AN EXPERIMENTAL STUDY ON HIGH PERFORMANCE BACTERIAL CONCRETE

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Abstract: Nowadays the utilization of the concrete is increase in construction industry. The introduction of mineral materials which is work as admixtures in cement has increased dramatically beside with the development of the concrete manufacturing industry, because of cost savings, energy savings, to guard the environment and supplying management considerations. However, environmental issues, both in provisions of the harm caused by raw material extraction and CO_2 released during cement production, have put pressure to limit cement use during the utilize of additional materials. High Performance Concrete (HPC) represents the latest concrete production. It has gained prominence in these years and it has been utilized in numbers of popular schemes. The utilization of these resources has shown increases in concrete's strength and hardness properties. For concrete, in current years, the utilization of bacteria has gain considerable attention. The outcome of this study shows that the compressive strength and water absorption of the HPC mixtures improved by the inclusion of the bacterial concentration in the concrete mixes using Bacillus Bacteria. This paper represents and shows the properties, namely the compressive strength (CS) and Water absorption. HPC mixtures incorporating different concentrations such as 10^3, 10^5 and 10^7 using Bacillus Pasteurri and Bacillus Megaterium Bacteria.

Keywords: **Bacterial Concrete, Bacillus Pasteurii, Bacillus Megaterium, High Performance Concrete, Microbiological Induced Calcite Precipitation (MICP).**

I. INTRODUCTION

In this world after the water, concrete is the majorly used material. However, when a broad range water decreased or super-plasticizer has been developed and has started to be utilizes to minimize the ratio of water / cement (w / c) or water / binder (w / b) relatively being used strictly as fluid has been modified for the regular concrete, on the other side there are some more improvement in the characteristics, like high fluidity, high elastic modulus, high flexural strength, low permeability, increased abrasion resistance, and good toughness, have also been shown to improvement in the strength of the concrete with minimum w / c or w / b ratios. It has contributed to the development of the HPC. HPC is the most recent breakthrough in the field of concrete. It is the one of the famous in now a days and it is utilized in many modern projects, like nuclear power plants, flyovers, multi-storey buildings, etc.

HPC has become very common in construction works since the 1990s. At present, the utilization of HPC has spread worldwide. In 1993, the American Concrete Institute (ACI) published a broad description of HPC and describes it as a concrete that satisfies unique performance and equality criteria that can't constantly be meet by using only traditional materials and mixing, Practices of positioning and treatment. Quality criteria can include enhancement of segregation-free positioning and compaction, long-term mechanical properties, early age efficiency, reliability, volume stability, or service years in harsh environments.

The bacterium-based method includes the utilization of bacillus ureolytic bacteria in the production of calcium carbonate minerals. Metabolism of this bacterial organism involves enzymatic urea hydrolysis of NH_3 and CO_2. The reaction also induces an rise in pH from acidic to alkaline states producing bicarbonate and carbonate ions precipitating calcium ions in concrete to form calcium carbonate minerals. Further crystallization of the fixes the pores and cracks of the concrete.

II. PREPARATION OF BACTERIAL CONCRETE

Bacteria are applied to the concrete mixes in the suspension condition and must follow those requirements. Bacteria used because they would be able to tolerate long-lasting high alkaline concrete conditions and be able to form spores (highly resistant structures) endure the pressure during the concrete mixing. Bacterial concrete mixture prepared using Bacillus Pasteurii and Bacillus Megaterium alongside with nutrients from in which the bacteria can possibly generate bio-minerals dependent on calcite. These would become involved as cracks develop on a concrete surface that would cause water to penetrate the structure. This effect would reduce the concrete pH condition in which the built-in bacteria are triggered.

III. EXPERIMENTAL PROGRAM

The following are the particulars of the materials which are utilized for the production of concrete.

