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Research Paper

Influence of biodeposition treatment on concrete durability in a sulphate environment

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Bacterial carbonate precipitation, which is based on urea hydrolysis, has been used as a surface treatment technique to decrease the permeation properties of concrete. Since permeability acts as the main reason of concrete degradation in harsh environments, this study evaluates microbial surface treatment in order to prevent sulphate ions penetration. Five groups of concrete specimens were cast and cured and were then surface treated applying three different microbial suspensions employing *Sporosarcina pasteurii*, *Bacillus subtilis* and *Bacillus sphaericus* bacteria. Durability was assessed through the mass losses, volume changes (expansion), water absorption and compressive strength. In order to consider further permeation properties, chloride penetration of biologically treated concrete was examined by a rapid chloride permeability test (RCPT). Experimental results and a durability loss index (DLI) indicated that biological surface treatment reduces concrete degradation in sulphate environments and improves durability characteristics. Also, the RCPT results confirmed that this technique limits chloride penetration into the concrete.

1. Introduction

Inherent heterogeneity, textural characteristics and harsh service environments make concrete susceptible to weathering, the ingression of aggressive substances such as sulphate and chloride and, subsequently, matrix degradation and eventual destruction if damaged areas are not repaired. In order to prolong the service life of concrete structures, it is necessary to protect them against harsh environment conditions. Various types of products have been introduced for the protection of concrete surfaces. Because of the air polluting effects of the organic coatings consisting of volatile organic compounds, inorganic coating materials have been developed (Moon, Shin, & Choi, 2007). Considerable research has been carried out to develop methods that utilise the potential of mineral-producing bacteria in improvement of concrete properties (De Muynck, De Belie, & Verstraete, 2010). Earlier promising results employing different microorganisms have motivated further investigations using bacteria in or on concrete.

Following demonstration of the ability of soil bacteria to precipitate calcium carbonate under laboratory conditions, microbially induced carbonate precipitation was considered for the protection of ornamental stone (De Muynck, De Belie et al., 2010). The ability of some bacteria such as *Sporosarcina pasteurii*, *Bacillus sphaericus* and *Bacillus subtilis* to precipitate calcite crystals have been studied extensively (Bang, Galinat,

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Nomenclature

RCPT	rapid chloride permeability test
S. pasteurii	*Sporosarcina pasteurii*
B. subtilis	*Bacillus subtilis*
B. sphaericus	*Bacillus sphaericus*
m_1	oven-dry mass of the specimen at the age of 28 d, kg
m_2	oven-dry mass of the specimen at testing time, kg
V_1	volume of the specimen at the age of 28 d, mm^3
V_2	volume of the treated specimen at testing time, mm^3
A	oven-dry mass of the specimen, kg
B	surface-dried mass of the specimen after immersion, kg
Q	charge passed, coulombs
I_0	current immediately after voltage is applied, amps
I_t	current at t minutes after voltage is applied, amps
DLI	durability loss index
f_1	relative mass reduction of the sulphate exposed specimens related to the water submerged specimens at a certain time, %
f_2	relative expansion of the sulphate exposed specimens related to the water submerged specimens at a certain time, %
f_3	strength loss of the sulphate exposed specimens related to the water submerged specimens at a certain time, %
f_4	water absorption increase of the sulphate exposed specimens related to the water submerged specimens at a certain time, %
α_i	weight coefficient of f_i parameter
BUC	Bacteria culture and urea-$CaCl_2$ solution
UC	Urea-$CaCl_2$ solution

