INFLUENCE OF SILICAFUME AND BACTERIA ON PROPERTIES OF CONCRETE

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***Abstract*—To improve mechanical and durability properties of concrete, the present investigation is to measure the strength and durability characteristics of the concrete by partial replacement of cement with silica fume which is a by-product ofsilicon metal or ferrosilicon alloys. In addition to silica fume, bacterial solution is added to the concrete which helps to heal the cracks by spraying of water and this type of concrete containing bacteria is also known as Bacterial concrete. In this present study cement mortar cubes are casted to determine the exact percentage of silica fume to be added to improve mechanical strength of concrete approximately among 0%, 5%, 10%, 15% and 20% percentages. Certain constant percentage of silica fume is considered and is partially replaced in cement for all mixes of concrete using bacteria subtilis(ml/litres) with different quantities like 5ml, 10ml and 15ml. The various physical and mechanical properties like compressive strength, split tensile strength and also durability properties are studied which consists of Acid attack, alkaline attack and water absorption test for M_{20} grade of concrete mix. This study was to investigate the quantity usage of bacteria with the combination of constant percentage of silica fume which improves properties of concrete.**

***Keywords*— Silica Fume (SF), Compressive strength, Split tensile strength, Durability, Bacteria subtilis**

I. INTRODUCTION

Concrete is one of the most produced materials in the world. The amount of cement, which acts as a binder in concrete produced by the industries it's about billion tonnes in a year and during the production process it exhibits large amount of CO2 which leads to global warming. So, now a days it is appreciable to replace cement in concrete with some other alternative materials like fly ash, silica fume, metakaolin and GGBS which improves properties also. Although concrete has high compressive strength, it is weaker to tensile forces. Therefore, concrete is often reinforced with steel bars. Micro cracks and pores in concrete arehighly undesirable because they provide an open pathway for the ingress of water and other deleterious substances. This leads to corrosion of reinforcement and reduces the strength and durability of concrete. Unfortunately, water entering through cracks in concrete can cause corrosion of the steel reinforcement and deterioration of the concrete matrix.

Consequently, it is necessary to find a non-labor-intensive method to repair concrete from the inside out. Ideally, concrete should be made in such a way that it is self-healing; making it heals itself without any external aid. A variety of techniques are available but majority of traditional repair systems are chemical based, expensive Lead to environmental and health hazards. Moreover, repair works have a significant adverse environmental impact particularly in cases where partial or complete replacement of structures is required.

The present-day world is witnessing the construction of very challenging and aesthetic structures. Concrete is being the most important and widely used material. Efforts are being made in the field of concrete technology to develop such concretes with special characteristics. To overcome these pointsthe present study is used to determine the properties of concrete using silica fume as constant percentage (15%) replacement in place of cement and bacteria subtilis in different percentages.

A. Bacillus Subtilis

Bacillus Subtilis(fig 1.1), known also as the hay bacillus or grass bacillus, is a Gram-positive, catalase-positive bacterium, found in soil and the gastrointestinal tract of ruminants and humans. A member of the genus Bacillus, Bacillus Subtilis is rod-shaped, and can form a tough, protective endospore, allowing it to tolerate extreme environmental conditions. Bacillus Subtilis has historically been classified as an obligate aerobe, though evidence exists that it is a facultative anaerobe. Bacillus Subtilis is considered the best studied Gram-positive bacterium and a model organism to study bacterial chromosome replication and cell differentiation. It is one of the bacterial champions in secreted enzyme production and used on an industrial scale by biotechnology companies.

Fig 1.1: Bacteria (Bacillus Subtilis) in Spore Form

This species is commonly found in the upper layers of the soil, and evidence exists that Bacillus Subtilis is a normal gut commensal in humans. A 2009 study compared the density of spores found in soil (about 106 spores per gram) to that found in human feces (about 104 spores per gram). The number of spores found in the human gut was too high to be attributed solely to consumption through food contamination. Bacillus Subtilis has been linked to grow in higher elevations and act as an identifier for both eco-adaptability and honey bee health.

B. Silica Fume

Silica fume (SF) is a byproduct of the smelting process in the silicon and ferrosilicon industry. The reduction of high-purity quartz to silicon at temperatures up to 2,000C produces SiO2 vapor's, which oxidizes and condense in the low temperature zone to tiny particles consisting of non-crystalline silica. By-products of the production of silicon metal and the ferrosilicon alloys having silicon contents of 75% or more contain 85–95% non-crystalline silica. The by-product of the production of ferrosilicon alloy having 50% silicon has much lower silica content and is less pozzolanic. Therefore, SiO2 content of the silica fume is related to the type of alloy being produced.

