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Use of microorganism to improve the strength of cement mortar

P. Ghosh[a], S. Mandal[a,*], B.D. Chattopadhyay[b], S. Pal[c]

[a]Civil Engineering Department, Jadavpur University, Kolkata, India
[b]Physics Department, Jadavpur University, Kolkata, India
[c]Department of Life Science and Biotechnology, Jadavpur University, Kolkata, India

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Abstract

This study describes a method of strength improvement of cement–sand mortar by the microbiologically induced mineral precipitation. A thermophilic anaerobic microorganism is incorporated at different cell concentrations with the mixing water. The study showed that a 25% increase in 28 day compressive strength of cement mortar was achieved with the addition of about 10^5 cell/ml of mixing water. The strength improvement is due to growth of filler material within the pores of the cement–sand matrix as shown by the scanning electron microscopy. The modification in pore size distribution and total pore volume of cement–sand mortar due to such growth is also noted. *E. coli* microorganisms were also used in the cement mortar for comparison, but no improvement in strength was observed.

Keywords: Compressive strength; Pore size distribution; SEM; Microstructure; Mortar

1. Introduction

Portland cement concrete has clearly emerged as the material of choice for the construction in the world today. This is mainly due to low cost of materials and construction for concrete structure as well as low cost of maintenance. Therefore, much advancement of Concrete Technology have occurred depending on (i) the speed of construction (ii) the strength of concrete (iii) the durability of concrete and (iv) the environmental friendliness of industrial material like, fly ash, blast furnace slag, silica fume, metakaolin etc. [1].

Recently, microbial mineral precipitation resulting from metabolic activities of some specific microorganisms in concrete to improve the overall behaviour of concrete has become an important area of research. A previous study with aerobic microorganism (*Bacillus pasteurii* and *Pseudomonas aeruginosa*) showed a significant improvement (about 18%) in compressive strength of cement mortar [2,3]. Scanning Electron Microscopy (SEM) also confirmed the role of microbiologically induced precipitation within the mortar matrix [4].

With this background in view, an attempt has been made to observe the effect of incorporating an anaerobic thermophilic microorganism instead of aerobic microorganism within the cement sand matrix. This study has measured the effects of varying additions of microorganisms on the compressive strength of cement mortars.

2. Experimental program

2.1. Materials

Ordinary Portland Cement conforming to IS 12269 [6] was used. Locally available clean, well-graded, natural river sand having fineness modulus of 2.89 conforming to IS 383-1970 [7] was used as fine aggregate. Distilled water was used as mixing water for the mortar to reduce other effects on the result.

* Corresponding author. Tel.: +91 33 24169490.
E-mail address: sarojmandal2001@yahoo.co.in (S. Mandal).

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Table 1
Effect of the anaerobic microorganisms addition on mortar strength

Cell conc./ml of water	Average mortar compressive strength in MPa							
	3 days		7 days		14 days		28 days	
	Strength ± S.D	% Increases relative to control	Strength ± S.D	% Increases relative to control	Strength ± S.D	% Increases relative to control	Strength ± S.D	% Increases relative to control
Nil	8.67 ± 0.28	–	12.60 ± 0.47	–	16.00 ± 0.81	–	23.13 ± 0.23	–
10	8.68 ± 0.44	0	12.74 ± 0.89	1.11	16.21 ± 0.22	1.31	24.21 ± 0.43	4.66
10^2	8.76 ± 0.47	1.04	12.87 ± 0.46	2.14	16.44 ± 0.38	2.75	25.00 ± 0.88	8.08
10^3	8.80 ± 0.69	1.49	12.98 ± 0.81	3.01	16.87 ± 0.64	5.43	25.40 ± 0.84	9.81
10^4	8.89 ± 0.87	2.53	13.4 ± 0.53	6.34	17.10 ± 0.37	6.87	25.44 ± 0.97	9.98
10^5	9.34 ± 0.81	7.73	14.70 ± 0.74	16.67	19.50 ± 0.42	21.87	28.98 ± 0.86	25.29
10^6	9.20 ± 0.28	6.11	13.80 ± 0.58	9.52	17.50 ± 0.81	9.38	26.52 ± 0.27	14.65
10^7	8.86 ± 1.01	2.19	13.00 ± 0.23	3.17	17.00 ± 0.45	6.25	25.69 ± 0.74	11.06

2.2. Microorganism

A thermophilic, anaerobic microorganism isolated from the hot spring of Bakreshwar, India, belonging to the *Shewanella* species [5] was used in this study. This iron-reducing microorganism was cultured anaerobically in a modified medium (pH 7.5) before adding to the cement–sand mortar mixture. *E. coli* microorganisms grown in standard Luria Broth (LB) medium having pH of 7.2 were also used to study their effect on mortar.