3.1 Cement

The broadly and most generally utilized cement which is common in construction works is Ordinary Portland Cement (OPC). The OPC 53 grade cement conforming to IS: 12269-1987 was utilized for all concrete mixes. Whereas the water is included in the portland cement, chemical reactions happen between the cement and H_2O and thus coming about within the energy release and the paste of cement event which is mindful for making hardened substance. This process of response happens amid H_2O and cement is named as the hydration process and the help of the energy during this process is named as the heat of hydration. For the research work, the Ordinary Portland Cement of 53-grade use. Chemical and Physical Properties of Cement shows below in Table 1.

Table 1 Chemical and Physical Properties of Ordinary Portland Cement

Sr. No.	Particular	Test Results	Requirement of IS 12269-1987
Chemical Properties			
1	Al_2O_3/Fe_2O_3	1.27	0.66
2	Insoluble residue	1.75	3.00
3	Magnesia(percentage by mass)	1.01	6.00
4	Total loss of Ignition (percentage by mass)	2.80	4.00
5	Total chloride (percentage by mass)	0.065	0.10
Physical Properties			
1	Fineness (m^2/kg)	320	225
2	Standard consistency (percentage)	28	30-35
3	Setting time (min.) a) Initial b) Final	 155 235	 30 600
4	Soundness a) Le chat expansion (mm) b) Autoclave development (percentage)	 0.7 0.062	 10.0 0.8
5	Compressive Strength (Mpa) a) 72+/-1hr. b) 168+/-2hr. c) 672+/-4hr.	 41.0 51.0 65.6	 27 37 53

3.2 Coarse Aggregate

The Coarse aggregate (CA) is crushed granite, with 60 percent pass via 20 millimeter and retain on 12.5 millimeter sieve and 40 percent pass via 12.5 mm and retain on 4.75 millimeter sieve. Coarse aggregate weight was 60% of the overall aggregate physical properties of coarse aggregates are shown below in Table 2.

Table 2 Physical properties of coarse aggregate

Property	Values
Source	Locally available, Anand
Fineness Modulus	6.94
Specific Gravity	2.84

3.3 Fine Aggregate

Such amounts from 4.75 mm to 150 microns are referred to as fine aggregates. Locally available clay, free of silt and organic matter, was used. River sand is being used for the production of the concrete compliance with the provision of IS code 383-1970. Physical properties of fine aggregates shown below in Table 3.

Table 3 Physical properties of fine aggregate

Property	Values
Source	Locally available, Anand
Fineness Modulus	3.16
Specific Gravity	2.65

3.4 Water

Locally available water supporting the requirements stated in IS code 456-2000 shall be used.

3.5 Bacterial Source

Microorganism Bacillus Pasteurii and Bacilus Megaterium were obtained from Department of Biosciences, Sardar Patel University, Anand, Gujarat. The bacillus bacterial culture was isolated at Ashok & Rita Patel Institute of Integrated Study and Research in Biotechnology and Allied Sciences (ARIBAS), New Vallabh Vidyanagar, Anand. Media Composition used for growth of culture was Nutrient Broth for 10^7 it is 2.25g/Lt, for 10^3 it is 1.7g/Lt and for 10^5 2.25g/Lt.

Sporosarcina pasteurii or Bacillus pasteurii is known to reason the occurrence of Microbial Induced Calcite Precipitation (MICP). Sporosarcin pasteurii commonly identified as Bacillus pasteurii. Bacillus pasteurii has been suggested to use it as an environmentally friendly microbial building material. With these bacteria, it has a strong capacity to produce calcite and to produce spores in concrete to improve the durability of the concrete and to improve the compressive strength of concrete needed for this analysis.

Bacillus megaterium is a gram-positive bacterium also it is a rod-like bacteria, mostly aerobic, bacterium-forming spore found in a large variety of habitats. This bacterial cell is 4 µm and its diameter is 1.5 µm, this is the famous known bacterium. Cells also exist in pairs and chains where the cells are connected together by polysaccharides on walls of the cells. This bacteria is found everywhere in the natural world. This can be present in various food and materials, like medicinal instruments, paper, etc.

