A REVIEW ON LIGHTWEIGHT AGGREGATE INCORPORATION IN BIO-CONCRETE FROM A STRUCTURAL VIEWPOINT

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Concrete is one of the most widely used materials in construction while it always encounters cracks due to several internal and external causes including earthquake which produces a wide range of cracks in concrete, from micro- to macro-cracks. Maintenance, repairing, and rehabilitation of the structures need a lot of budget, human efforts, and resources. Bacterial self-healing concrete (Bio-concrete) has recently been suggested as a sustainable eco-friendly building material to heal the cracks in the existing and newly-built structures, either for avoiding widening the microcracks or repairing and rehabilitation purposes (Luo et al., 2015). Bio-concrete with LWA as bacterial agent can keep a trade-off between the expected quality and quantity of concrete material, notably the ability of being self-healed in a short amount of time, longer service life, improved insulating and permeability properties, reduced weight, declined stiffness and inertial forces, increased load capacity, and therefore reduced cracking in comparison to normal concrete (ACI Committee 213, 2014).

From a biological perspective, a wide variety of alkaline spore-forming bacteria such as Bacillus species can generate calcium carbonate extracellularly from different pathways in the presence of calcium ions (Figure 1, Table 1). Those bacteria are agents of a series of chemical reactions which is called Microbial Induced Calcium carbonate Precipitation (MICP). Three methods of incorporating bacteria in the concrete matrix have been evolved to help them live and serve longer, namely, direct-based method (Figure 2-a), encapsulation-based method (Figure 2-b), vascular-based method (Figure 2-c) (Joshi et al., 2017). Furthermore, there are many other factors impacting on the bacteria's ability to form calcium carbonate, including the pH of the environment, culture medium, cell concentration, carbon and calcium source, temperature, water quality and level of aeration (Al-Salloum et al., 2017).

A structural point of view declares that, porous lightweight aggregate is a good carrier for bacteria and their spores, its food and calcium source which enable the bacteria to produce calcium carbonate after waking up from the dormant state and save them from harsh environment of concrete. Besides, the uptake of water in porous lightweight aggregates is more than normal aggregates which is beneficial for the MICP procedure, and makes the interface of the concrete matrix more condensed. Moreover, porous aggregates possess a lower density in comparison to the normal aggregates. As lateral forces acting on a structure during earthquake motions are directly proportional to the inertia of the structure and the ductility of the system, tensile strength, shear capacity, development length, and modulus of elasticity and modulus of rupture of the material vary with the implemented modifications, considerations should be adapted in the seismic design. For instance, the decreased modulus of elasticity should be used in the slenderness effects related codes for this composite material (Balam et al., 2017; ACI Committee 213, 2014). Furthermore, it is no secret that earthquake motions create micro and macro cracks in concrete, even inside the structures that do not appear damaged after the quake. Bio-treatment in that concrete helps the small- and micro-cracks of the structure heal on their own efficiently, and enables it to endure earthquake motions repeatedly. MICP not only enriches the mechanical properties of concrete but also helps the concrete survive from corrosion, chemical or salt attacks due to the healing of the cracks and filling the voids inside the concrete matrix.

To wrap it up, there are plenty of factors which cannot be neglected for incorporating bacteria in concrete and should be studied carefully to optimize MICP for structural use. Although there are some researches available on using the porous lightweight aggregates in concrete as the bacteria carrier, there is still a very few detailed studies on comparing the structural effects of bacterially treated porous lightweight aggregates and the recovered mechanical properties of bio-concrete with LWA after being yield and healed by itself. In this paper, previous studies on corporation of porous lightweight aggregates in bio-mortar and bio-concrete have been discussed, and such deficiencies for further studies have been pointed out.

Figure 1. Left: Calcium carbonate crystals bacterially precipitated inside a LWA, Right: Schematic extracellular calcium carbonate formation.

Table 1. Different metabolic pathways of bacterial calcium carbonate precipitation (Vijay et al., 2017).

Autotrophic bacteria	**Heterotrophic bacteria**				
Non-methylotrophic methanogenesis	**Assimilatory pathways**	**Dissimilatory pathways**			
	Urea decomposition	Oxidation of organic carbon			
Anoxygenic photosynthesis		Aerobic		Anaerobic	
		process:	e-acceptor	process:	e-acceptor
Oxygenic photosynthesis	Ammonification of amino acids	Respiration:	O_2	NO_x reduction:	NO_3^-/ NO_2^-
		Methane oxidation:	CH_4/O_2	Sulfate reduction:	SO_4^{2-}

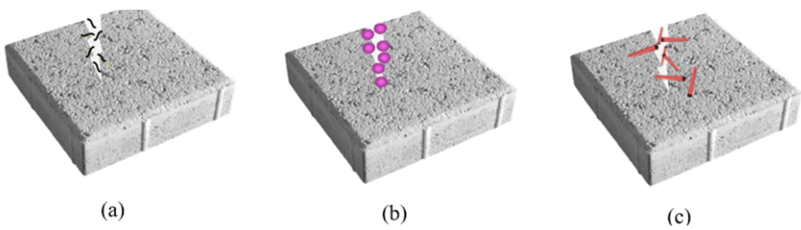

Figure 2. Methods of incorporating bacteria in the concrete matrix.

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