Fig 1.2: Silica Fume powder

II.MATERIALS

A. Cement

The Cement used throughout the test program was Ordinary Portland Cement (OPC) of 53 grade Zuari cement conforming to IS 12269-1987.The physical properties of cement are tabulated below,

Table 1
Properties of Cement

S.No	Property	Values
1	Fineness of Cement	6%
2	Specific Gravity	3.13
3	Normal Consistency	33 %
4	Setting Time i) Initial Settingtime ii) Final settingtime	40 mins 350 mins
5	Soundness	1mm

B. Fine Aggregate

Locally available river sand confirming to zone II of IS: 383-1970. Table 2 shows physical properties of fine aggregate.

Table 2
Properties of Fine Aggregate

S.No	Property	Values
1	Specific Gravity	2.6
2	Fineness modulus	3.12
3	Bulking of sand	15.38%
4	Bulk Density	1618 Kg/m^3

C. Coarse Aggregate

The coarse aggregate maximum size 20 mm and 12.5 mm angular types are used. The experimental studies are carried out to find the properties of coarse aggregate. As per IS 383-1970 & IS 2386-1983 and are shown in Table3.

Table 3
Properties of Coarse Aggregate

S.No	Properties	Value
1	Specific Gravity	2.76
2	Bulk Density	15.41 kN/m^3
3	Water Absorption	0.41%
4	Fineness Modulus	7.9

D. Silica Fume

Silica fume used in the present study is obtained from astrra chemicals, Chennai and the chemical and physical properties are tabulated below which are given by the manufacturer.

Table 4
Properties of Silica Fume

S.No	Properties	Value
1	Specific Gravity	2.2
2	Bulk Density (Densified)	480 to 720 Kg/m^3
3	Particle size	<1 μm
4	Powder type	Amorphous
5	Silicon dioxide	>85%

E. Water

Ordinary water available in the laboratory was used for the experimental investigations and for curing purpose. Water is an important ingredient in concrete ingredients which leads to hydration reaction with cement. Tap water available in college premises is used for mixing and curing.

F. Bacteria Subtilis

Bacillus Subtilis, known also as the hay bacillus or grass bacillus, is a Gram-positive, catalase-positive bacterium, found in soil and the gastrointestinal tract of ruminants and humans. A member of the genus Bacillus, Bacillus Subtilis is rod-shaped, and can form a tough, protective endospore, allowing it to tolerate extreme environmental conditions. Bacillus Subtilis has historically been classified as an obligate aerobe, though evidence exists that it is a facultative anaerobe. Bacteria (bacillus subtilis) is obtained from pharmacy college, NTR University, Vijayawada.

III. CULTURING OF BACILLUS SUBTILIS

- Primarily preparation of Nutrient Broth (media) was done by adding 2.5 grams of Peptone, 1.5 grams of Beef extract and 2.5 grams of Sodium Chloride (NaCl) to a 500 ml of distilled water in a conical flask as shown in the fig 3.1.

Fig 3.1 Preparation of nutrient broth solution

- Conical flask was covered with a cotton plug and was enclosed with silver foil as shown in fig 3.2.

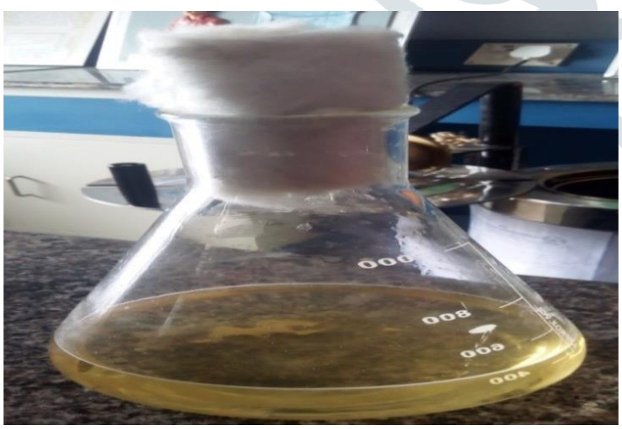

Fig 3.2 conical flask with cotton plug

- Solution was sterilized using an autoclave for about 20 minutes at a constant temperature of 121°C and pressure of 15 lbs. In autoclave, water should be filled up to level 1 as shown in fig 3.3.