IV. DESIGN MIX

The mixes amount of HPBC is not as same as conventional concrete. There are no exact codal provisions for preparation for mix design. This research depends on trial and error so the mixes amount is depending on the literature review and guideline given by IS: 10262-2019. For every mix proportions, the water-cement ratio (w/c ratio) 0.48 is adopted for every mix proportions. All the mix designs are prepared with 10^3, 10^5 and 10^7 bacterial concentrations using different bacteria. The Design mix nomenclature are shown in Table 4, and Design mix properties for $1m^3$ concrete mix shown in Table 5.

Table 4 Nomenclature for design mixes properties

Meaning	Description
A1	Control Mix Design for M30 Grade of Concrete
B1	Bacillus Pasteurii Bacterial Concrete (M30) of 10^3 cells/ml Concentration
B2	Bacillus Pasteurii Bacterial Concrete (M30) of 10^5 cells/ml Concentration
B3	Bacillus Pasteurii Bacterial Concrete (M30) of 10^7 cells/ml Concentration
C1	Bacillus Megaterium Bacterial Concrete (M30) of 10^3 cells/ml Concentration
C2	Bacillus Megaterium Bacterial Concrete (M30) of 10^5 cells/ml Concentration
C3	Bacillus Megaterium Bacterial Concrete (M30) of 10^7 cells/ml Concentration

Table 5 Design mix properties for $1m^3$ concrete mixes

Concrete Mixes	Materials					
	Bacillus Bacteria (Liter)	Nutrient Broth (NB) (Gram)	Cement (Kg)	Fine aggregate (Sand) (Kg)	Coarse aggregate (20mm Down) (Kg)	Grit (Kg)
A1	0.00	0.00	387.50	645.36	1261.89	0.00
B1	0.60	3.38	387.50	645.36	1261.89	0.00
B2	1.20	3.50	387.50	645.36	1261.89	0.00
B3	1.20	4.50	387.50	645.36	1261.89	0.00
C1	0.60	3.38	387.50	645.36	1261.89	0.00
C2	1.20	3.50	387.50	645.36	1261.89	0.00
C3	1.20	4.50	387.50	645.36	1261.89	0.00

V. Experimental Methodology

The test examination conducted on high performance bacterial concrete (HPBC) by adding different bacterial concentrations in concrete. For all mixes, w/c ratio is 0.48. HPBC contains cement, fine aggregate, coarse aggregate, water, and Bacillus bacteria. Determination of compression test and Water absorption test both three cube tests were cast on mould size 150X150X150 millimeter for every concrete mixes with different bacterial concentrations like 10^3, 10^5 and 10^7 for compression test and Water absorption test.

5.1 Compressive strength test (IS: 516-1959)

Concrete cubes are casted by using M30 grade concrete. Specimens with Ordinary Portland cement (OPC) means standard concrete and specimens with addition of bacterial solution replaced with some percentage of water and making concentration of an

10^3, 10^5 and 10^7. During the casting, the cubes are mechanically vibrated vibrator. After the 24 hours the concrete cubes are detached from the moulds and put in the water tank for the water curing. (immersion curing) for 7, 28, 56 days. After the curing, the concrete cubes are collected from the water tank for the test namely compressive strength and using a calibrated compression testing machine of 2,000 kN capacities. The compression test is conducted on the specimens at the end of 7, 28, 56 days of curing.

5.2 Water absorption test

Standard measure concrete blocks ought to be completely submerged in fresh water at 28°C for 24 hours. All concrete blocks should be dried out in a oven at 100 to 115°C for 24 hours, and measuring the saturated weight. After that the tests conducting in oven by keeping up 100 ± 5° C for one day. Oven dry weight of the samples is recorded.

VI. Experimental results and discussion

The experimental results of compressive strength test and water absorption test are as follow.

6.1 Compressive strength test results

The following figure 1 and table 6 appears compressive strength force against deformation at 7, 28, 56 days which are as follows.

