Experimental Study on Green Concrete with Bacterial Inclusion

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ABSTRACT: *Today, concrete use is steadily increasing throughout the world due to its availability of basic ingredients. Because cement is the key concrete element, it has a higher environmental impact on global warming because 10% of total CO_2 emissions are attributed to cement industry. So, it has become essential to minimize the use of cement and to identify the alternate waste material which can be used to partially replace the cement and can improve the characteristics of concrete. Due to the continued reduction in the availability of the aggregate has recently encountered problems. To a certain extent, today there is a solution called "green concrete". Green concrete should adopt the methodology of reduction, reuse and recycling or any two concrete processes. In this research work microbial mineral precipitation which is used to improve the quality of concrete by precipitating calcium carbonate is studied. This experimental work was conducted on concrete samples containing Bela stone powder as replacement of cement in concrete at 5% 10%, 15%, and 20% by weight without and with the inclusion of bacterial concentration of 10^5. The standard cube measures the compressive strength after 7 days, 28 days and 56 days and water absorption test and cost compared this to that of control mixes of M30 grade.*

Keywords: Bela stone powder, Green Concrete, Industrial Waste, Microbial Incubation-Bacillus Megaterium & Bacillus Pasteurii, Bacterial Concrete, Calcite Precipitation.

1. Introduction

The use of concrete in the modern world is only surpassed by natural water. Demand for natural sand in developing countries is very high in order to meet the rapid growth of infrastructure. Some other materials have already been used to replace natural sand, such as quarry dust, fly ash and pebble powder. Limestone and recycled sand are used as a partial or complete substitute for natural sand in concrete and mortar mixtures. Green Concrete Methodology shown in Figure: 1.

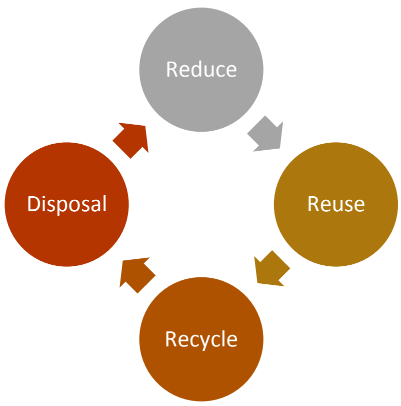

Figure 1- Green Concrete Methodology

Green concrete is also inexpensive to produce because of waste are used as partial substitutes for cement, disposal costs are reduced, lower energy required in production and the durability is greater.

2. Mechanism of Preparation of Bacterial Concrete

Bacterial concrete can be prepared in two ways in this experimental work the concrete was prepared by direct application method

The bacterial solution was prepared by mixing the nutrient broth and bacteria in 400 ml flask each as per requirement of solution and sterilized for 24 hours in incubator. This bacterial solution was added directly to concrete in the direct application process when concrete is mixed as it does not alter the normal concrete properties. For obvious reasons, as fractures appear in the frame. Healing process of Bacteria is shown below in Figure: 2.

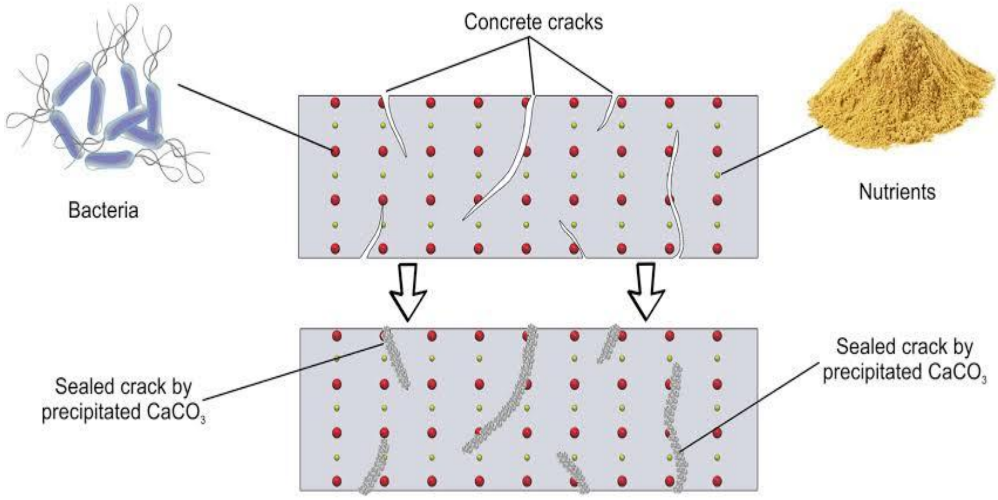

Figure 2- Healing Process by Bacteria **[19]**

The bacteria are vulnerable to changes in the climate. They germinate and feed on when water comes into contact with this bacterium. Calcium lactate and limestone is produced. Small cracks can be treated with bacterial concrete at such a width of around 0.5 mm.

