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Crack healing in concrete using various bio influenced self-healing techniques

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HIGHLIGHTS

- Experimental study was carried out in order to find optimum self-healing technique.
- Concrete crack healing was observed for various bacteria incorporation techniques.
- Graphite nanoplatelets emerged as good carrier compound for short period healing.
- Light weight aggregate depicted as good carrier compound for long period healing.
- Light weight aggregate incorporation improved compressive strength of concrete.

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ABSTRACT

Crack formation and progression under tensile stress is a major weakness of concrete. These cracks also make concrete vulnerable to deleterious environment due to ingress of harmful compounds. Crack healing in concrete can be helpful in mitigation of development and propagation of cracks in concrete. This paper presents the process of crack healing phenomenon in concrete by microbial activity of bacteria, *Bacillus subtilis.* Bacteria were introduced in concrete by direct incorporation, and thorough various carrier compounds namely light weight aggregate and graphite nano platelets. In all the techniques, calcium lactate was used as an organic precursor. Specimens were made for each mix to quantify crack healing and to compare changes in compressive strength of concrete. Results showed that bacteria immobilized in graphite nano platelets gave better results in specimens pre-cracked at 3 and 7 days while bacteria immobilized in light weight aggregates were more effective in samples pre-cracked at 14 and 28 days. In addition, concrete incorporated with bacteria immobilized in light weight aggregate, also exhibited significant enhancement in compressive strength of concrete.

1. Introduction

Concrete is most widely used engineering material in construction due to its strength, durability and low cost as compared to other construction materials. The major drawback of concrete is its low tensile strength which makes it susceptible to progression and coalescence in microcracks resulting in low strength and durability. These tensile stresses can be due to tensile loading, plastic shrinkage and expansive chemical reactions [1]. This liability to cracking not only results in strength reduction of concrete, but also makes concrete vulnerable to deleterious environment. Entry of harmful chemicals through these cracks may result in concrete deterioration through chemical attack and can also cause corrosion of steel reinforcement [2]. This corrosion leads to increase in crack damage resulting in loss of strength and stiffness of concrete structures [3]. This deterioration in reinforced concrete for both concrete and reinforcement results in high maintenance cost. According to report of Federal Highway Administration [4], United States of America spends 4 billion dollars annually in terms of direct cost of maintenance of concrete highway bridges. De Rooij, Van Tittelboom [5] stated that UK spends 45% of its annual construction cost on maintenance of existing concrete structures. With the capability of self-healing in concrete, the formation and propagation of cracks can be reduced and a concrete with dense microstructure can be obtained. As a result, more durable structural concrete, with reduced maintenance cost can be produced.

Different strategies are used to retard crack propagation and bridge cracks leading to increased durability of concrete. However, most of the strategies, such as epoxy systems, acrylic resins and sil-

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icone based polymers, involve the use of materials which are non-compatible with concrete, expensive and mostly hazardous to environment [6]. As a result of recent studies, bio concrete or bio influenced self-healing concrete is emerging as a viable solution for controlling crack propagation. Bio concrete is a product which involves healing of cracks by production of mineral compounds through microbial activity in the concrete. Autonomous healing through this process increases the structural durability through reduction in concrete cracks and on the other hand reduces the maintenance required for reinforced concrete structures. Bio mineralization is preferred as it is a natural process, environmental friendly and improves the compressive strength of cracked concrete [6].

The process of self-healing is directly related to the production of calcium carbonate which depends on many factors including pH of concrete, dissolved inorganic carbon, nucleation sites and presence of calcium ions throughout the mixture [7]. In addition, other variables such as type of bacteria, their varying concentrations, various curing procedures and material used for incorporation of bacteria also contribute towards efficient self-healing of concrete. For better action at depth in concrete matrix and to keep bacteria readily available, these bacteria along with organic mineral precursor compound are incorporated in the concrete during the mixing phase, instead of external application. Among the different bacteria capable of crack healing and its incorporation techniques in concrete used for self-healing purpose, there is need to identify the effectiveness of bacteria namely, "*Bacillus subtilis*", introduced in concrete by different incorporation techniques. The effects of these techniques on magnitude of crack healing and importance of influence on compressive strength of concrete is also envisaged necessary.

2. State-of-the-art review

Over the past few years many different types of bacteria have been used for crack remediation in concrete. However, it was noted that addition of bacteria not only effects the self-healing in concrete but also results in a change in compressive strength. Fig. 1 shows effect of different bacteria on the compressive strength of concrete and cement mortar. Results by Ramachandran, Ramakrishnan [8]show that using *Bacillus pasteurii*, 28 days compressive strength of concrete increased by 18% at concentration of 7.6×10^3 cells/cm^3. Whereas, the research work by Ghosh, Mandal [9] shows that, at the concentration of 10^5cells/cm^3, Shewanella results in 25% increase in 28 day compressive strength and *Escherichia coli* results in 2% increase in compressive strength. This improvement in compressive strength due to Shewanella is greater as compared to the 18% increase due to *B. pasteurii*, as reported by Ramachandran, Ramakrishnan [8]. In the case of *Bacillus pseudofirmus*, used by Jonkers, Thijssen [10] it can be seen that a concentration of 6×10^8 cells/cm^3 results in a 10% decrease in the strength of mortar. Research work done by Wang, Van Tittelboom [11] shows that *Bacillus sphaericus* decreased the 28 days compressive strength of mortar by 35% at the replacement level of 5%.