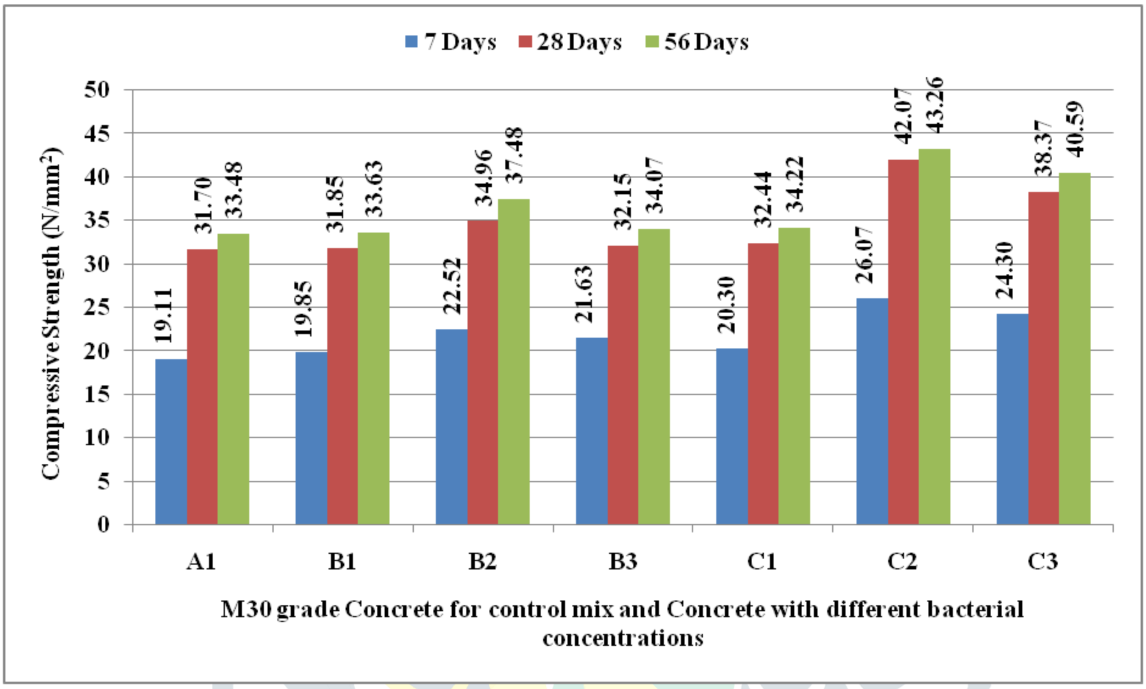

Figure 1 Compressive Strength Results for M30 grade mix: Standard Concrete and Concrete with different bacterial concentrations 10^3, 10^5, and 10^7 at 7, 28, 56 days

Table 6 Comparative Experimental Results of Compressive Strength Test Results for Control Mix and Concrete with different bacterial concentrations 10^3, 10^5, and 10^7 at 7, 28, 56 days for M30 grade concrete

Concrete Mixes	Compressive Strength (N/mm²)			% Change in Compressive Strength at		
	7 Days	28 Days	56 Days	7 Days	28 Days	56 Days
A1	19.11	31.70	33.48	0	0	0
B1	19.85	31.85	33.63	(+) 3.87	(+) 0.47	(+) 0.44
B2	22.52	34.96	37.48	(+) 17.84	(+) 10.28	(+) 11.94
B3	21.63	32.15	34.07	(+) 13.18	(+) 1.41	(+) 1.76
C1	20.30	32.44	34.22	(+) 6.22	(+) 2.33	(+) 2.21
C2	26.07	42.07	43.26	(+) 36.42	(+) 32.71	(+) 29.21
C3	24.30	38.37	40.59	(+) 27.15	(+) 21.04	(+) 21.23

Table 6 appears Compressive strength at 7, 28, 56 days for different HPBC mixes. A1 represent 33.48 N/mm² at 56 days. B1 is made with 10^3 bacterial concentration shows 33.63 N/mm² at 56 days. C2 is made with 10^5 bacterial concentration shows 43.26 N/mm² at 56 days. C3 is made with 10^7 bacterial concentration shows 40.59 N/mm² at 56 days. It shows the increase in bacterial concentration from 10^5 to 10^7 the compressive strength is decrease in HPBC.