3. EXPERIMENTAL MATERIALS

3.1 Bela stone powder

The composition of Bela stone is quite similar to that of sandstone that essentially consists of quartz. The natural cementing material which binds the sand together as rock is usually composed of silica, calcium carbonate, or iron oxide. The percentage constitution of each constituent varies between certain limit but the silica content is highest in Bela stone. The source of Bela stone powder used in this study was Wankaner Morbi District Gujrat. The following figure 3 shows the Bela stone powder.

Figure 3- Bela stone powder

Following table 1 shows the chemical properties of Bela stone powder.

Table 1 Physical Properties of Bela stone powder

Sr. No.	Particular	Value
1	**Silica (SiO_2)**	**82.36 %**
2	**Alumina (Al_2O_3)**	**2.71 %**
3	**Calcium oxide (CaO)**	**0.16 %**
4	**Magnesium Oxide (MgO)**	**3.45 %**
5	**Iron oxide (Fe_2O_3)**	**2.71 %**
6	**Sulphur trioxides (SO3)**	**0.24 %**

(Source: YOR Laboratory Rajkot)

3.2 Cement

Cement is a binder used in construction that hardens, hardens and adheres to other materials in order to bind them. Cement is rarely used alone, but rather to bind fine aggregate and coarse aggregate. The OPC 53 grade cement conforming to IS: 12269-1987 was utilized for all concrete mixes. The Chemical and Physical Properties of Cement shown below in Table 2.

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	155	30
	b) Final	235	600
4	Soundness		
	a) Le chat expansion (mm)	0.7	10.0
	b) Autoclave development (percentage)	0.062	0.8
5	Compressive Strength (Mpa)		
	a) 72+/-1hr.	41.0	27
	b) 168+/-2hr.	51.0	37
	c) 672+/-4hr.	65.6	53

Table 2 Chemical and Physical Properties of Cement

3.3 Fine Aggregate and Coarse Aggregate

Those fractions from 4.75 mm to 150 microns are termed as fine aggregate. Locally available sand, free from silt and organic matters was used. The river sand is be used in combination as fine aggregate conforming to the requirements of IS 383- 1970.

Coarse Aggregate is crushed granite metal with 60% passing 20 mm and retained on 12.5mm sieve and 40% passing 12.5mm and retained on 4.75mm sieve were used. The weight of coarse aggregate was 60% of the total aggregate and specific gravity of coarse aggregate was 2.84.

Table 3 Properties of Fine Aggregate and Coarse Aggregate

Property	Fine Aggregate	Coarse Aggregate 20 mm
Specific Gravity	2.65	2.84
Fineness Modulus	3.16	6.94

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 10^5 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.

4. Experimental Methodology

The following mix design was used in proposed research work.

4.1 DESIGN MIXES

The mixes amount of bacterial concrete with industrial waste 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 10^5 bacterial concentrations using different bacteria with addition of different percentages of Bela stone powder. 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
A0	M30 Control Mix Design
B1 BS5%	5% Bela Stone Powder with replacement of cement in concrete
B2 BS10%	10% Bela Stone Powder with replacement of cement in concrete
B3 BS15%	15% Bela Stone Powder with replacement of cement in concrete
B4 BS20%	20% Bela Stone Powder with replacement of cement in concrete
M1 BS5%+B	5% Bela Stone Powder with replacement of cement inclusion of 10^5 Bacterial Solution in concrete
M2 BS10%+B	10% Bela Stone Powder with replacement of cement inclusion of 10^5 Bacterial Solution in concrete
M3 BS15%+B	15% Bela Stone Powder with replacement of cement inclusion of 10^5 Bacterial Solution in concrete
M4 BS 20%+B	20% Bela Stone Powder with replacement of cement inclusion of 10^5 Bacterial Solution in concrete