2.3. Mix proportion and test specimens

Microorganisms of different cell concentration were added to mortar via the mixing water for the present experimental study. The cement to sand ratio was used as 1 : 3 (by weight), and the water to cement ratio was fixed at 0.4. A cube mould of 70.6 mm was used, as per IS 4031-1988 [8]. Seven different cell concentrations ranging from 10 to 10^7 per ml of mixing water were incorporated both for the anaerobic and *E. coli* microorganisms. The cell concentration of the microorganism was determined from the standard curve made by observing optical density at 620 nm vs. bacterial cell numbers counted in haemocytometrically under microscope. Different cell concentrations were derived from the bacterial growth culture by serial dilution method. Twelve cube specimens were tested for each age and microorganism concentration. Control mortar specimens were cast without the addition of any microorganisms. Each experiment was also repeated.

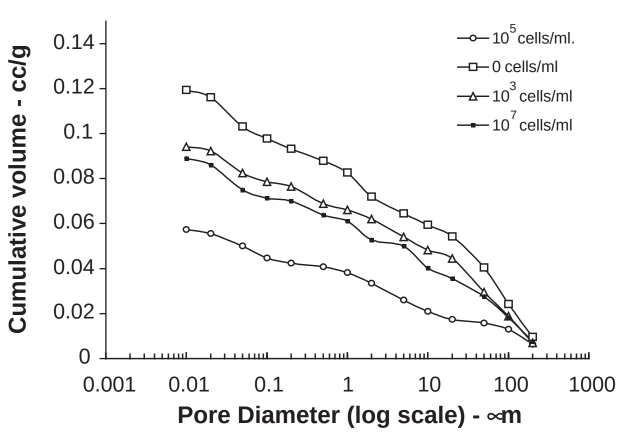

Fig. 1. Cumulative volume of pores larger than indicated pore diameter in cement–sand mortar at 28 days.

2.4. Mix procedure and testing

Sand and cement was thoroughly mixed and mixing water along with the required cell concentration of the microorganism was then added. Cubes were cast and compacted in a vibration machine, and after demolding all specimens were cured in air at room temperature (30 ± 2 °C) until compression testing at 3, 7, 14 and 28 days. SEM examinations were made on the broken samples collected from the mortar cubes tested at 28 days. SEM specimens were dried, then gold coated and stored in the desiccators prior to examination using a Jeol JSM 5200. Mercury intrusion porosimetry was also undertaken on cement mortar specimens with/without microorganisms at 28 days to ascertain the modification in pore size distribution.

3. Result and discussion

The main objective of this experiment is to study the effect of addition of the anaerobic microorganism on the

Table 2
Effect of *E. coli* microorganism additions on mortar strength

Cell concentration/ml of water	Average compressive strength in MPa			
	3 days	7 days	14 days	28 days
Nil	8.72 ± 0.53	12.58 ± 0.23	16.32 ± 0.26	23.13 ± 0.61
10	8.68 ± 0.47	12.60 ± 0.28	16.33 ± 0.13	23.00 ± 0.31
10^2	8.74 ± 0.38	12.44 ± 0.25	16.28 ± 0.47	23.11 ± 0.27
10^3	8.44 ± 0.28	12.53 ± 0.42	16.23 ± 0.37	23.14 ± 0.27
10^4	8.58 ± 0.69	12.61 ± 0.45	16.00 ± 0.42	23.10 ± 0.11
10^5	8.71 ± 0.44	12.56 ± 0.23	16.34 ± 0.38	23.12 ± 0.31
10^6	8.18 ± 0.64	12.49 ± 0.14	16.29 ± 0.34	23.60 ± 0.24
10^7	8.73 ± 0.68	12.66 ± 0.16	16.41 ± 0.22	22.50 ± 0.36

compressive strength of cement–sand mortar. Table 1 summarizes the 3 days, 7 days, 14 days and 28 days compressive strength of the mortar cubes containing different concentration of such microorganisms. The compressive strength of mortar cubes increased at all levels of anaerobic microorganism addition. The greatest improvement in compressive strength occurs at cell concentrations of 10^5 cells/ml for all ages: this increase reaches 25% at 28 days.