As per table 6 it was shows that at 7 days compared to B2 mix 17.84%, the percentage in compressive strength increased in C2 mix which is 36.42%, same as at 28 days and 56 days the percentage change in compressive strength test was increased in C2 mix as compared to all other mixes. It was shows that in 10^5 bacterial concentration bacillus megaterium have more ability to produced calcite and produced endospore in concrete. So, according to this study bacillus megaterium bacteria has more ability to increase in compressive strength compare to other bacteria's.

B1 mix shows 0.47% and 0.44% minor percentage change in compressive strength at 28 days and 56 days respectively, same in C1 mix the percentage change shows minor percentage change in compressive strength at 28 days as 2.33% and 56 days as 2.21% compared to 7 days as 6.22%. B3 and C3 mixes shows improvement in compressive strength percentage compare to B1 and C1 mixes by 1.41% and 21.04% at 28 days and 1.76% and 21.23% at 56 days.

6.2 Water absorption test results

Following figure 2 and table 7 appears the results of percentage water content submerged in cubes for the water absorption test done on concrete cubes at 28 days for M30 grade concrete control mix concrete and concrete with different bacterial concentrations 10^3, 10^5 and 10^7.

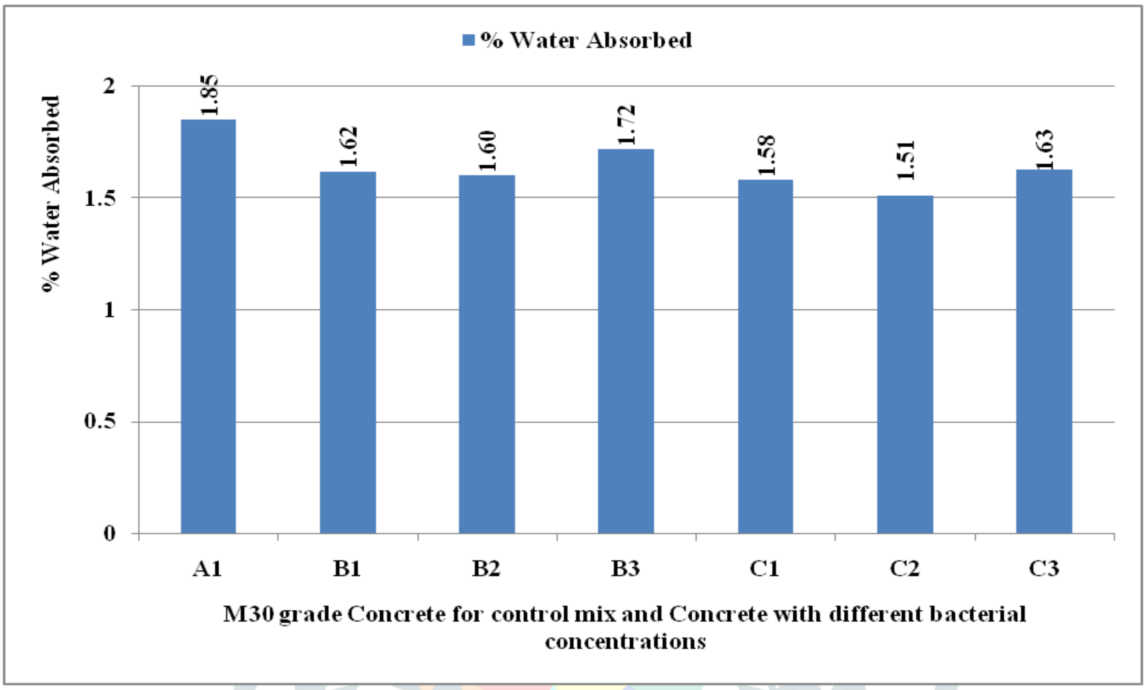

Figure 2 Percentage Water Absorbed for Control Mix and Concrete with different bacterial concentrations 10^3, 10^5 and 10^7 for M30 grade Concrete

From figure 2, it is notice that for HPBC mix percentage water absorbed were decreases in 10^5 bacterial concentration in concrete. The most elevated water absorption ratio is observed at A1 which is 1.85% and the least water absorption ratio is observed at C2 which is 1.51%.which states that bacillus megaterium has ability to reduce the water absorption ratio without changing its property.

