Study on the Effectiveness of Incorporation of Bacteria and Nanomaterials for Durability in Concrete

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Abstract

The durability of cement based materials such as mortar and concrete typically suffers from water and chloride ingression, which corrodes the load-bearing steel reinforcement. Most existing strategies to increase the water resistance of cementitious materials are based on additional surface treatments of the material after the casting process. A complementary strategy could be a bulk modification of cementitious materials by altering their mineralized nanostructures, such as ettringites. Controlling mineralization processes through bio-inspired approaches or integrating nanomaterials as hydrophobic components into the bulk volume of the material improves the durability. In this paper, the bacterial content in concrete is varied for concentrations of 105, 106, 107 cells/ml of water added to the concrete mix and strength and durability tests were performed. Highest strength and durability performance was obtained for bacterial concentration of 107 cells/ml. Also, cement was partially replaced with nanosilica of percentage varying as 1%, 2% & 3% of cement by weight. Strength and durability performance has improved for nanosilica incorporated concrete when compared to normal concrete. The various durability tests performed were water absorption test, chloride attack, sulphate attack, and sorptivity test.
Keywords: Durability, Bacteria, Nanosilica, Strength, Chemical Attack

I. INTRODUCTION

Physical and chemical deterioration of reinforced concrete structures is often closely related to the ingress of water. Deleterious substances such as chloride and sulphate ions diffuse into concrete with water, causing corrosion of steel bars and sulphate erosion, respectively. Water itself, as an agent, can also cause chemical or physical attack to concrete. For example, in the case of alkali silica reaction, gel products swell when absorbing water, and cause expansion pressure to lead to map cracking. In freezing and thawing process, water is directly involved to cause internal stress arising from the expansion when freezed. The ability of a material to withstand the effect of its environment such as chemical attack, physical stress, and mechanical assault may be termed as Durability. In the viewpoint of durability, improvement of water tightness of concrete is an important measure for alleviating deterioration and extending the service life of structures.

II. OBJECTIVES OF THE STUDY

The present investigation is to develop bacterial concrete as well as incorporating nanomaterials into concrete to get durable concrete. Concrete mixes with different percentages of biofilm content and nanomaterials are prepared for optimization of the percentage of biofilm and nanomaterials to develop durable concrete and to study the various durability characteristics of concrete incorporating nanomaterials and bacteria.

III. SCOPE OF THE STUDY

Tests are to be conducted only on 53 grade Ordinary Portland Cement. The present investigation is limited to develop M35 concrete. The durability parameters include sulphate resistance, chloride resistance and water absorption of concrete. The nanomaterial to be used is nanosilica only.

IV. LITERATURE REVIEW

A. *Bacterial Concrete*

Muynck et al. (2008) reported the effects of bacterial $CaCO_3$ precipitation on parameters affecting the durability of concrete and mortar. Bacterial deposition of a layer of calcite on the surface of the specimens resulted in a decrease of capillary water uptake and permeability towards gas. [1]

Grumbein et al. (2016) studied hydrophobicity of the biofilm enriched hybrid mortar using *Bacillus subtilis species*. The biofilm content varied from 0.5% to 3% of the cement content to optimize the biofilm content for a workable mix for mortar. The SEM analysis, light profilometry, water absorption tests were carried out. The contact angle measurements showed that the hybrid mortar became hydrophobic due to the addition of biofilm. [2]

B. *Nanomaterials Incorporated Concrete*

Li et al. (2006) studied the abrasion resistance, at age of 28 days, of concretes modified with NT versus that modified with NS. Cement was partially replaced with either NT or NS at levels of 0%, 1%, and 3%, by weight. The enhancement in the surface index of the abrasion resistance of specimens modified with 1% and 3% NT over that modified with NS was 15.1% and 45.53%, respectively. [3]

Li et al. (2007) studied the workability and flexural strength, at age of 28 days, of concretes modified with either 1% NT or 1% NS, by weight. The specimens containing NT exhibited 5.8% higher flexural strength than that containing NS. [4]

V. MATERIALS USED

The cement used for this project work is Ordinary Portland Cement of 53 grade. The fine aggregate to be used in the study is manufactured sand. The material used to partially replace cement is Nanosilica. For the production of bacterial concrete, Bacillus subtilis is used. The recommended superplasticizer is MasterGlenium SKY 8233. Mix design was done for M35 mix.

