate formation, blocking of cracks by impurities present in water and further hydration of unreacted cement. In addition, chemical admixtures, polymers and geo-materials was used to produce self-healing in concrete [20]. Furthermore, calcium carbonate precipitating microorganism were found to induce self-healing in concrete [61,63]. Materials that have expansive characteristics after being introduced into cementitious materials and when combined with mineral additions and or admixtures could improve the self-healing capacity. However, it has to be protected to prevent premature expansion upon reaction with cement in the presence of water.

Parks et al. [53] found that if concrete is made with bulk water containing dissolved salts of Magnesium Silicates and Calcium, it could plug micro-cracks. But, the cracks are not completely healed. They only reduce in size due to a plugging effect. Also efforts have been made to produce some damages in a high strength concrete using tensile preloading. Upon environmental exposure and in the presence of water the artificially simulated crack shows autogenous healing [90]. In this regard, synthetic fibres were introduced into cementitious composite. Consequently, artificially created cracks were successfully healed [50]. Moreover, Van Tittelboom et al. [78] used supplementary cementing materials, to induce an improved self-healing effect of cracks in the concrete at micro level. Such materials, have dual advantages of both the reduction in the cement consumption and also to trigger an enhanced repair of concrete cracks [31]. Also, Ahn et al. [7] figured out, that cementitious composite can be reinforced with high performance fibre. And a better self healing effect than the previous approaches was observed when subjected to different curing regimes. These were the water, sea water and oil water submersions. Though there was self-healing effect, but, only cracks below 50 μm were successfully filled. Hosoda et al. [29] have previously cured, cracked concrete in a continuous water leakage instead of still water. Consequently, an improved self-healing performance was observed. Recently, the efficiency of autogenous healing has been enhanced by post-tensioning of concrete using shrinkable polymer [44]. In this regard, Yıldırım et al. [91] have investigated engineered cementitious material. They found it to be promising self-healing material with an improved self healing performance. Siad et al. [67] have added limestone powder to the engineered cementitious composite. They found that it to substantially recover most of its functionality. Most recently, Pang et al. [14] have investigated the effect of carbonated steel slag as a self healing agent in concrete. The results have shown that, the maximum length and