Table 5 Design mix properties for 1m³ concrete mixes

Concrete Mixes	MATERIALS						
	Bela stone powder	Bacillus Bacteria	Nutrient Broth	Cement	Fine aggregate (Sand)	Coarse aggregate (20mm Down)	Grit
A0	0.00	0.00	0.00	387.50	645.36	1261.89	0.00
B1 BS5%	19.38	0.00	0.00	368.13	645.36	1261.89	0.00
B2 BS10%	38.75	0.00	0.00	348.75	645.36	1261.89	0.00
B3 BS15%	58.13	0.00	0.00	329.38	645.36	1261.89	0.00
B4 BS20%	77.50	0.00	0.00	310.00	645.36	1261.89	0.00
M1 BS5%+B	19.38	1.20	3.5	368.13	645.36	1261.89	0.00
M2 BS10%+B	38.75	1.20	3.5	348.75	645.36	1261.89	0.00
M3 BS15%+B	58.13	1.20	3.5	329.38	645.36	1261.89	0.00
M4 BS 20%+B	77.50	1.20	3.5	310.00	645.36	1261.89	0.00

4.2 Test Methods

The test examination conducted on Bela stone powder concrete and the same with addition of bacterial concentrations of 10^5 in concrete. For all mixes, w/c ratio is 0.48. This concrete contains cement, fine aggregate, coarse aggregate, water, Bela stone powder and Bacillus bacteria. Determination of compression test and Water absorption test both three cube tests were cast on mould size 150X150X150 millimetre for every concrete mixes with bacterial concentrations 10^5 and different percentages of Bela stone powder for compression test and Water absorption test.

4.3 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 the replacement of cement by Bela stone powder at 5%, 10%, 15% and 20% with addition of bacterial solution replaced with some percentage of water and making concentration of 10^5. 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 ofcuring.

4.4 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 an oven at 100 to 115°C for 24 hours, and measuring the saturated weight. After that the tests was conducted on oven dry samples after keeping up 100 ± 5° C for one day. Oven dry weight of the samples is recorded.

5. Experimental results and discussion

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

5.1 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.