VI. RESULTS AND DISCUSSION

A. *Compressive Strength*

Table - 1
Compressive strength of nanosilica concrete

Mix Designation	*Nanosilica (%)*	*Bacterial concentration in cells/ml*	*Compressive strength in MPa 28th day*
CS0	*0*	*0*	*40*
NS1	*1*	*0*	*42.96*
NS2	*2*	*0*	*44.44*
NS3	*3*	*0*	*45.33*
NAB7	*0*	10^7	*47.257*
NAB6	*0*	10^6	*46.22*
NAB5	*0*	10^5	*45.33*

The compressive strength of normal concrete at 28 day is 40 MPa. From the results, it is observed that on addition of nanosilica, 28 day strength increased at all replacement level. The maximum compressive strength obtained is 45.33MPa for 3% partial replacement of cement with nanosilica. The strength of nanosilica concrete with 1% and 2% replacement level is lower than 3% replacement level. It is observed that the compressive strength of bacterial concrete with different bacteria cell concentrations are higher as compared to normal concrete. The maximum 28-day strength was obtained for the mix NAB7 with 10^7cell/ml. For the mixes NAB6 and NAB5, the strength increased compared to normal concrete but less than the mix NAB7. Comparing the strength of bacterial concrete with normal concrete, the increase in strength is 18.14%, 15.55 % & 13.325% for NAB7, NAB6 & NAB5 respectively. Comparing the strength, maximum strength is obtained for the mix NAB7 and is 47.257MPa. The improvement in compressive strength is due filling of the pores inside the cubes with microbiologically induced calcium carbonate.

