International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 2 Feb 2021, pp: 390-395 www.ijaem.net ISSN: 2395-5252

Permeability Studies On Quaternary Blended Bacterial Self-Compacting Concrete

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Submitted: 02-02-2021 Revised: 18-02-2021 Accepted: 22-02-2021

ABSTRACT: Self-compacting concrete (SCC) is widely used nowadays. Improvement in the permeability of SCC is important because durability is greatly dependant upon permeability. Pores are reduced by adopting low w/c ratio and more SCMs. Another method is the use of bacteria in concrete. Bacteria synthesiscalcite as a result of its metabolism. The calcite produced seals the pores and reduce permeability of concrete. In this study, an attempt has been made to investigate permeability characteristics of Quaternary Blended Bacterial Self-Compacting Concrete (QBBSCC), a blend of 40% cement, 10% microsilica, 25% flyash and 25% GGBFS. Bacillus Subtilis (MCC 2183) was used. For w/b ratios 0.3 & 0.4, super-plasticiser dosage of 1.8 % & 1.6% by weight of binder respectively were used. Scanning Electron Microscope (SEM) analysis, water permeability and Rapid Chloride Permeability Test (RCPT) were carried out on QBBSCC and reference concrete without bacteria (QBSCC).QBBSCC exhibited better resistance to permeability than QBSCC.

Keywords: Quaternary, self-compacting, concrete, bacteria, permeability.

I. INTRODUCTION

Durability is the key pre-requirement for the performance of any concrete structure subjected to different environmental conditions throughout its designed life-span. Durability is governed by permeability of concrete [1]. A durable concrete is believed to have very less pores.The presence of micro-cracks / pores in concrete and the interconnectivity of the pores are the means of access for water and other chemicals like chlorides, sulphates, acids & alkalies and carbon-dioxide into the concrete,which causes either corrosion of steel or volume change in concrete and which finally leads to distintegration ofconcrete.

Pores are formed in concrete due to use of more water content, inadequate compaction and improper curing. Use of excess water content increases size of the pores in concrete and also brings about the interconnectivity of pores. The interconnectivity of pores leads to high permeability in concrete. The other reasons for permeability of concrete are age of concrete, rapid evaporation of water from concrete surface and properties of different materials used in concrete.

To reduce the pores, usually the w/c ratio is reduced or supplementary cementitious materials (SCMs) are used in the concrete.In both these cases, a super-plasticiser is used to improve the workability of the concrete.

In recent times, a lot of researches are being done on bacteria-based concrete. Bacteria, when used in concrete produce calcium carbonate (calcite) as a byproduct of its metabolism. These calcite crystals are found to grow in size in the pores of the concrete, which subsequently seals the pores of the concrete. This method of using bacteria in concrete reduces porosity in concrete, thereby ensuring durability of the concrete.

II. NEED FOR THE STUDY

Self-compacting concrete (SCC) has been widely used nowadays for the ease with which it can be placed, at locations with congested reinforcement, steep and narrow situations, without compaction. But SCC shows development of early-age cracking due to plastic shrinkage. This may be due to evaporation, hydration and other chemical reactions in the concrete [2]. These cracks propagate under loading, resulting in low tensile strength of the concrete.

Many researches have been done so far to reduce micro-cracks / pores in SCC using mineral admixtures and fibres. Use of high volume of blast furnace slag has been found to self-heal the cracks in SCC. This is due to the presence of significant amount of unhydrated particles in its microstructure [3]. Glass fibres in SCC reduce propagation of micro-cracks [4]. Steel fibres have also been tried in SCC to produce a more ductile material, so that cracks do not propagate [5]. Also, use of polypropylene fibres form bridge between micro-cracks, thereby resisting propagation of cracks [6]. In another research, internal curing of SCC using light-weight aggregates reduced permeability of concrete [7].From these researches, it is clear that the micro-cracks formation is common and cannot be prevented not only in SCC but also in other types of concrete with cement. But its width can be reduced or further propagation of it can be prevented.

