Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 04, April-2022

Chemical Resistance of Quaternary Blended Bacterial Self-Compacting Concrete

[1]Dr. M. Sridevi, [2]Dr. P. Srinivasa Rao
[1]Associate Professor,
ACE Engineering college, Ghatkesar, Hyderabad, Telangana, India.
[2]Professor of Civil Engineering,
JNTU College of Engineering, Kukatpally, Hyderabad, Telangana, India.

***Abstract*:- Chemical resistance of concrete increases to a great extent with reduced permeability. In bio-concrete, it is proved that bacteria incorporated in concrete produces calcium carbonate ($CaCO_3$), which seals the pores of the concrete and reduces permeability. Also, the use of blended concrete is notable for contributing to the reduction of pores in concrete. Self-Compacting Concrete (SCC) has been widely used nowadays. So, in this study, an attempt has been made to evaluate the chemical resistance of Quaternary Blended Bacterial Self-Compacting Concrete (QBBSCC) by immersing the cubes in 5% H_2SO_4, 5% HCl and 5% Na_2SO_4 solutions for 28, 90 and 180 days respectively. QBBSCC comprises 40% cement, 10% micro-silica, 25% flyash and 25% GGBFS as binder. Bacillus Subtilis was used. Two water-binder (w/b) ratios 0.3 & 0.4 were used in the study, for which super-plasticiser 1.8 % & 1.6% by weight of binder respectively were used. Percentage loss in weight and compressive strength were found. It was found that QBBSCC exhibited better chemical resistance than reference concrete without bacteria (QBSCC).**

Keywords: Quaternary, self-compacting, concrete, bacteria, acid, alkali.

I. INTRODUCTION

Cement is alkaline in nature. More the cement, more the alkalinity. But when the calcium present in the cement comes into contact with acids like H_2SO_4, HCl etc., it forms water-soluble calcium compounds which get leached out. In other words, concrete deteriorates as pH decreases. On the other hand, siliceous aggregate present in concrete which is resistant to most of the acids,sometimes reacts with alkali of the concrete. This alkali-silica reaction results in change in volume of concrete leading to cracks and spalling.

The chemicals first attack the concrete near the surface and then penetrate into it to deteriorate the concrete further. So, in order to improve the chemical resistance of concrete, permeability of concrete has to be reduced. It is said that low permeability is the main key to chemical resistance of concrete [1]. Usually, low permeability is achieved by using low water content or by using blended concrete with flyash, silica-fume, metakaolin etc. This makes the concrete dense and water-tight [2]. In addition, use of blended cement reduces alkalinity of concrete, thus improving chemical resistance of concrete further. Further improvement in chemical resistance of concrete has also been done using alkali activated slag [3], carbonated flyash [4], High Volume Flyash Concrete (HVFC) [5], nano-silica [6] etc. Study on chemical resistance of bacterial concrete has shown that weight loss and strength loss were less compared to controlled concrete [7].

NEED FOR THE STUDY

Self-compacting concrete (SCC) is being used widely nowadays.It is preferred for the ease with which it can be placed at difficult locations and congested reinforcement, without much compaction. But the disadvantage with SCC is that it is prone to early age cracking due to plastic shrinkage. These cracks may lead to permeability in SCC, allowing water and chemicals to enter and thus affecting the durability of the concrete. On the other hand,bacteria used in bio-concrete precipitates $CaCO_3$, as a result of its metabolism. This $CaCO_3$sealsthe micro-cracks of the concrete and lowers permeability. Further, use of blended concrete was also found to lower the permeability. Thus, an attempt has been done to evaluate the chemical resistance of Quaternary Blended Bacterial Self-Compacting Concrete (QBBSCC) by immersing the cubes in 5% H_2SO_4, 5% HCl and 5% Na_2SO_4 solutions for 28, 90 and 180 days respectively.

International Journal of Engineering Research & Technology (IJERT)
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II. OBJECTIVES AND EXPERIMENTAL STUDIES

Objectives of the study

1. To evaluate the percentage loss in weight and percentage loss in compressive strength of QBBSCC andreference concrete without bacteria (QBSCC) for two w/b ratio 0.3 and 0.4, after 28, 90 and 180 days immersion in 5% H_2SO_4, 5% HCl and 5% Na_2SO_4 solutions.
2. To evaluate the acid durability factor of QBBSCC and reference concrete without bacteria (QBSCC) for two w/b ratios 0.3 and 0.4, after 28, 90 and 180 days immersion in 5% H_2SO_4 and 5% HCl solutions.