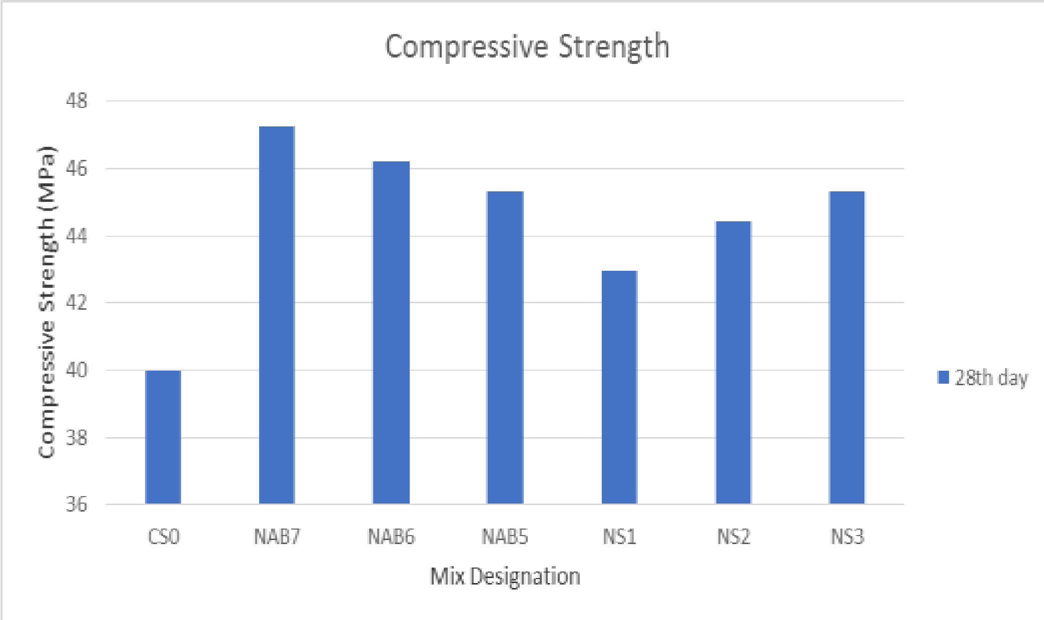

Fig. 1: Comparison of compressive strength of different mix designations

B. Sulphate Attack test

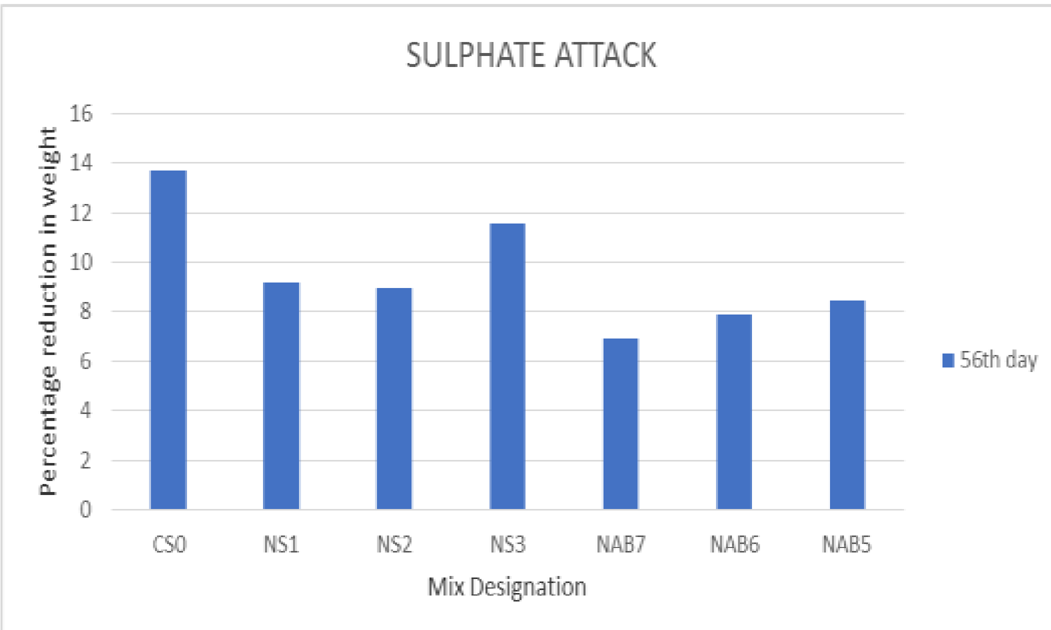

Fig. 2: Comparison of percentage reduction of strength for sulphate attack

From the test results, it is observed that the strength of all mixes decreased after 56-day immersion in 5% Magnesium Sulphate ($MgSO_4$) solution compared to 56-day compressive strength of all mixes. The strength reduction is compared on the basis of percentage reduction of strength. The maximum reduction of strength 13.72% is for normal concrete. For nanosilica concrete and bacterial concrete the percentage reduction of strength is lower compared to normal concrete. The increased sulphate resistance of nanosilica concrete is due to filler effect of nanosilica particles in the capillary pores which reduces the ingress of sulphate ions. The percentage reduction of strength of bacterial concrete is also lower than nanosilica concrete. The minimum strength reduction 6.91% obtained for the mix NAB7. It is clear that the addition of bacteria in concrete increases the resistance against sulphate attack and it is due to the deposition of calcium carbonate in the pores.

C. *Chloride Attack test*

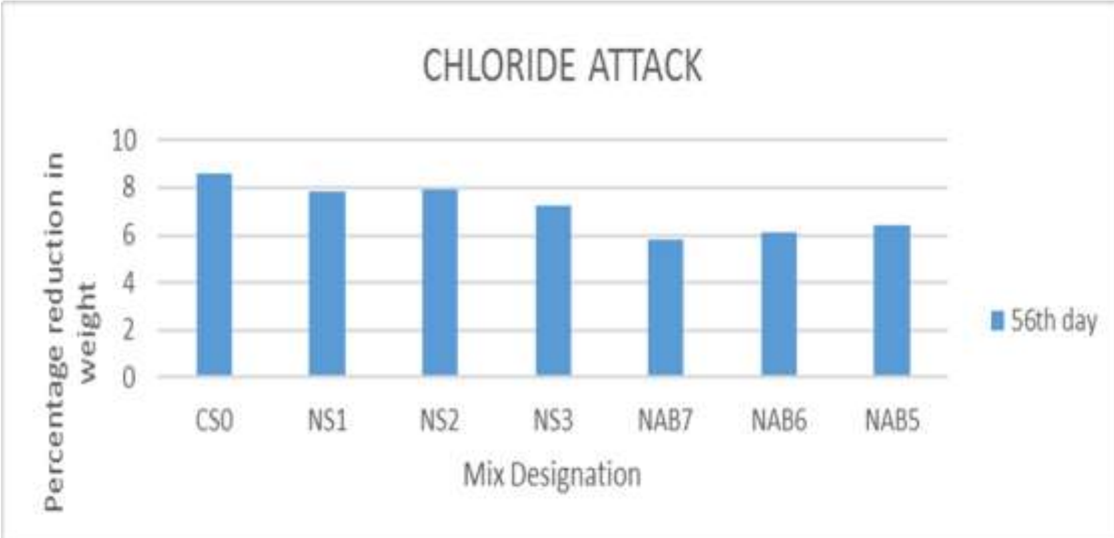

Fig. 3: Comparison of percentage reduction of strength for chloride attack

From the results, it is observed that the 56-day strength of all mixes decreased after immersed in 5% Sodium Chloride (NaCl) solution. The strength reduction is compared on the basis of percentage reduction of strength. The maximum reduction of strength 8.60% is for normal concrete. For nanosilica concrete and bacterial concrete the percentage reduction of strength is lower compared to normal concrete. Increase in chloride resistance of nanosilica concrete is due to continuous reaction between nanosilica and lime liberated by hydration of cement, which continue to form additional C-S-H gel. This C-S-H gel fills the capillary pores and reduces the ingress of chloride ions. The percentage reduction of strength of bacterial concrete is also lower than nanosilica concrete. The minimum strength reduction 5.81% obtained for the mix BC5. It is clear that the addition of bacteria in concrete increases the resistance against chloride attack and it is due to the deposition of calcium carbonate in pores.