Bacteria-based concrete is gaining popularity nowadays. Bacteria precipítate calcite as a result of its metabolism. If bacteria are used in SCC, the calcite produced by the bacteria may fill the micro-cracks / pores of the concrete, seals it and reduces permeability of the concrete, thereby enhancing the durability of SCC [8]. Another study on bacteria enriched steel fiber reinforced SCC shows that good workability, increase in compressive strength and durability is obtained when compared to normal SCC [9] but the permeability characteristics of it has not been studied.

In this research, an attempt has been made to study the permeability characteristics of a bacteria-based self-compacting concrete with a quaternary blend of cement, micro-silica, flyash and GGBFS to assess whether the micro-cracks / pores are reduced by the calcite or not.

III. OBJECTIVES AND EXPERIMENTAL STUDIES

The objectives of this study are as follows:

1. Scanning Electron Microscope (SEM) analysis of Quaternary Blended Bacterial Self-Compacting Concrete (QBBSCC) and reference concretewithout bacteria (QBSCC) of w/b ratios 0.3 and 0.4
2. Evaluation of water permeability by IS 3085:1965 of Quaternary Blended Bacterial Self-Compacting Concrete (QBBSCC) and reference concrete without bacteria(QBSCC) of w/b ratios 0.3 and 0.4.
3. Evaluation of Rapid Chloride Permeability Test (RCPT) by ASTM C1202 of QBBSCC and reference concrete without bacteria(QBSCC) of w/b ratios 0.3 and 0.4.

Bacillus Subtilis (MCC 2183): As the pH of the concrete is high,Bacillus Subtilis(MCC 2183), a harmless, gram-positive, rod - shaped soil bacterium, which grows at pH equal to 12 was used. The bacteria was sub-cultured by inoculating a single colony of the culture in an autoclaved nutrient broth medium and incubated at 37ºC for 24 hours, when required to be used in concrete.Bacteria was added in concrete in terms of number of cells / ml of water. The bacterial concentration was measured using Haemocytometer.

Concentration of B. Subtilis (MCC 2183) used: Out of the different concentrations of B. Subtilis (MCC 2183) i.e, 10^3, 10^4, 10^5 and 10^6 no. of cells / ml of water used in QBBSCC in the previous study, maximum value of compressive strength, split tensile strength and flexural strength were obtained for B. Subtilis (MCC 2183) concentration of 10^6 no. of cells/ml of water, when compared to reference concrete without bacteria (QBSCC). So, in this investigation, B. Subtilis (MCC 2183) of optimised concentration 10^6 no. of cells/ ml of water and reference concrete without bacteria were used. A 1% solution of calcium lactate was used as nutrient for B. Subtilis(MCC 2183) in concrete.

QBBSCC Mix proportion: The QBBSCC mix proportion was designed using Nan Su method [10] but the cement has been replaced by 10% microsilica, 25% flyash and 25% GGBFS. A packing factor of 1.1 was assumed for the design. Two w/b ratio 0.3 and 0.4 have been used. For w/b ratio 0.3 and 0.4, Master Glenium Sky 8662, a two-in-one super-plasticiser cum Viscosity Modifying Agent (VMA) of 1.8% & 1.6% by weight of binder respectively were used.Materials required for 1m^3 of QBBSCC is given in Table 1.

Table 1. Materials required for 1m^3 of QBBSCC

% of Admixtures	w/b ratio	Super-plasticiser dosage (%)	Cement (Kg)	Microsilica (Kg)	Flyash (Kg)	GGBFS (Kg)	Sand (Kg)	Coarse Aggregate (Kg)	Water (Litres)
40% OPC, 10% microsilica,	0.3	1.8	172	43	107	107	851	793	130
	0.4	1.6	172	43	107	107	851	793	172

25% flyash, 25% GGBFS									

SCANNING ELECTRON MICROSCOPE (SEM) ANALYSIS

The finely powdered QBSCC and QBBSCC samples of both w/b ratio 0.3 and 0.4 were analysed using Scanning Electron Microscope (SEM) for the micro-structure of the sample.