Table 7 Water Absorption Test Results for Control Mix and Concrete with different bacterial concentrations at 28 Days for M30 grade Concrete

Concrete mixes	Oven dry weight (W1) (Grams)	After 24 hours water bath weight (W2) (Grams)	Water Absorption % age	% change in water absorption
A1	8760	8920	1.85	'0
	8490	8650		
	8670	8830		
B1	8730	8870	1.62	(-) 12.43
	8450	8590		
	8810	8950		
B2	8670	8800	1.60	(-) 1.23
	8490	8620		
	8820	8950		
B3	8340	8490	1.72	(-) 7.02
	8180	8330		
	8470	8620		

C1	8750	8880	1.58	(-) 14.59
	8440	8590		
	8830	8960		
C2	8700	8830	1.51	(-) 18.37
	8710	8830		
	8850	8970		
C3	8360	8510	1.63	(-) 11.89
	8290	8420		
	8430	8560		

VII. COST COMPARISON

Following table 8 shows the rate analysis total cost of M30 grade high performance bacterial concrete for 1 m^3. Cost comparisons are shown in Table 8.

Table 8 Total Cost of Concrete Mixes for control mix and different bacterial concentrations 10^3, 10^5, and 10^7 for 1 m^3

Concrete Mixes	Cost of Material of Concrete/ m^3	% Change in Cost
A1	3338.26	0
B1	3452.50	(+) 3.42
B2	3501.61	(+) 4.89
B3	3642.01	(+) 9.09
C1	3452.50	(+) 3.42
C2	3501.61	(+) 4.89
C3	3642.01	(+) 9.09

As per table 8 it is clearly shows that compare to A1 mix all the mixes made by bacterial concentrations shows percentage increment in total cost of 1 m^3 concrete, there is a only reason that concrete made with different bacterial concentrations 10^3, 10^5 and 10^7, are using bacillus bacteria and the process making of bacterial concrete is very costly because after collected the bacterial culture from the any source, it has to be isolated at microbiology lab. Then as per requirement the bacterial growth has been done.

The bacterial food Nutrient Broth (NB) 100 gram price is about to 500 rupees and as per requirement of bacterial concentrations NB quantity is decided. Here in this study in 10^3 bacterial concentrations required 3.38 gram NB same as 10^5 and 10^7 bacterial concentrations required 3.50 and 4.50 gram NB for bacterial growth.

From below Figure 3, it is observed that HPBC mix with Inclusion of bacterial concentrations gives higher rates for 1 m^3 concrete compared to Control Mix Concrete A1. Rates of HPBC increase with an increment in Bacterial Concentrations from 10^3 to 10^7.