This improvement in compressive strength is probably due to deposition on the microorganism cell surfaces and within the pores of cement–sand matrix, which plug the pores within the mortar [2–4]. Mercury Porosimetry confirms the modification in pore size distribution due to the addition of microorganisms (Fig. 1), and shows that a cell concentration of 10^5 cells/ml generates the greatest reduction in porosity. The extra cellular growth produced by the microorganism is expected to contribute more to the strength of cement mortar with a longer incubation period and thus the strength improvement is found to be more at 28 days. Even the dead cells may simply remain in the matrix as organic fibers [2].

E. coli microorganisms were added to cement mortar at the same concentrations as the anaerobic microorganism. The observed changes in compressive strength were less than 1% in almost all cases and there was no consistent improvement/degradation of strength with any given microorganism concentration (Table 2). This suggests that the choice of microorganism is important if mortar compressive strength is to be improved.

SEM examination shows that in a mortar made with a 10^5/ml cell concentration, the pores are almost completely filled with narrow strands of filler (Fig. 2), and more modification in pore size distribution is noticed (Fig. 1).

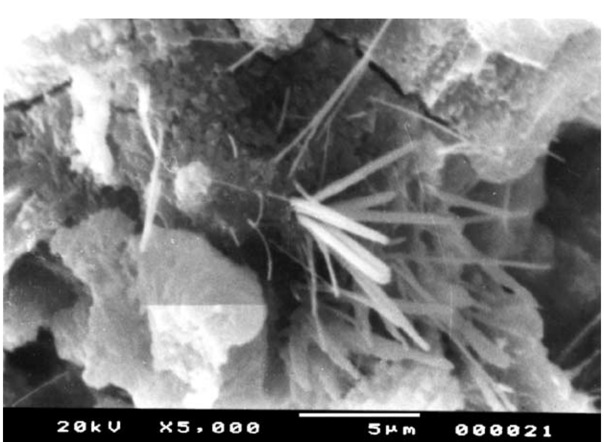

Fig. 2. SEM micrograph of mortar with anaerobic microorganisms of 10^5/ml cell concentration.

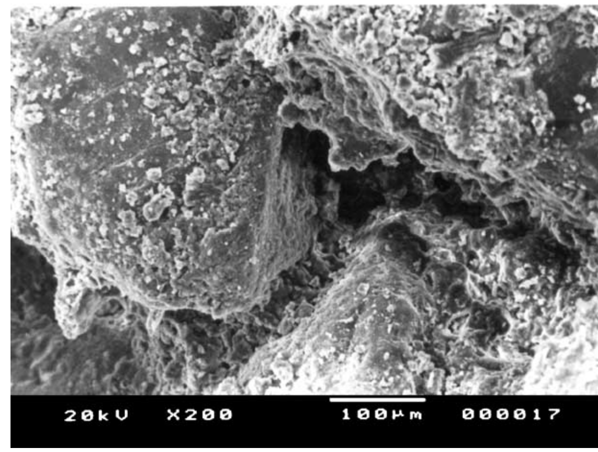

Fig. 3. SEM micrograph of mortar without any microorganisms.

This compares with the control sample where no filler material was observed (Fig. 3).

4. Conclusion

Addition of *Shewanella* anaerobic microorganisms has a positive effect on the compressive strength of mortar. Improvement in compressive strength reaches a maximum at about 10^5/ml cell concentration. SEM examination reveals the growth of fibrous filler material within the pores due to the presence of such microorganisms. This growth is beneficial by the modification of the porosity and pore size distribution of cement mortar which it generates.

There is no improvement in strength of mortar with the addition of *E. coli*.

Further investigation is necessary to identify the specific mechanisms, which alter the pore size distribution and improve the compressive strength when appropriate microorganisms are included in cementitious materials.

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