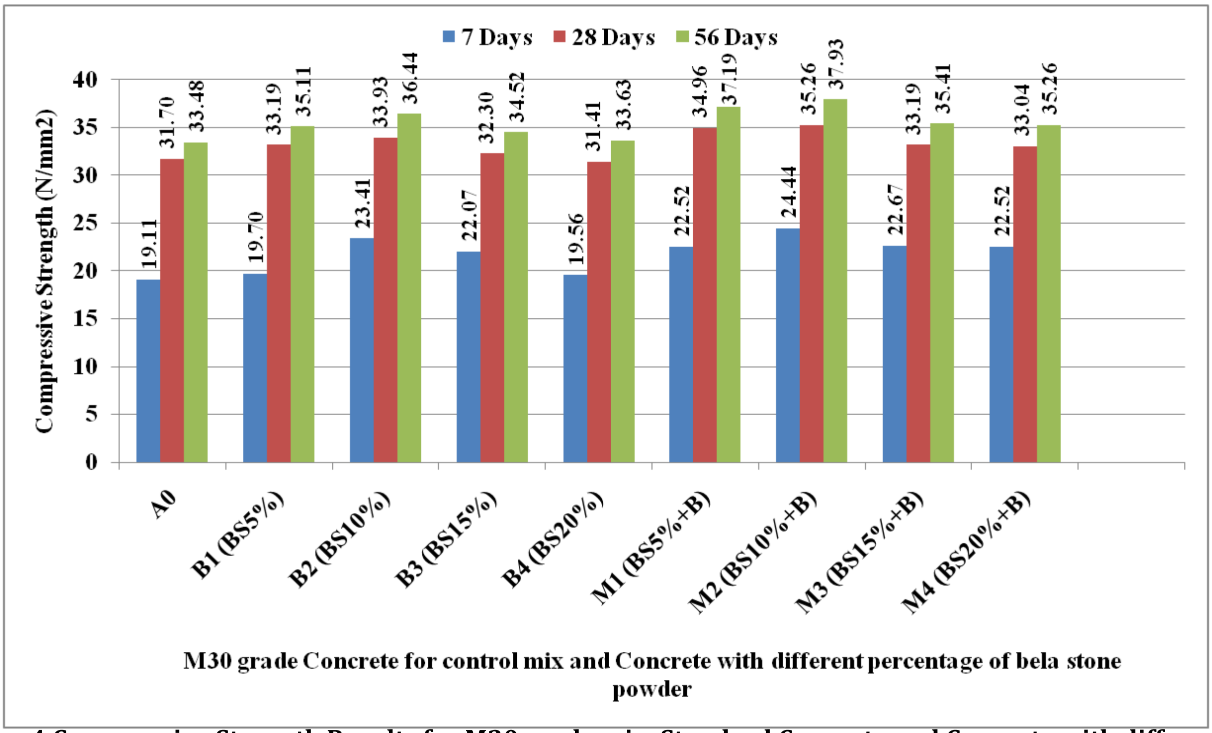

Figure 4 Compressive Strength Results for M30 grade mix: Standard Concrete and Concrete with different percentages of Bela stone powder and bacterial concentration at 7, 28, and 56 days

Compressive Strength (N/mm²)				% Change in Compressive Strength at		
Concrete Mixes	7 Days	28 Days	56 Days	7 Days	28 Days	56 Days
A0	19.11	31.70	33.48	0	0	0
B1 BS5%	19.70	33.19	35.11	3.09	4.70	4.87
B2 BS10%	23.41	33.93	36.44	22.50	7.03	8.84
B3 BS15%	22.07	32.30	34.52	15.49	1.89	3.10
B4 BS20%	19.56	31.41	33.63	2.35	0.91	0.45
M1 BS5%+B	22.52	34.96	37.19	17.84	10.28	11.08
M2 BS10%+B	24.44	35.26	37.93	27.89	11.23	13.29
M3 BS15%+B	22.67	33.19	35.41	18.63	4.70	5.76
M4 BS 20%+B	22.52	33.04	35.26	17.84	4.22	5.31

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

Table 6 appears Compressive strength at 7, 28, 56 days for different mixes. A0 represent 33.48 N/mm² at 56 days. B2 is made with 10% Bela stone powder shows 36.44 N/mm² at 56 days. M2 is made with 10^5 bacterial concentration and 10% Bela stone powder shows 37.93 N/mm² at 56 days. It shows the increase in compressive strength with bacterial concentration 10^5 as compared to the concrete with only Bela stone powder.

5.2 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 bacterial concentration 10^5 and different % of Bela stone powder.