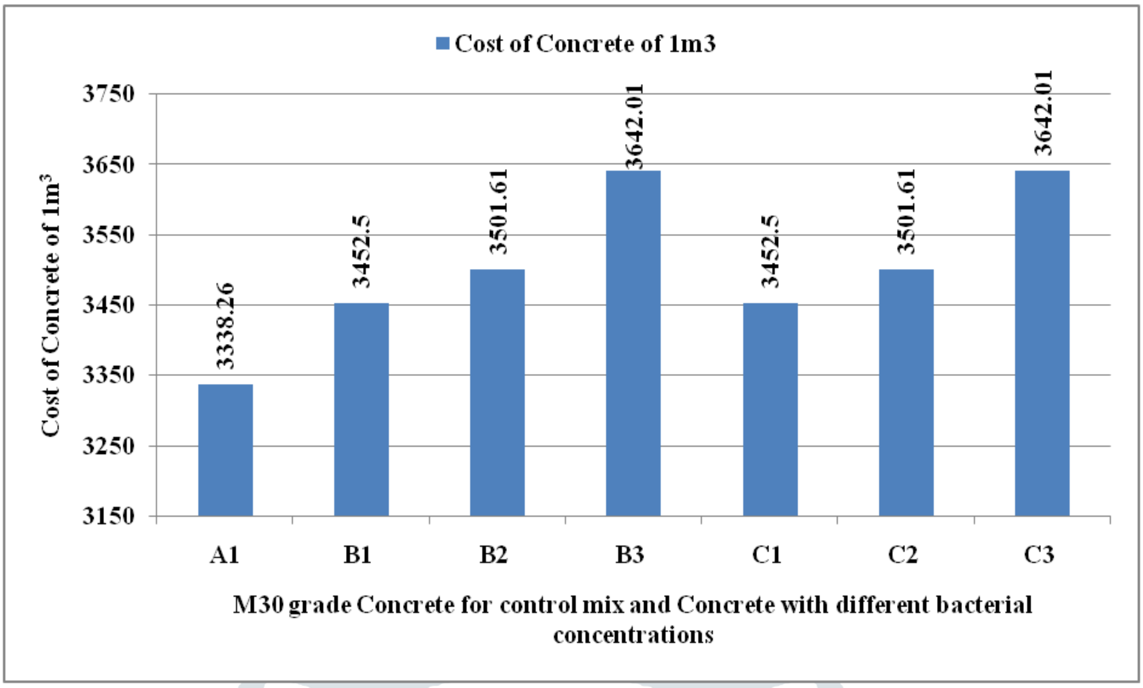

Figure 3 Cost of 1 m^3 Concrete for Control Mix and Concrete with different bacterial concentrations 10^3, 10^5 and 10^7 for M30 grade Concrete

VIII. CONCLUSION

The conclusions based on experimental work are as follows,

- Compressive strength of concrete was increasing up to adding 10^5 bacterial concentration in different bacterial concentrations for concrete mixes as compared to control mix. In concrete mixes of M30 grade B2 mix made with 10^5 bacterial concentration shows 11.94% more compressive strength then control mix A1 shows both after 56 days.
- For C2 mix made with 10^5 bacterial concentration shows 43.26 N/mm^2 (29.21%) compressive strength and control mix A1 shows 33.48 N/mm^2 both after 56 days. After increasing in bacterial concentrations from 10^5 to 10^7 the compressive strength of both mixes B3 and C3 has been decreasing which is 34.07 N/mm^2 and 40.59 N/mm^2 means 21.23% more respectively at 56 days compare to B2 and C2 mixes.
- Percentage water absorption in concrete was decreasing by increasing adding bacteria in different concentration as compared to control mix. The lower water absorption was observed up to certain addition in concrete compared to normal concrete mix. In B batch of M30 grade concrete mixes with addition of bacterial concentration, B2 mix made with 10^5 bacterial concentrations shows 1.60% water absorption and control mix A1 shows 1.85% water absorption both after 28 days which is 1.23 % less.
- In C batch of M30 grade concrete mixes with addition of bacterial concentration, C2 mix made with 10^5 bacterial concentration shows 1.51% water absorption and control mix A1 shows 1.85% water absorption both after 28 days which is 18.37% less. The water absorption results of C3 mix 10^7 bacterial concentration is less than the control mix A1 but it is higher than C1 and C2 mixes which are made with 10^3 bacterial concentration and 10^5 bacterial concentration respectively.
- The cost analysis shows that compare to conventional concrete the concrete made with different bacterial concentration was costly. As per this study the in B mixes B3 mix made with 10^7 bacterial concentrations using bacillus pasteurii bacteria shows 9.09% more costly compare to A1 mix same as in C mixes C1 and C2 mixes shows 3.42% and 4.89% more cost compare to A1 control mix.

IX. FUTURE SCOPE

From the available literatures on concrete incorporating bacillus bacteria and based on the findings in this research, following works are suggested for further research. Following are the various future scope of the experimental work.

- More study required to reduce the cost of bacterial concrete.
- Further study required to overcome on the limitations of bacillus pateurii and bacillus megaterium bacteria.
- More work should be done on the long term effect of bacteria on human life.
- The concept of to make a durable concrete is still a thing of the future for commercial and residential buildings due to the production cost.
- As this technology continues to develop in the future, the bacterial concrete could make a huge impact on the construction industry, as well as the environment.

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