D. *Water Absorption Test*

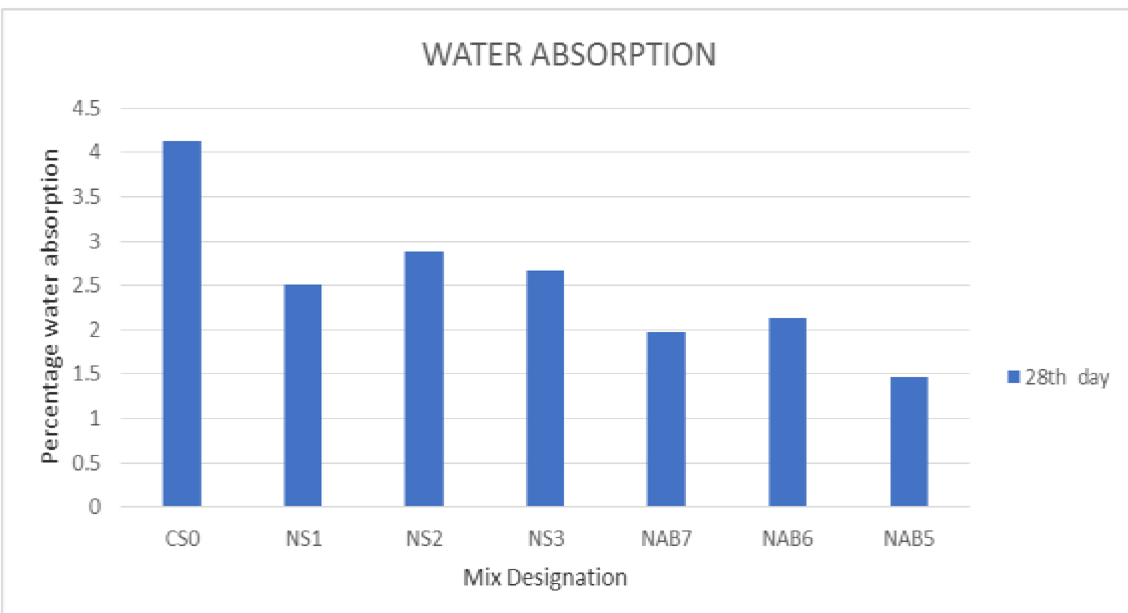

Fig. 4: Comparison of 28th day water absorption

Comparing the results obtained, water absorption of nanosilica concrete with 1% of nanosilica content is the least among mixes with partial replacement of cement with nanosilica. The presence of bacteria resulted in a significant decrease in the water uptake at 28 days compared to normal and nanosilica concrete. For bacterial concrete the water absorption decreased to 1.47%. The deposition of a layer of calcium carbonate on the surface and inside pores of the concrete specimens resulted in decrease in water absorption for bacterial concrete.