Fig 3.3 sterilizing the solution by using auto clave equipment

- After sterilization, the solution was contaminant free and it was in clear orange colour as shown in fig 3.4.

Fig 3.4 contaminant free solution after sterilization process

- Later, the flask will be opened in lamina air flow chamber and a small pinch of the bacteria was added to the solution as shown in fig.3.5.

  Then it was incubated in an orbital shaker with a speed of 125 rpm at 37°C.After 24 hours, it was observed that the colour of bacterial solution changed to whitish yellow turbid as shown in fig which indicates the growth of bacillus Subtilis.

Fig 3.5: Adding the Bacillus Subtilis to the Nutrient Broth Medium in Aseptic Room inside the Laminar Air Flow Equipment

IV. MIX DESIGN

Mortar mix ratio of 1:3 is considered and different cubes were casted using silica fume as a partial replacement of cement about 0%, 5%, 10%, 15%, 20 percentages. The mix details are given below in table 5.

Table 5
Mix Proportion

Mix Proportions	1:3	1:3	1:3	1:3	1:3
Cement (%)	100	95	90	85	80
Silica Fume (%)	0	5	10	15	20
Fine aggregate (%)	100	100	100	100	100

Mixes of M_{20} grade were designed as per IS 10262-1982and IS 456-2000and the specimens were casted. In this study, the cementis partially replaced with silica Fumeas a constant percentage of about 15% and the bacteria solution is added as 0, 5, 10 and 15ml/Lt of concrete.The mix details are obtained asfollows,

Table 6
Details of mixes

S. No	Detailed Mix	Mix
1	Control concrete	C1
2	15% silica fume & 5ml/lt of bacteria in concrete	C2
3	15% silica fume & 10ml/lt of bacteria in concrete	C3
4	15% silica fume & 15ml/lt of bacteria in concrete	C4

Table 7
Mix Proportion

Proportions	Water	Cement	Fine aggregate	Coarse aggregate
By weight	192	383.16	716.56	1157.52
By ratio	0.50	1	1.87	3.02

V. RESULTSAND DISCUSSIONS

A. *Compressive Strength*

The mortar cube specimens of size 70.5mm x 70.5mm x 70.5mm were casted using silica fume with different percentages and tested in Compression Testing Machine (CTM) after 3, 7, and 28 days of curing period for different proportions of mortar mix.The average of three specimens for each proportion is shown in Table 8.

Table 8
Compressive strength values of cement mortar cubes using silica fume in different percentages

Percentage of silica fume added	Compressive strength (Mpa)		
	3 Days	7 Days	28 Days
0	29.52	36.56	54.23
5	28.56	34.10	54.97
10	28.03	32.21	56.73
15	26.51	32.07	**57.01**
20	26.11	30.13	56.81

Among the mixes mentioned above, the compressive strength for the mix casted using 15% replacement of silica fume in cement shown higher strength about 57.1MPa compared to other values. So, from this test the constant percentage of silica fume(15%) is considered for casting of concrete cubes using bacteria subtilis.

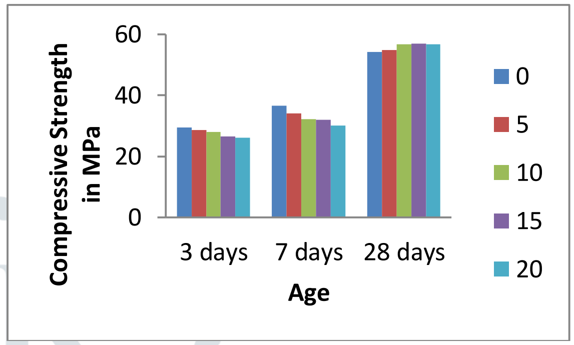

Fig 5.1 Compressive strength values of cement mortar

The concrete cube specimens of size 150mm x 150mm x 150 mm were casted using partial replacement of cement with silica fume of about 15% (constant) and Bacteria subtilis in different percentages. The specimens were tested in Compression Testing Machine (CTM) after 7, 14, 28, 56 and 90 days of curing period for different proportions of mix. The average of three specimens for each proportion is shown in Table 9.