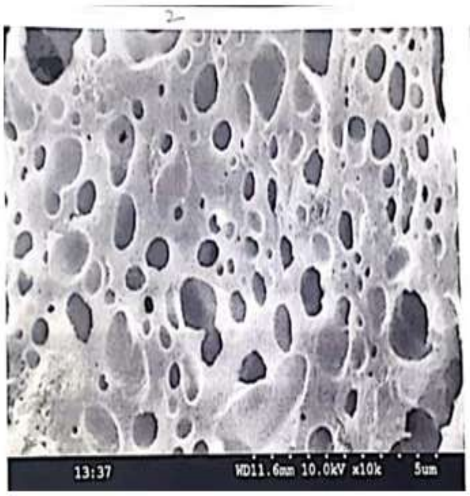

Fig 1. SEM analysis of QBSCC of w/b ratio 0.3

Fig 2. SEM analysis of QBBSCC of w/b ratio 0.3

Fig 3. SEM analysis of QBSCC of w/b ratio 0.4

Fig 4. SEM analysis of QBBSCC of w/b ratio 0.4

Results and discussions of SEM analysis

Fig 1 and Fig 3 shows the pores formed in QBSCC of w/b ratio 0.3 and 0.4 respectively. The pores of QBSCC of w/b ratio 0.4 is found larger than that of w/b ratio 0.3. Fig 2 and Fig 4 shows the filling up of the pores by calcite precipitated by the B. Subtilis (MCC 2183). The difference in the figures clearly proves that B. Subtilis (MCC 2183) precipitates calcite and the precipitated calcite fills up the pores of the concrete.

WATER PERMEABILITY TEST (IS 3085:1965)

Preparation of test specimens

For measuring the water permeability, QBBSCC and QBSCC cylindrical specimens of size 150mm diameter and 150mm height of w/b ratio 0.3 and 0.4 were casted and cured for 28 days. The end faces of the dried specimens were rubbed with sand-paper. The specimens' were then tightly sealed in the permeability cell using a hot mixture of bee-wax and rosin. The seal was ensured water-tight.

Water permeability test set-up

The permeameter was filled with water. A standard test pressure of 10 kg/cm^{2}was maintained in the reservoir. Clean collection bottle wereused to collect the water percolating through the specimens. The quantity of percolate and the gauge-glass reading were recorded at periodic intervals. Permeability test was continued for 100 hours after the steady state of flow was reached (Fig 5). The average quantity of water percolating over the entire period of test after the steady state has been reached was noted for 3 specimens. The test was carried out at room temperature.

The formula used to calculate coefficient of permeability is as follows:

k = Q / (A x T x (H/L))
k = coefficient of permeability (m/s)
Q = quantity of water percolating over the entire period of test after the steady state has been reached (ml)
A = area of the specimen face (cm^2) = π x $(15/2)^2$
T = time over which Q is measured = 100 hour = 100 x 3600 s
H/L = ratio of the pressure head to thickness of specimen both in same units = 100/0.15.

Fig 5. Water Permeability test set-up

Results and discussions of Water Permeability test on QBBSCC

The results of water permeability test are given in Table 2.

TABLE 2. Water Permeability test results of QBSCC and QBBSCC

w/b ratio	Type of concrete	Quantity of water collected (ml)	Coefficient of permeability k x 10^{-11} m/s	Percentage decrease in permeability (%)
0.3	QBSCC	59	1.39	-
	QBBSCC	38	0.89	35.97
0.4	QBSCC	64	1.50	-
	QBBSCC	49	1.15	23.3

From table 2, it is observed that the coefficient of permeability of QBBSCC is found to be less than QBSCC. This is due to the calcite precipitated by B. Subtilis (MCC 2183) filling the pores of the concrete.

Also, the coefficient of permeability, for both QBSCC and QBBSCC and for both the w/b ratio, is found to be less than the maximum coefficient of permeability of 1.5 x 10^{-11} m/s, recommended for a water-tight structural concrete, according to ACI standard 301 – 89. This shows that not only the bacterial precipitation but also the SCMs contribute for the reduction in pores in this concrete.