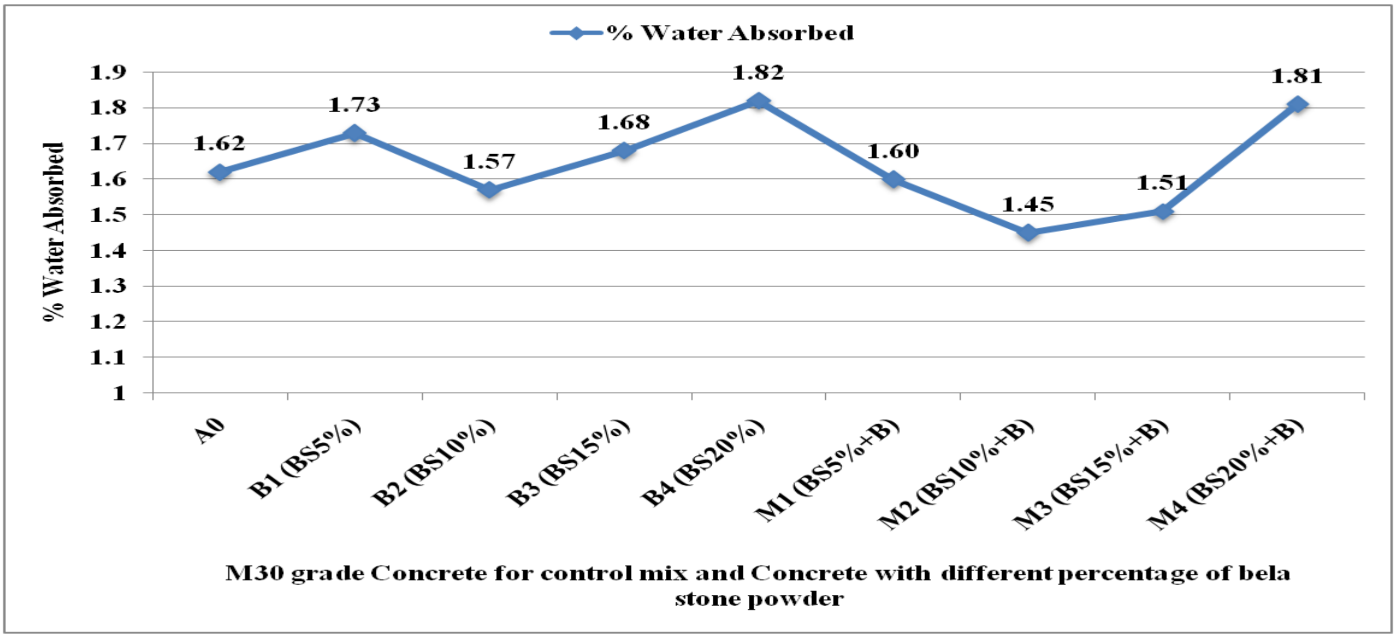

Figure 5 Percentage Water Absorbed for Control Mix and Concrete with different % of Bela stone powder and bacterial concentration for M30 grade Concrete

From figure 5, it is notice that for mix percentage water absorbed were decreases in 10^5 bacterial concentration in concrete. The most elevated water absorption ratio is observed at B4 which is 1.82% and the least water absorption ratio is observed at M2 which is 1.45%.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 % of Bela stone powder and bacterial concentration at 28 Days for M30 grade Concrete

Concrete Mixes	Oven Dry Weight (W1) Grams	After 24 Hours Water Bath Weight (W2) Grams	Water Absorption in % age (W2-W1/W1) x 100	Water Absorption % age
A0	8740	8880	1.60	**1.62**
	8500	8640	1.65	
	8630	8770	1.62	
B1 BS5%	8780	8930	1.71	**1.73**
	8450	8600	1.78	
	8860	9010	1.69	
B2 BS10%	8670	8800	1.50	**1.57**
	8430	8560	1.54	
	8840	8970	1.47	
B3 BS15%	8300	8440	1.69	**1.68**

	8190	8330	1.71	
	8460	8600	1.65	
B4 BS20%	8280	8430	1.81	**1.82**
	8170	8320	1.84	
	8330	8480	1.80	
M1 BS5%+B	8840	8980	1.58	**1.60**
	8550	8690	1.64	
	8890	9030	1.57	
M2 BS10%+B	8770	8900	1.48	**1.45**
	8530	8660	1.52	
	8950	9070	1.34	
M3 BS15%+B	8400	8530	1.55	**1.51**
	8200	8330	1.59	
	8580	8700	1.40	
M4 BS 20%+B	8200	8350	1.83	**1.81**
	8290	8440	1.81	
	8400	8550	1.79	

6. COST COMPARISON

Following table 8 shows the rate analysis total cost of M30 grade Bela stone powder concrete with bacteria for 1 m^3. Cost comparisons are shown in Table 8.

As per table 8 it is clearly shows that compare to A0 mix all the mixes(M Batch) made by bacterial concentrations shows percentage increment in total cost of 1 m^3 concrete, there is a only reason that concrete made with bacterial concentration 10^5 is 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.
While in B batch the cost of concrete is comparatively less than control mix A0 because of replacement of cement by Bela stone powder.

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 10^5 bacterial concentrations required 3.50 gram NB for bacterial growth.

Table 8 Total Cost of Concrete Mixes for control mix and bacterial concentrations 10^5 with Bela stone **powder for 1 m³**

Concrete Mixes	Cost of Material of Concrete/ m³	% Change in Cost
A0	3338.26	0
B1 BS5%	3239.45	-2.96
B2 BS10%	3140.64	-5.91
B3 BS15%	3041.83	-8.88
B4 BS20%	2943.01	-11.84
M1 BS5%+B	3976.43	+19.11
M2 BS10%+B	3877.61	+16.15
M3 BS15%+B	3778.80	+13.20
M4 BS 20%+B	3679.98	+10.23