Table 9
Compressive strength values of concrete cubes using silica fume and bacteria subtilis solution

Mix	Compressive strength (Mpa)				
	7 Days	14 Days	28 Days	56 Days	90 Days
C1	16.65	19.45	22.54	24.87	26.15
C2	18.89	21.92	25.07	27.23	28.64
C3	21.29	24.45	27.69	29.65	31.14
C4	23.75	26.96	30.36	32.10	33.76

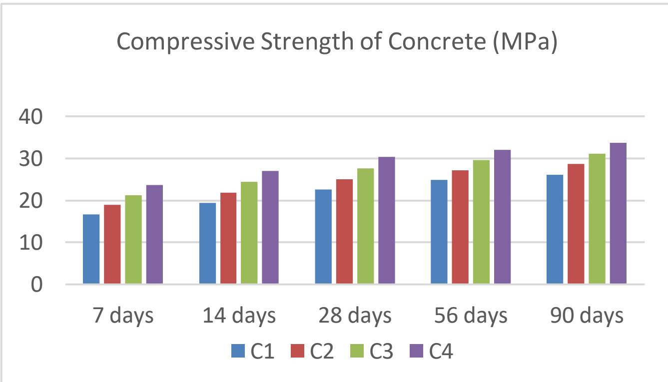

Fig 5.2 Compressive strength test results for concrete cubes

Among the mixes casted using silica fume and bacteria subtilis, the mix with 15 % silica fume and 15% bacteria subtilis shown higher strength value at 90 days about 33.76Mpa compared to all other mixes. The percentage increase in strength compared to conventional mix is about 29.10% as shown in the fig 5.3.

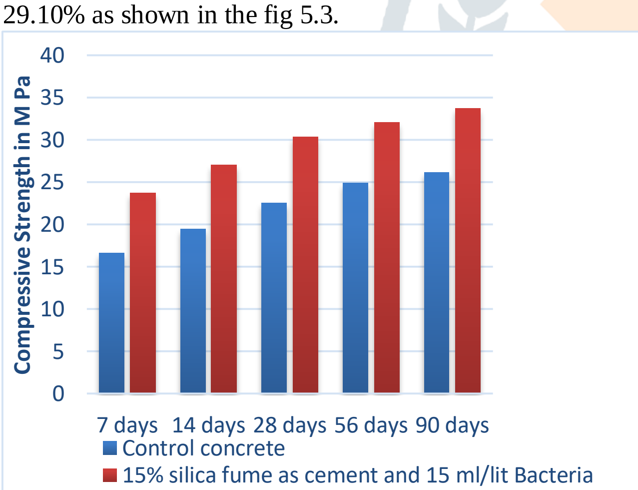

Fig 5.3 Compressive strength results comparison of C1 and C4 Mix

From the Fig 5.3, it is observed that the compressive strength of concrete gradually increases with the age of concrete. The compressive strength at 7, 14, 28, 56 and 90 days are 23.75 N/mm2,26.96N/mm2, 30.36N/mm2, 32.1N/mm2 and 33.76N/mm2 respectively

B. Durability tests

i) Water absorptiontest

One of the most important properties of a good quality concrete is low permeability, especially one resistant to freezing and thawing. The water absorption test is carried out at the age of 28 days according to standard procedure ASTMC642-11. For the water absorption test,150x150×150 mm size of cubes are driedinan ovenat 100^0C fornotless than 24 hours. After removingeach specimen from the oven, the specimen is cooled at room temperature and the weight of specimen is noted as shown in table 10.

Water absorption is expressed as increase in weight percent.

Percentage of Water Absorption = [(Wet weight - Dry weight)/Dry weight] x 100

Table 10
Compressive strength values of concrete cubes using silica fume and bacteria subtilis solution

S. No	MIX	Wet weight (Kg)	Dry weight (Kg) B	Water absorption (%)
		A	B	((A-B)/B)x 100
1	C1	16.65	19.45	22.54
2	C2	18.89	21.92	25.07
3	C3	21.29	24.45	27.69
4	C4	23.75	26.96	30.36