& Ramakrishnan, 2001; De Muynck, Cox, & De Belie, 2007; De Muynck, De Belie, & Verstraete, 2007; Reddy, Seshagiri, Aparna, & Sasikala, 2010; Stocks-Fischer, Galinat, & Bang, 1999). Bacteria catalyse the hydrolysis of urea which produces carbonate and ammonium ions; releasing the latter in surroundings causes pH increase through hydroxide producing. Presence of calcium ions in the environment leads to the accumulation of $CaCO_3$ crystals. One mol of urea is hydrolysed intracellularly to 2 mol of ammonium (Eq. (1)) (Okwadha & Li, 2011; Siddique & Chahal, 2011; Van Tittelboom, De Belie, De Muynck, & Verstraete, 2010). Due to the negatively charged cell walls, bacteria are ideal nucleation sites for divalent cation (Okwadha & Li, 2011). Therefore, bacteria cells not only create an alkaline environment inducing further growth of $CaCO_3$ crystals, but also provide a nucleation site for $CaCO_3$ precipitation (Ferris, Fyfe, & Beveridge, 1987; Stocks-Fischer et al., 1999).

$$CO(NH_2)_2 + 2H_2O + Ca^{2+} \xrightarrow{Urease} 2NH_4^+ + CaCO_3\downarrow \quad (1)$$

This reaction is controlled by some factors in the natural environment such as type of bacteria, cell concentration, urea concentration, calcium concentration, ionic strength, pH and temperature (Okwadha & Li, 2011). Much research has been carried out utilising biodeposition methods for sand consolidation (Gollapudi, Knutson, Bang, & Islam, 1995; Nemati & Voordouw, 2003; Stocks-Fischer et al., 1999), repair of concrete cracks (Bang et al., 2001; Van Tittelboom et al., 2010; Wiktor & Jonkers, 2011), concrete compressive strength improvement (Chahal, Siddique, & Rajor, 2012; Ghosh, Biswas, Chattopadhyay, & Mandal, 2009; Ghosh, Mandal, Chattopadhyay, & Pal, 2005; Jonkers, Thijssen, Muyzer, Copuroglu, & Schlangen, 2010), concrete durability improvement (Achal, Mukerjee, & Sudhakara Reddy, 2013; De Muynck, Cox et al., 2007; De Muynck, De Belie et al., 2007), providing self-healing concrete (Jonkers et al., 2010; Wang, Van Tittelboom, De Belie, & Verstraete, 2012; Wiktor et al., 2011) and other various areas. De Muynck, Debrouwer, De Belie, and Verstraete (2008) used a biodeposition treatment on the surface of the mortar specimens in order to compare the results of the permeation properties assessments and resistance towards degradation processes with conventional surface treatments. They reported that the surface deposition of carbonate crystals decreased the water absorption which consequently resulted in an increased resistance of mortar specimens towards carbonation, chloride penetration and freezing and thawing. Furthermore, they demonstrated that the biodeposition treatment showed a similar protection towards degradation processes as some of the conventional surface treatments under investigation.

Because of the above research, and due to the reduced permeability of biological treated concrete and safe working environment of biosealant based on its high thermal stability (Okwadha, & Li, 2011), the current study was aimed at utilising microbial carbonate precipitation to improve the durability of biodeposition treated concrete under harsh environments. Creating a barrier against sulphate ions penetration through the concrete surface seems to be an effective method to mitigate external sulphate attack (ESA) in concrete constructions in contact with sulphate containing environments such as groundwater, seawater, sulphate-bearing soils and sewage. Regarding the earlier studies illustrating the formation of a carbonate layer on the surface of the concrete specimens subjected to biodeposition treatment (De Muynck, Cox, Belie, & Verstraete, 2008; De Muynck, De Belie et al., 2007; De Muynck, Debrouwer, et al., 2008; Okwadha, & Li, 2011), the objective of the current research was to assess the influences of biodeposition treatment on durability of sulphate exposed concrete specimens employing three different calcium carbonate-producing bacteria strains containing *B. sphaericus*, *B. subtilis* and *Bacillus pasteurii* (now reclassified as *S. pasteurii* (Siddique & Chahal, 2011)). Durability of treated and control specimens were evaluated through measurement of mass losses, volume changes (expansion), water absorption and compressive strength. Moreover, in order to assess further permeation properties, the chloride penetration of biologically treated concrete was examined using the rapid chloride permeability test (RCPT) and compared to control (i.e. untreated) specimens. Finally, the results were compared using a durability loss index (DLI) which ranks the more durable bacterial treatment in sulphate environment.