In addition to the type of bacteria, the use of carrier compound for protection of bacteria in the concrete matrix is also of prime importance. Introduction of bacteria without the use of carrier compound greatly decreases the viability of bacterial survival over the period of time Jonkers, Thijssen [10]. Therefore, researchers have used different carrier compounds to increase the viability of bacterial survival in concrete and increase the efficiency of self-healing process. De Belie and De Muynck [12] and Van Tittelboom, De Belie [13] used sol gel as mode of bacteria protection. On the other hand, Wang, Van Tittelboom [11] used polyurethane and Wang, Soens [14] used the technique of microencapsulation to provide bacteria with better cover for survival in concrete. In all of the above mentioned studies water permeability test was used as a measure of crack healing and the minimum value of water permeability was observed by the technique of micro-encapsulation. However, the process of microencapsulation, involving poly-condensation reaction, is still quite novel and complex. Therefore, there is a need to determine more practical and conducive carrier technique that can be used at a large scale in concrete practices.

Carrier compounds are not only helpful in increasing the possibility of bacteria survival but they also have significant effect on the mechanical properties of the concrete. As mentioned above, the low tensile strength of concrete is a major cause of crack formation in concrete therefore, it is desirable to use a carrier compound which not only increases the possibility of bacteria survival but also increases the tensile strength of concrete.

Fig. 2 shows the effect of light weight aggregates (LWA), polyurethane (PU), graphite nano platelets (GNP) carrier compounds on flexural properties of concrete. Light weight aggregates (LWA), when used by Wiktor and Jonkers [15], as a carrier compound for bacteria in self-healing concrete, provided a better cover to bacteria but it also resulted decrease the flexural strength of concrete and made it more liable to cracking. Wang, Van Tittelboom [11] used both polyurethane (PU) and silica gel as a carrier compound for bacteria and observed that bacteria immobilized in polyurethane produced better self-healing. However, when studied by Gadea, Rodríguez [16] polyurethane foam wastes (PFW) in making lightweight cement based mortar it was found that polyurethane had a negative effect on the flexural strength of cement mortar. Therefore, PU is also undesirable for its use as a carrier compound and there is still a need of carrier compound which enhances the tensile strength of concrete. Sixuan [17] investigated the possibility of using graphite nano platelets (GNP) in cement based mortar

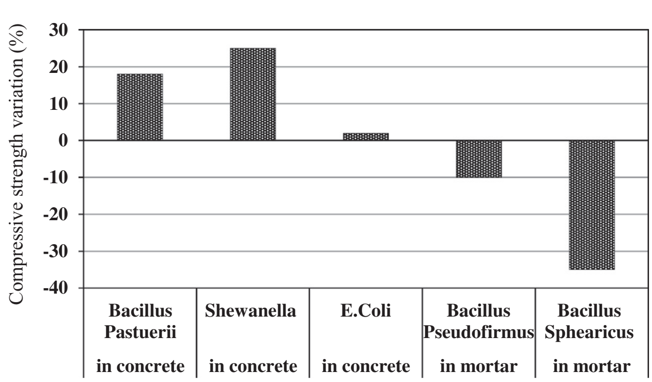

Fig. 1. Effect of various bacteria on compressive strength of concrete.

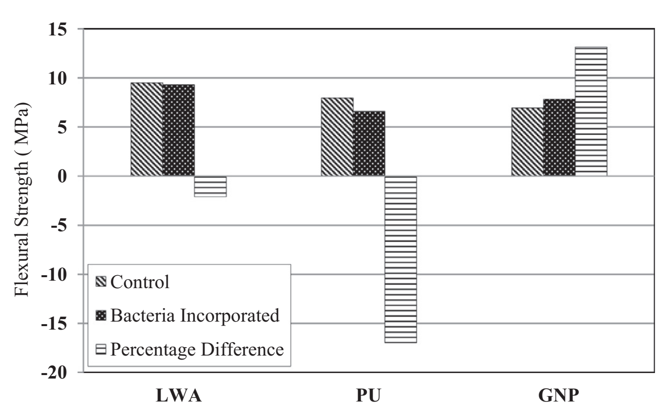

Fig. 2. Comparison of flexural strength in LWA, PU, and GNP incorporated concrete.