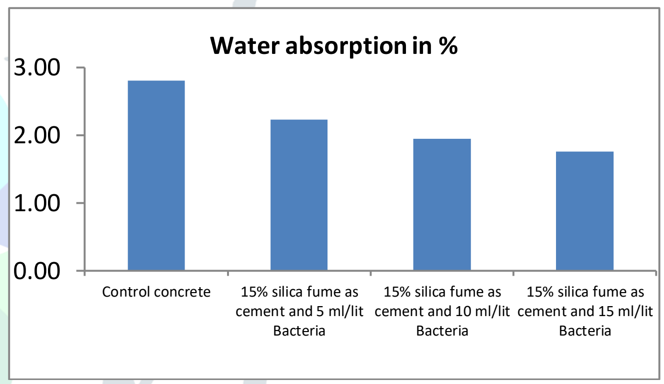

Fig 5.4 Water absorption test results of all mixes

The concrete specimens casted using silica fume and bacteria subtilis is tested for water absorption and from fig 5.4 it is observed that the water absorption is low for the cubes casted using 15 % silica fume and 15% bacteria subtilis compared to other mixes. The specimens with low surface water absorption indicates that concrete sample is less permeable. So, the mix C4 specimens are less permeable compared to other mixes.

ii) Acid Attack test

The Acid attack test is conducted for the specimens which are cured for 28 days. For the Acid attack test, 150x150x150mm size concrete cubes are removed from curing and dried and also weight of the cubes is noted before the test. The cubes with different percentage replacements were immersed in a solution of Hydrochloric acid (HCl) with 0.1M and allow curing for 28 days. After 28 days curing period, the cubes were removed and weight of the cubes were noted. The results are shown in the table 11.

Table 11
Compressive strength values and percentage reduction in weight when cured in HCL for 28 days

Mix	Weight of concrete before test	Weight of cubes after test(curing in HCL)	% Reduction in weight	Compressive strength (MPa)	% reduction in strength compare to water curing
C1	8.784	8.357	4.86	19.51	13.44
C2	8.562	8.268	3.43	23.33	6.94
C3	8.603	8.297	3.56	26.18	5.45
C4	8.489	8.178	3.66	29.02	4.41

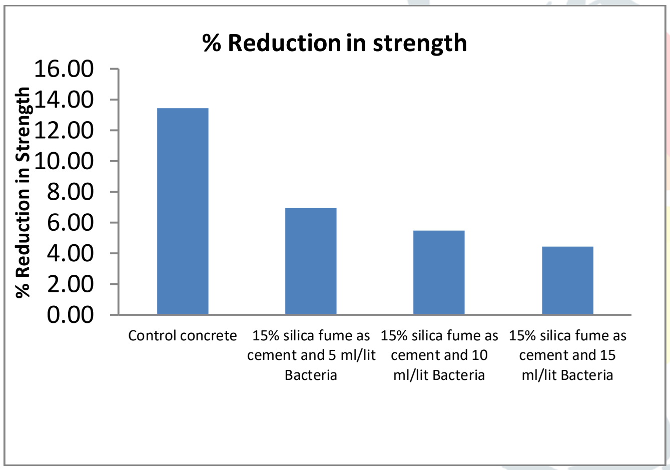

Fig 5.5 Graphical representation of acid attack test result (% reduction in compressive strength)

Among all mixes, the mix with 15% silica fume and 5% bacteria subtilis casted specimens shown less reduction in weight about 3.43% after 28 days of acid curing compared to other mixes. But the same mix didn't show better result in compressive strength while the mix with 15% silica fume and 15% bacteria subtilis shown lesser reduction in compressive strength about 4.41% compared to other mixes as shown in fig 5.5.

iii) Alkaline Attack test

For the determination of the resistance of cubes withreplacement of cement by silica fume and addition of bacteria subtilis, the cubes were immersed in a solution of SodiumSulphate (Na_2SO_4) about 5% of water and allowcuring for 28 days. The alkalinity of the water was constantly monitored throughout the curing period. After 28 days curing period in sodium sulphate solution, the cubes were removed, allow drying and tested for the compressive strength. The results obtained from the compressive strength test are shown in the table 12.