Materials used

The following materials were used:

Cement: OPC 53 grade conforming to IS: 12269 - 2013 was used.

Micro-silica: Micro-silica of specific gravity 2.63 and silica content 99% was used.

Flyash: Flyash of specific gravity 2.18 was used.

Ground Granulated Blast Furnace Slag (GGBFS): GGBFS of specific gravity 2.92 was used.

Fine aggregate: Natural river sand of specific gravity 2.68 and loose bulk density of 1520 kg/m^3 conforming to Zone III of IS 383-1970 was used.

Coarse aggregate: Rounded aggregate of maximum size 20 mm, specific gravity 2.7 and loose bulk density of 1420 kg/m^3 conforming to IS 383-1970 was used.

Super-plasticiser: MasterGlenium SKY 8662, a high performance polycarboxylate ether based super-plasticizer cum Viscosity Modifying Agentwas used.

*Bacterial culture:*Bacillus Subtilis (MCC 2183), a non-toxic, gram positive, rod - shaped soil bacterium, which grows at pH = 12 was used. The bacteria was sub-cultured and preserved in nutrient agar medium for future use. Whenever required,a single colony of the culture was inoculated in an autoclaved nutrient broth (liquid medium), incubated at 37ºC for 24 hours and was used.

B. Subtilis concentrations of 10^3, 10^4, 10^5 and 10^6 no. of cells/ml of water and reference without bacteria were used in the previous study. Out of four different concentrations, 10^6 no. of cells/ml of water gave maximum compressive, split tensile and flexural strength. Hence, in the present investigation, only bacterial concentration of 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 in concrete.

Mix Design: The QBBSCC mix proportion was designed using Nan Su method [8]. Two w/b ratios 0.3 & 0.4 and super-plasticiser of 1.8% & 1.6% by weight of binder respectively were used.The bacterial culture and calcium lactate were added into the concrete during the mixing stage.Table 1. shows the materials required for 1m^3 of QBBSCC.

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, 25% flyash, 25% GGBFS	0.3	1.8	172	43	107	107	851	793	130
	0.4	1.6	172	43	107	107	851	793	172

The QBBSCC cubes in triplicate of size 100mm x100mm x 100mm of w/b ratio 0.3 and 0.4 were casted and water-cured for 28 days.The cubes were air-dried for 1 week at room temperature. Initial weight of the specimens were taken.The specimens were then immersed in different tubs containing 5% sulphuric acid (H2SO4), 5% hydrochloric acid (HCl) and 5% sodium sulphate (Na2SO4) for 28 days, 90days, and 180 days to assess the deterioration of QBBSCC in acidic and alkaline environments. After the immersion, the specimens were removed and air-dried. Final weight of the specimens were taken and tested for residual

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 04, April-2022

compressive strength.Acid durability factor was calculated for the two acids used, using the below formula:

Acid durability factor (D.F) = Sr x N / M

Where
Sr - Relative strength at N days(%)
N - Number of days at which the durability factor is needed.
M - Number of days at which the exposure is to be terminated.
(In this case, acid attacks were terminated at180 days. Therefore, M = 180 days.)

Fig 1. QBBSCC of w/b ratio 0.3 after immersion in 5% H_2SO_4 Solution for 180 days

Fig 2. QBBSCC of w/b ratio 0.4 after immersion in 5% H_2SO_4 Solution for 180 days

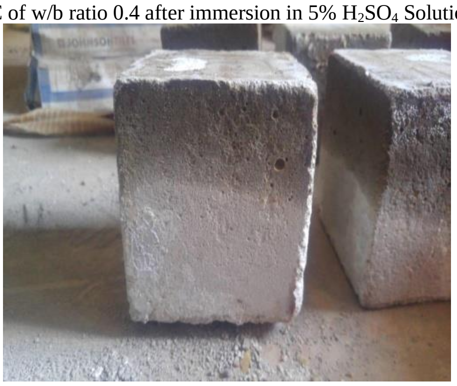

Fig 3. QBBSCC of w/b ratio 0.3 after immersion in 5% HCl Solution for 180 days

Fig 4. QBBSCC of w/b ratio 0.4 after immersion in 5% HCl Solution for 180 days

Fig 5. QBBSCC of w/b ratio 0.3 after immersion in 5% Na_2SO_4 solution for 180 days