E. Sorptivity Test

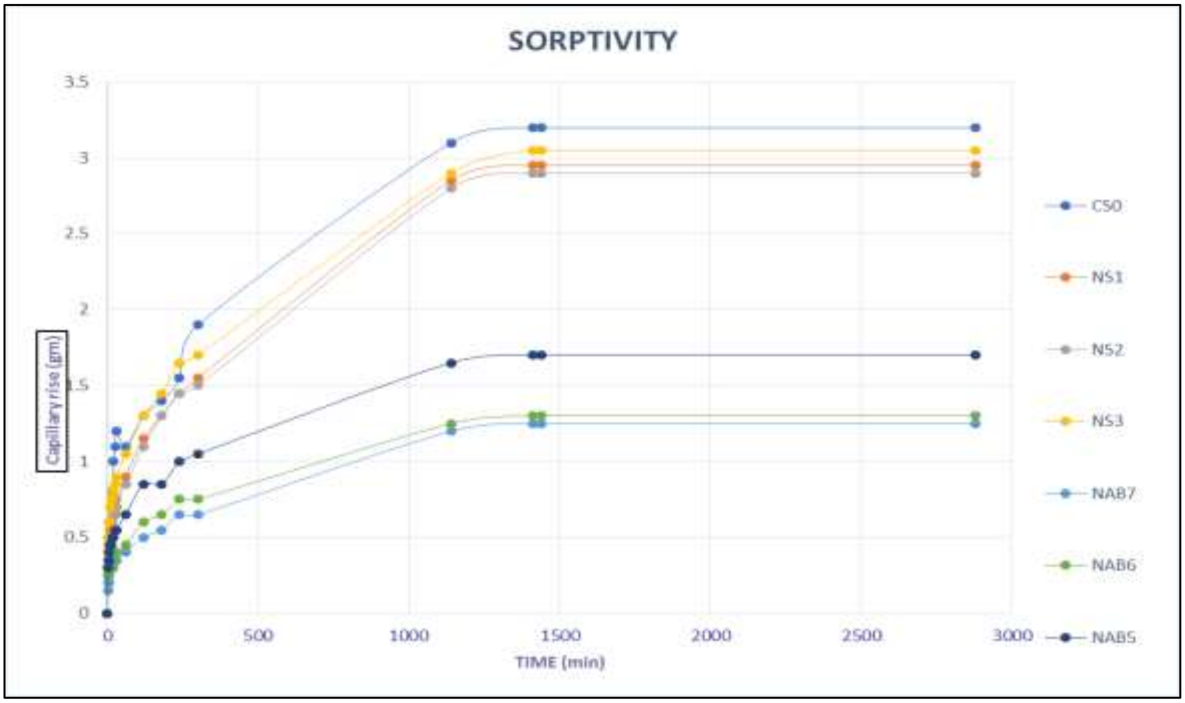

Fig. 5: Comparison of capillary rise for different mix designations

The sorptivity test was conducted on concrete cores obtained through core cutting. The cores were of 7 cm diameter and 3 cm thick. Comparing the results obtained, capillary rise of bacterial concrete with 10^7 cells/ml of bacterial concentration is the least. The presence of bacteria resulted in a significant decrease in the capillary rise compared to normal and nanosilica concrete. The deposition of a layer of calcium carbonate on the surface and inside pores of the concrete specimens resulted in decrease in capillary rise for bacterial concrete. Also, the capillary rise in nanosilica concrete is lower than that of the normal concrete. This is predominantly due to the filling of the pores in the concrete due to nanoscale silica.

VII. CONCLUSIONS

- Compressive strength of nanosilica concrete increased at 28 day compared to normal concrete. The maximum strength is obtained for the 3% replacement of cement with nanosilica and the strength increased by 13.325% compared to 28-day strength of normal concrete.
- In bacterial concrete, the maximum strength for 28 day is obtained for the mix NAB7. For the mix NAB5 and NAB6, strength has increased compared to normal and nanosilica concrete but less than BC5. Comparing the strength of bacterial concrete, 28-day strength bacterial increased by a maximum of 18.14% with normal concrete.
- The strength of all mixes decreased after 56-day immersion in Magnesium Sulphate ($MgSO_4$) solution. The maximum reduction of strength 13.72% is for normal concrete. The percentage reduction of strength of bacterial concrete is lower than nanosilica concrete and normal concrete. The minimum strength reduction 6.91% obtained for the mix NAB7. The resistance against sulphate attack is due to the deposition of calcium carbonate in the pores. For nanosilica concrete the minimum strength reduction for sulphate attack obtained is for NS2 mix designation and the compressive strength reduction is 8.92%.
- The 56-day strength of all mixes decreased after immersed in Sodium Chloride (NaCl) solution. The maximum reduction of strength 8.60% is for normal concrete. The minimum reduction in strength was obtained for bacterial concrete of mix designation NAB7. It is clear that by the addition of bacteria in concrete increases the resistance against chloride attack. The percentage reduction of strength of bacterial concrete is also lower than nanosilica concrete. The minimum strength reduction for nanosilica concrete was obtained for NS3 mix designation and the reduction in strength is 7.23%.
- The water absorption of nanosilica and bacterial concrete has decreased compared to normal concrete. The minimum water absorption was obtained for the mix NAB5 and was 1.47 %. The maximum water absorption was obtained for normal concrete and is 4.13%. The water absorption obtained for nanosilica concrete was comparatively lower than that of normal concrete but higher than bacterial concrete.
- The capillary rise of water for bacterial concrete and nanosilica concrete was lower than that of normal concrete. The lowest value for capillary rise was obtained for mix designation NAB7 followed by NAB6 and NAB5 in order. For nanosilica concrete, the lowest capillary rise was obtained for NS2 mix designation.

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