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Permeation properties of concrete made with fly ash and silica fume: Influence of ureolytic bacteria

Navneet Chahal [a,*], Rafat Siddique [b]

[a] Department of Biotechnology and Environmental Sciences, Thapar University, Patiala, Punjab, India
[b] Department of Civil Engineering, Thapar University, Patiala, Punjab, India

HIGHLIGHTS

- *Sporosarcina pasteurii* effects the permeation properties of fly ash and silica fume concrete.
- Bacterial deposition of calcite increases the strength of concrete.
- Deposition of calcite thereby reduces water porosity, absorption and chloride permeability.

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ABSTRACT

Durability of concrete can be enhanced by using a novel technique which involves bacterial-induced calcite precipitation. Bacteria are capable of precipitating calcium carbonate by providing heterogeneous crystal nucleation sites in super-saturated $CaCO_3$ solution. The initial objective of the research work involved the isolation of urease producing bacteria from alkaline soil. The bacteria were identified by the ability to sustain itself in alkaline environment of cement/concrete. The bacterial isolate was analyzed through DNA sequencing and the bacteria was identified as *Sporosarcina pasteurii*, which showed maximum urease production when it was grown on urease agar and broth. The significant objective of the research work further involved the use of ureolytic bacteria (*S. pasteurii)* in concrete which would make it, self-healing. The bacteria present in the concrete rapidly sealed freshly formed cracks through calcite production. The bacterial concentrations were optimized to 10^3, 10^5 and 10^7 cells/ml. In concrete mix, cement was replaced with fly ash, and silica fume. The percentage replacement of fly ash and silica fume was by weight of cement. The percentage use of fly ash was 0%, 10%, 20% and 30%, and that silica fume were 0%, 5% and 10%. The experiments were carried out to evaluate the effect of *S. pasteurii* on the compressive strength, water absorption, water porosity and rapid chloride permeability of concrete made with fly ash and silica fume up to the age 91 days. The test results indicated that inclusion of *S. pasteurii* enhanced the compressive strength, reduced the porosity and permeability of the concrete with fly ash and silica fume. The improvement in compressive strength was due to deposition on the bacteria cell surfaces within the pores which was scanned by electron microscopy and confirmed by XRD which revealed calcium carbonate precipitation. This precipitation reduced the chloride permeability in concrete with fly ash and silica fume. The bacteria improve the permeability of concrete by improving its pore structure and thereby enhancing the life of concrete structures.

1. Introduction

Concrete is a composite building material comprised of aggregate and a binder (cement). Concrete finds good use in all types of building construction. Fly ash and silica fume can be used in concrete mix because of its lightweight and high thermal insulation. Durability of concrete is another major aspect of concern. Durability is defined as the capability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. It normally refers to the duration of trouble-free performance. Concrete require different degrees of durability depending on the exposure environment and properties desired. There are different methods which would thereby improve the concrete durability and these include (a) Chemical methods: By applying epoxy coating which thereby reduces steel contact with water and oxygen. Also penetrating sealer siloxane can be used, as these materials combine with siliceous portions of cement and aggregates (b) Physical methods: Use of pozzolans like silica fume, fly ash can improve the concrete durability by enhancing

* Corresponding author. Tel.: +91 9419255806.
E-mail address: navneetkchahal@gmail.com (N. Chahal).

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Table 1
Physical properties of ordinary Portland cement (OPC).

Physical property	Value
Consistency of standard cement paste (%)	36
Initial setting time (min)	123
Final setting time (min)	174
Compressive strength (MPa)	
3 day	16
7 day	35
28 day	46
Specific gravity	2.9
Standard consistency (%)	34

Table 2
Chemical properties of fly ash (ASTM C618).

Compound	% By mass
SiO_2	58.11
Al_2O_3	27.21
Fe_2O_3	5.23
CaO	2.14
MgO	0.72
$K_2O + Na_2O$	1.0
Loss on ignition	1.52

Table 3
Physical properties of fly ash (ASTM C 618).

Color	Dark gray
Specific gravity	2.4
Bulk density (kg/m^3)	700
Surface area (kg/m^2)	6500

Table 4
Physical properties of silica fume (ASTM 1240).

Color	Light gray
Specific gravity	2.5
Bulk density (kg/m^3)	700
Surface area (kg/m^2)	22,000

Table 5
Chemical properties of silica fume (ASTM 1240).

Compound	% By mass
SiO_2	92.65
Al_2O_3	0.36
Fe_2O_3	0.53
CaO	0.48
MgO	2.5
$K_2O + Na_2O$	2.50

Table 6
Concrete mix proportions with and without fly ash (FA) and silica fume (SF).

Mixture no.	M-1	M-2	M-3	M-4
Cement (kg/m^3)	390	351	312	273
Natural sand (kg/m^3)	568.7	568.7	568.7	568.7
Fly ash (% by weight)	0	10	20	30
Coarse aggregate (kg/m^3)	1164.12	1164.12	1164.12	1164.12
W/C ratio	0.5	0.5	0.5	0.5
Water (kg/m^3)	185	185	185	185
Slump (mm)	90	85	80	80

M: denotes Mix.
In each of the above mixes 5% and 10% Silica fume (by weight) was added.

Fig. 1. Casted samples for compressive strength.

impermeability and chemical durability. Sulfate resistance in concrete can be improved by incorporating supplementary cementing materials. Permeability is one of the most important properties of durability. Use of supplementary cementing materials such as fly ash and silica fume improve the microstructure of the concrete matrix, resulting in the impermeability of concrete. Once impermeability in enhance, concrete becomes more durable against sulfate resistance, and resistance due to chemicals, etc. For that reason, it enhances the chemical durability. (c) Development of Self-healing bacterial concrete: A novel technique for the remediation of damaged structural formations has been developed by employing a selective bacterial plugging process, in which metabolic activities promote precipitation of calcium carbonate in the form of calcite. Bacteria can affect the carbonate precipitation both through affecting local geochemical conditions and by serving as potential, nucleation sites for mineral formation.

Calcium carbonate is an appropriate mineral to use for the reduction of porosity of underground formations for many reasons. Ca^{2+} is one of the most abundant cations while carbonate ions (HCO^{3-} and CO_3^{2-}) are some of the most abundant anions in most subsurface waters. In order to produce the most mineral mass, utilizing elements already present in the subsurface is a more efficient method than adding another chemical. A variety of ions can non-specifically get deposited on bacterial cell surface at the nucleation site. It has been studied that the bacteria have the largest surface area to volume ratio of any life form [1] and have a net electronegative charge [2]. The combination of the large surface area and net negative charge results in the binding of dissolved metal ions on the surface of the bacteria. The common contaminants play an important role in the amount of calcium carbonate precipitation

Fig. 2. Casted samples for RCPT [ASTM C 1202].