Fig 6. QBBSCC of w/b ratio 0.4 after immersion in 5% Na_2SO_4 solution for 180 days

III. RESULTS AND DISCUSSION

Table 2.Percentage loss in weightof QBSCC and QBBSCC

w/b ratio	Percentagelossin weight for 28days		Percentage loss in weight for 90days		Percentage loss in weight for 180days	
	QBSCC	QBBSCC	QBSCC	QBBSCC	QBSCC	QBBSCC
Immersed in 5% H_2SO_4 solution						
0.3	5.17	2.96	6.58	3.52	8.26	5.55
0.4	5.46	3.53	7.85	3.74	9.75	6.33
Immersed in 5% HCl solution						
0.3	2.11	1.55	2.91	2.52	4.7	4.53
0.4	2.43	1.57	3.4	2.69	5.55	4.91
Immersed in 5% Na_2SO_4 solution						
0.3	0.2	0.05	2.55	1.44	3.41	2.24
0.4	0.45	0.20	2.97	2.06	3.82	2.96

Table 3.Percentage loss in compressive strength of QBSCC and QBBSCC

w/b ratio	Percentageloss in compressive strengthfor 28 days		Percentageloss in compressive strengthfor 90 days		Percentageloss in compressive strength for 180days	
	QBSCC	QBBSCC	QBSCC	QBBSCC	QBSCC	QBBSCC
Immersed in 5% H_2SO_4solution						
0.3	32.92	19.24	58.38	24.10	77.53	40.27
0.4	35.97	20.10	61.13	26.53	79.63	41.53
Immersed in 5% HCl solution						
0.3	17.51	10.66	29.94	15.94	48.41	20.56
0.4	19.61	10.71	33.14	16.10	50.57	21.67
Immersed in 5% Na_2SO_4 solution						
0.3	7.38	6.56	13.79	12.70	21.35	16.65
0.4	8.37	7.15	16.69	13.42	24.71	17.22

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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Table 4.Acid Durability Factors for QBSCC

	5% H_2SO_4 solution				5% HCl solution			
w/b ratio	**Sr**	**N**	**M**	**D.F**	**Sr**	**N**	**M**	**D.F**
0.3	67.07	28	180	10.43	82.48	28	18	12.50
	41.61	90		20.80	70.05	90	180	35.02
	22.46	180		22.46	51.58	180	180	51.58
0.4	64.02	28	180	9.95	80.38	28	18	12.50
	38.86	90		19.43	66.85	90	180	33.42
	20.37	180		20.37	49.42	180	180	49.42

Table 5.Acid Durability Factors for QBBSCC

	5% H_2SO_4				5% HCl			
w/b ratio	**Sr**	**N**	**M**	**D.F**	**Sr**	**N**	**M**	**D.F**
0.3	80.7	28	180	12.5	89.3	28	180	13.9
	75.9	90		37.9	84.0	90		42.0
	59.7	180		59.7	79.4	180		79.4
0.4	79.9	28	180	12.4	89.2	28	180	13.8
	73.4	90		36.7	83.9	90		41.9
	58.4	180		58.4	78.3	180		78.3

From table 2, it is observed that the percentage loss in weight ofQBSCC and QBBSCC increases as days of immersion in acids and alkali increases. The percentage loss in weight of w/b ratio 0.3 is less compared to w/b ratio 0.4. The percentage loss in weight is more for immersion in 5% H_2SO_4 than in 5% HCl. In case of H_2SO_4, it may be due to the product of hydration $Ca(OH)_2$ reacting with H_2SO_4 to form calcium sulphate (gypsum) in the regions close to the surface of QBBSCC, causing spalling of the outer surface and exposing the inner portion for further attack. In case of HCl, it may be due to $Ca(OH)_2$ reacting with HCl to form soluble calcium chloride and water, which is leached out.But, the percentage loss in weight for both QBSCC and QBBSCC immersion in 5% Na_2SO_4 is very less compared to acids. It may be due to the reason that sulphates present in Na_2SO_4 deteriorates the concrete but since it is not as corrosive as acids, the effect may be less. It is also found that percentage loss in weight of QBBSCC is less compared to QBSCC. This may be due to the $CaCO_3$ produced by the bacteria filling the microcracks and reducing penetration of chemicals into the concrete and further deteriorating it.