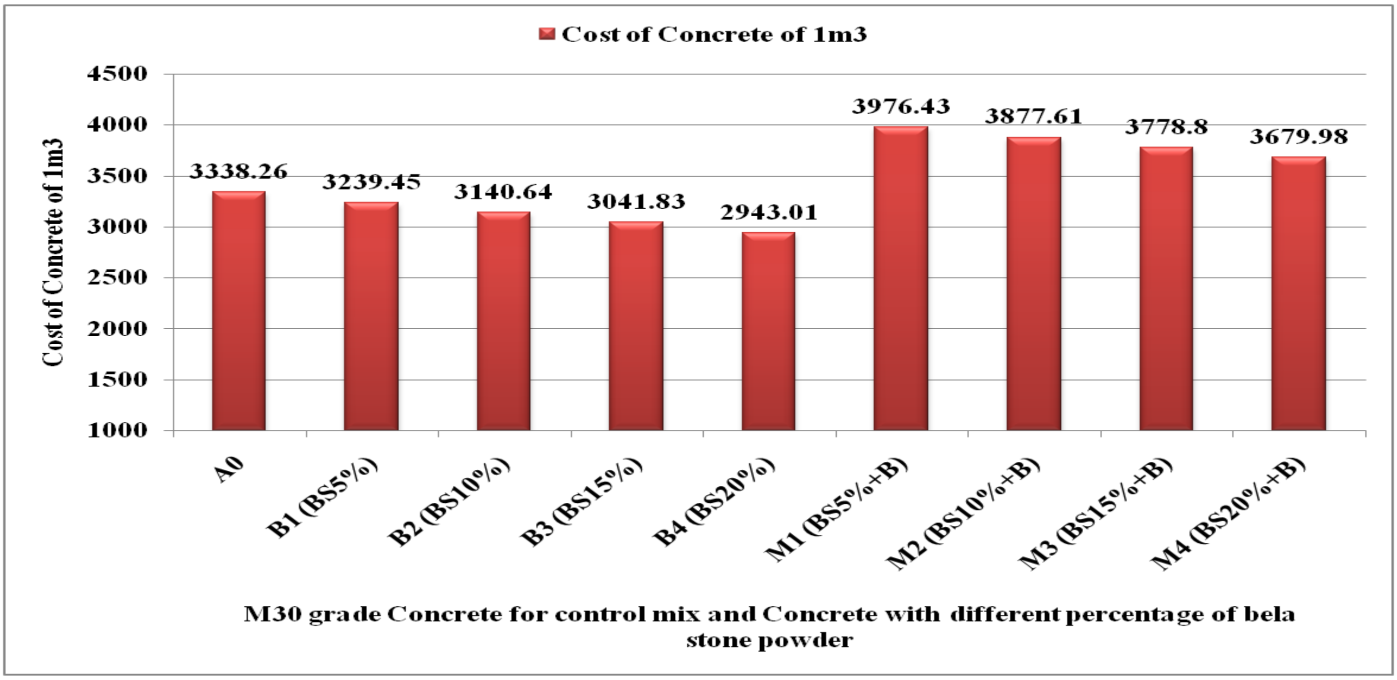

Figure 6 Cost of 1 m³ Concrete for Control Mix and Concrete with bacterial concentration 10^5 with Bela stone powder for M30 grade Concrete

7. CONCLUSIONS

The conclusions based on experimental work are as follows,

1. In concrete mixes of M30 grade B2 mix made with 10% Bela stone powder shows 36.44 N/mm² compressive strength and control mix A0 shows 33.48 N/mm² both after 56 days.

2. For M2 mix made with 10^5 bacterial concentration and 10% Bela stone powder shows 37.93 N/mm^2 compressive strength and control mix A1 shows 33.48 N/mm^2 both after 56 days.
3. Concrete mixes made with 10^5 bacterial concentration of bacillus bacteria and Bela stone powder gives more compressive strength of 28 days compare to control mix.
4. In B batch of M30 grade concrete mixes with addition of 10% Bela stone powder shows 1.57% water absorption and control mix A0 shows 1.62 % water absorption both after 28 days.
5. In M batch of M30 grade concrete mixes with addition of bacterial concentration of 10^5 and 10% Bela stone powder , M2 mix shows 1.45% water absorption and control mix A0 shows 1.62% water absorption both after 28 days.
6. Concrete mix M30 with addition of Bela stone powder in different proportion have lower rates 5.91% less at B2 for 1 m^3 concrete with compared to standard A0 concrete mix.
7. Concrete mix M30 with addition of Bela stone powder in different proportion and bacteria have higher rates16.15% at M2 for 1 m^3 concrete with compared to standard A0 concrete mix.

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