RAPID CHLORIDE PERMEABILITY TEST (RCPT)

Preparation of test specimens

RCPT is used to measure the ability of concrete to resist chloride ion penetration into it, which is an indicator of concrete permeability. QBBSCC and QBSCC cylindrical specimens of size 100mm diameter and 200mm height of w/b ratio 0.3 and 0.4 were casted and cured for 28 days. Test samples of size 100mm x 50 mm were cut from 100mm x 200 mm specimens. The sides of the test specimens were coated with epoxy. The dried test samples were water saturated.

RCPT Test set-up

Each test cell is made up of two reservoirs. The test samples are placed in between the reservoirs. One of the reservoirs is filled with 3% NaCl solution and the other filled with 0.3N NaOH solution. The reservoirs were connected to a DC supply. A voltage of 60 V is applied to the test specimens at both ends for 6 hours (Fig 6). Current passing through the concrete is measured for every 30 minutes.

The formula used to calculate the total charge passed through the sample is as follows:

$Q = 900 [I_0 + 2 I_{30} + 2 I_{60} + \ldots + 2 I_{330} + I_{360}]$

Q - current flowing through one cell (coulomb)

I_0- Current reading in ampere immediately after voltage is applied

I_t- Current reading in ampere at t minutes after voltage is applied.

Fig 6. RCPT test set-up

Results and Discussions of RCPT on QBBSCC

Table 3 gives the RCPT ratings as per ASTM C1202. The results of RCPT on QBBSCC and QBSCC are given in Table 4.

TABLE 3. RCPT Ratings (as per ASTM C1202)

Charge passed (Coulomb)	Chloride ion Permeability
>4000	High
2000 – 4000	Moderate
1000 – 2000	Low
100 – 1000	Very low
<100	Negligible

TABLE 4. RCPT Results for QBSCC and QBBSCC

w/b ratio	Type of concrete	Charge passed (Coulomb)	Chloride ion permeability	Percentage decrease in chloride ion permeability (%)
0.3	QBSCC	1653.66	Low	-
	QBBSCC	908.66	Very low	45.05
0.4	QBSCC	2062.33	Moderate	-

	QBBSCC	1432.80	Low	30.52

From table 4, it is observed that the charge passed in RCPT for QBBSCC is found to be less than QBSCC. This is again due to the calcite crystals precipitated by B. Subtilis (MCC 2183) filling the pores of the concrete. The percentage decrease in chloride ion permeabilityfor QBBSCC is 45.05% and 30.52% for w/b ratio 0.3 and 0.4 when compared to QBSCC. Comparing with table 3, QBBSCC falls in the range of very low chloride ion permeability for w/b ratio 0.3 and low for w/b ratio 0.4

IV. CONCLUSION

1. Water Permeability of Quaternary Blended Bacterial Self Compacting Concrete (QBBSCC) is 0.89 x 10^{-11} m/s and 1.15 x10^{-11} m/s for w/b ratio 0.3 and 0.4 respectively.
2. Water Permeability of Quaternary Blended Self Compacting Concrete (QBSCC) is 1.39 x10^{-11} m/s and 1.5 x10^{-11} m/s for w/b ratio 0.3 and 0.4 respectively.
3. The percentage decreases in water permeability of QBBSCC were 35.97% and 23.3% when compared to QBSCC for w/b ratio 0.3 and 0.4 respectively.
4. The percentage decreases in permeability by RCPT of QBBSCC were 45.05% and 30.52% when compared to QBSCC for w/b ratio 0.3 and 0.4 respectively.
5. The decrease in permeability values of QBBSCC is due to the combined effect of calcite precipitated by B. Subtilis (MCC 2183) and SCMs filling the pores of the concrete.
6. SEM analysis shows calcite precipitated by Bacillus Subtilis (MCC 2183) filling up the pores of the concrete.
7. Less w/b of 0.3, use of bacteria anduse of micro-silica, flyash and GGBFS can reduce the permeability of concrete.

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International Journal of Advances in Engineering and Management
ISSN: 2395-5252

IJAEM

Volume: 03 Issue: 02 DOI: 10.35629/5252

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