From table 3, it is observed that the percentage loss in compressive strength ofQBSCC and QBBSCC increases as days of immersion in acids and alkali increases. It is found that percentage loss in compressive strength of QBBSCC is less compared to QBSCC. The percentage loss in compressive strength of w/b ratio 0.3 is less compared to w/b ratio 0.4. The percentage loss in compressive strength is more for immersion in 5% H_2SO_4 than in 5% HCl and 5% Na_2SO_4.

From table 4 and 5, it is observed that the acid durability factor of QBSCC and QBBSCC increases as no. of days of immersion increases but the increase inacid durability factor of QBBSCC is more when compared to QBSCC, i.e., QBBSCC showed better chemical resistance compared to concrete without bacteria (QBSCC). This significant improvement is due to the combined effect of calcium carbonate precipitated by bacteria and fineness & pozzolanic reaction of microsilica, flyash and GGBFS used in QBBSCC, plugging the pores and controlling further penetration of chemicals into the concrete and deteriorating it.

IV. CONCLUSION

1. The percentage loss in weight for QBSCC was 5 - 9.75% for immersion in 5% H_2SO_4, 2 – 5.6% for immersion in 5% HCl and 0.2 – 3.9 % for immersion in 5% Na_2SO_4whereas for QBBSCC, it was 2.9 - 6.4% for immersion in 5% H_2SO_4, 1.5 – 5% for immersion in 5% HCl and 0.05 – 3 % for immersion in 5% Na_2SO_4 for 28,90 and 180 days.
2. The percentage loss in compressive strength for QBSCC was 32 - 80% for immersion in 5% H_2SO_4, 17 – 51% for immersion in 5% HCl and 7 – 25 % for immersion in 5% Na_2SO_4whereas for QBBSCC, it was 19 - 42% for immersion in 5% H_2SO_4, 10 – 22% for immersion in 5% HCl and 6 – 18 % for immersion in 5% Na_2SO_4 for 28,90 and 180 days.
3. The acid durability factor for QBSCC was 9 - 22% for immersion in 5% H_2SO_4 and12.5 – 51% for immersion in 5% HCl whereas for QBBSCC, it was 12 - 59% for immersion in 5% $H_2SO_4$and 13 – 79% for immersion in 5% HCl for 28,90 and 180 days.
4. QBBSCC showed better chemical resistance compared to concrete without bacteria (QBSCC).

V. FUTURE STUDIES

1. The experiment can be conducted for higher concentration of acids and alkali.
2. The experiment can be conducted for other acids like acetic acid etc.

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AUTHORS PROFILE

Dr. M. Sridevi is an Associate Professor in Civil Engineering, ACE Engineering College. She has obtained B. Tech (Civil Engineering) and M. Tech (Advanced Construction Technology) from Pondicherry Engineering College, Pondicherry University and Ph.D from JNTU, Hyderabad. She has vast experience in teaching and training in the Construction Industry. She has several research papers in International journals and International Conference. She has also given guest lectures at ESCI, NAC and GMR Infrastructure Ltd, Hyderabad. She has guided many B.E/B.Tech and M.E students.

Dr. P. Srinivasa Rao is a Professor in Civil Engineering, JNTU College of Engineering, Hyderabad. He is specialised in structural engineering and his research interests are concrete technology, structural design, high performance concrete, prefabricated structures, special concrete and use of micro silica, fly ash in building materials. He has been associated with a number of design projects, for a number of organisations and involved as a key person in quality control and mix designs. He has guided 8 Ph.D and guided 10 Ph.D students and guided more than 200 M.Tech projects. He is a member of ISTE, ICI and Institution of Engineers and has delivered invited lectures in many organisations and institutions. He was recipient of Best Teacher Award of 2015 by Govt. of Telangana and also outstanding Concrete Engineer of Telangana – 2015 (Indian Concrete Institute)