Table 12
Compressive strength values and percentage reduction in weight when cured in Na_2SO_4 for 28 days

Mix	Weight of concrete before test	Weight of cubes after test(curing in Na_2SO_4)	% Reduction in weight	Compressive strength (MPa)	% reduction in strength compare to water curing
C1	8.742	8.359	4.381	19.86	13.49
C2	8.568	8.237	3.863	22.89	9.52
C3	8.641	8.379	3.032	25.48	8.67
C4	8.769	8.587	2.075	28.46	6.68

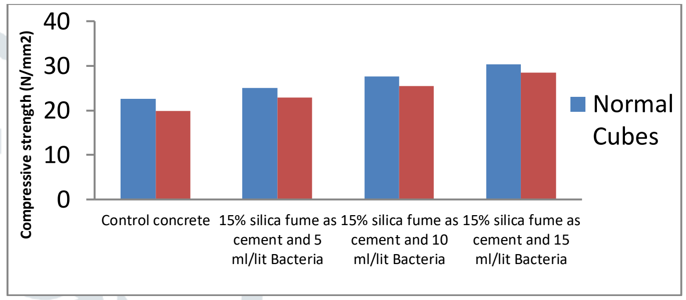

Fig 5.6 Graphical representation of Alkaline attack test result (% reduction in compressive strength)

Among all mixes, the mix with 15% silica fume and 15% bacteria subtilis casted specimens shown less reduction in weight about 2.075% after 28 days of alkaline curing and also the same mix shown better result in compressive strength. It is observed that reduction in compressive strength compare to normal concrete mix is about 6.68% which is less compared to other mixes as shown in fig 5.6.

iv) X ray Diffraction test

This test was conducted for the mix with 15% silica fume and 15% bacteria subtilis to determine the crystalline structure of the specimen and also calcite percentage. The apparatus features are like Bruker- D8, ADVANCE diffracto-meter, with 2.2KW Cu-anode ceramic tube (wavelength 1.5406), Lynx Eye Detector (Silicon strip detector technology) & Scintillation Detector (for low angle XRD analysis). The data were acquired at 300 K with a step size 0.0499026 and a step time of 43.4s.

Table 13
XRD Analysis results

Formula Sum	Name	Amount (%)	Crystal System
O2 Si	Quartz	51.6	Trigonal (Hexagonal Axes)
O2 Si	Si O2	26.5	Hexagonal
Ca C O3	Calcite	21.8	Trigonal (Hexagonal Axes)
Unidentified Peak Area		9.3	

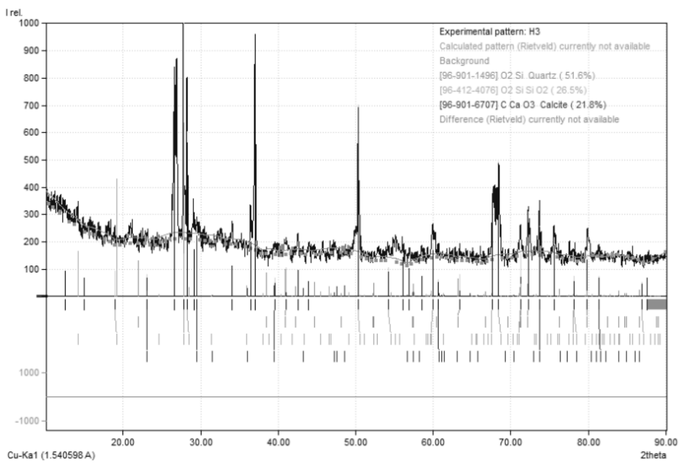

Fig 5.7 XRD Analysis of the sample with 15% silica fume as cement and 15 ml/lit Bacteria

VI. CONCLUSIONS

Compressive strength and Durability Test studies have been carried out on concrete cubes by incorporating Bacillus Subtilis with various concentrations along with Silica fume with constant percentage. It has been found that the use of bacterial concrete can enhance the durability, mechanical and permeation aspects of concrete. Based on present investigation, some of the following conclusions have been drawn.

- Bacteria is capable of improving hardened properties of concrete
- Compressive strength of concrete with 15% silica fume as cement and 15 ml/lit Bacteria is about 29.10 % more than the control concrete and is considered as optimum mix.
- Calcite precipitate of bacteria indirectly increases the strength of concrete by filling the voids.
- The performance against Acid and Alkaline attack is significantly better than that of controlled concrete.
- Based on XRD results Silicon Oxide, Quartz and calcite place more crucialrole instrength development when compared to all other compounds
  - Bacterial concrete is advantageous than conventional concrete due to its self-healing capacity and eco-friendly nature.
  - The cost of Bacterial concrete is more. So, it is profitable when we go for higher RC structures.
  - The Bacillus Subtilis were isolated from soil and these bacteria are environment friendly which is proved to be safe.

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