# An Experimental Investigation on High Strength Concrete Incorporated with Bacteria

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***Abstract:*** Concrete plays a remarkable role as a construction material across the globe. New technologies have helped to develop new forms of construction and alternative materials within the concrete area. One of most recent and advanced way of improving mechanical properties of concrete is through mineralization of bacterial isolates. Bacterial organisms have the unique capacity to produce calcite through metabolic activity. This paper investigates the prospect of achieving the higher strength of the concrete by using the microbiologically induced unique growth or filler. Here an investigation was done by using the bacteria "Bacillus megaterium" utilized in concrete grade of M70. The purpose of this research is to check the strength and costing of varied concentrations $10^3$ cells/ml, $10^5$ cells/ml and $10^7$ cells/ml of bacterial concrete with conventional high strength concrete of M70 grade and to determine the optimum concentration. Bacterial concretes shows compressive strength compared to traditional concrete. The concentration $10^5$ cells/ml gives optimum result compared to other concentrations.

***Index Terms*** **- Bacillus Megaterium, Bacteria, Bacterial Concrete, Compressive Strength (CS), High Strength Concrete (HSC)**

## 1. INTRODUCTION

Concrete is generally most utilized and favored material for development reason all through the world as it is strong, and simple to make at construction site and it is relatively simple to handle as well. The fundamental element of concrete is effectively accessible in the greater part of the places which makes concrete significantly progressively famous [15]. Concrete is prepare with 3 main components: cement, aggregate (course and fine) and water. Cement is used as binding material when it is mixed with aggregates and water. It is versatile, has needed engineering properties, made with price effective materials which might be casted into any form. It's also brittle in nature. Concrete are consumed annually. Based on international usage, it was placed in second position next to water. Admixtures with filling capacity can be added into the concrete to improve its properties [4].

Utilization of HSC in development segment has expanded gratitude to its improved mechanical properties contrasted with standard concrete. Compare to standard HSC contains a uniaxial CS more prominent than the standard concrete got in an exceedingly specific area. According to Indian Standard 456:2000-Plain and Reinforced Concrete code of practice the high strength concrete can be defined as the concrete with specified CS more than 60 N/mm$^2$ after 28 days [11]. This definition does exclude a numerical incentive for CS demonstrating a transfer from a conventional concrete. Presently HSC is being widely used all across the globe. Most uses of HSC is in elevated structures, bridges and in some special applications and in some special applications in structures. In developed countries, using HSC in structures today would result in both technical and economic advantage. In HSC [19], it's important to downsize the water/cement ratio and which generally increases the quantity of cement. To cope up with low workability issue, various types of pozzolonic mineral materials like fly ash, silica fume, rice husk ash, GGBS, metakaoline, etc. and chemical admixtures are utilized to achieve the required workability [2].

The 'bacterial concrete' could also be made by implanting microscopic organisms inside the concrete which is able to continually precipitate calcite. This process is understood as microbiologically instigated calcite precipitation. A traditional soil microorganism, Bacillus Megaterium, was acclimated initiate $CaCO_3$ precipitation. The essential principle for this application are that the bacterial hydrolyzes urea to provide ammonia and dioxide which is why the ammonia is releasing in surroundings and subsequently it increases pH, resulting in accumulation of insoluble $CaCO_3$. This calcite precipitation by microbes will enhance the mechanical characteristics of the concrete [22]. The advantages bacterial concrete are as follows [5]:

(a) Improve the CS of concrete.
(b) Increase the resistance against freeze thaw effect.
(c) Reduce the permeability of concrete.
(d) Reduction in corrosion of reinforced concrete.
(e) Eco- friendly concrete.
(f) Increased durability and
(g) Used as self-healing material.

## 2. EXPERIMENTAL MATERIALS

The materials used during the present research are bacillus megaterium, cement, fine aggregate, silica fume, coarse aggregate, fly ash, superplasticizer and water.

### 2.1. Bacterial Strain

Generally when the water and cement water are mixed together they has pH value up 12. Most of the bacteria cannot survive in environment having pH 10 or more. Bacillus megaterium bacteria can survive in the environment which is having pH 12 or more and also can grow without oxygen if the nitrate is present. Bacillus megaterium bacteria can be generally found at the interface of root soil, in decomposing plant residue, air, soil, water and air. For this research work the bacillus megaterium bacteria were procured from MTCC Chandigarh, India. Following figure 1 shows the bacteria in collected form. Following table 1 represents the characteristics of bacteria [15].

Figure 1 Bacillus megaterium bacteria

Table 1 Properties of bacillus megaterium bacteria

| Properties | Description |
|---|---|
| Gram Strain | Gram positive |
| Colony Morphology | White, Irregular |
| Size | 0.6 to 0.8 micro meter |
| Shape | Long rode |
| Lactose | No acid, No gas |
| Dextrose | No acid, No gas |

### 2.2. Cement

In this research work OPC 53 Grade cement conforming to IS: 12269-1987 was utilized [9] for all concrete mixes which purchased from local market, Anand, Gujarat. Figure 2(a) and table 2 shows properties of cement.

Table 2 Physical properties of cement

| Property | Values for Cement | Codal Requirements |
|---|---|---|
| Initial setting time | 35 min | 30 minutes min |
| Final setting time | 178 min | 600 minutes max |
| Specific Gravity | 3.15 | 3.10-3.15 |

### 2.3. Coarse aggregate 10mm (Grit)

Based on IS 383:1970, an aggregate which is retained on IS 10mm sieve is called coarse aggregate [10]. Figure 2(b) shows the graded aggregate and table 3 shows properties of 10mm graded coarse aggregate (grit) which procured from local market, Anand, Gujarat.

Table 3 Physical properties of coarse aggregate (Grit)

| Property | Values for Coarse Aggregate |
|---|---|
| Source | Sevaliya, Gujarat |
| Fineness modulus | 6.08 |
| Specific gravity | 2.87 |

### 2.4. Coarse aggregate 20mm

Based on IS 383:1970 an aggregate which is retain on IS 20mm sieve is called coarse aggregate [10]. Coarse aggregates (CA) are responsible for providing 70-75% bulk within the constituents of concrete. CA size 20 mm graded based on IS 383:1970 locally available is utilized for HSC. Figure 2(c) shows the graded aggregate and table 4 shows properties of 20mm graded coarse aggregate which procured from local market, Sevaliya, Gujarat.

Table 4 Physical properties of coarse aggregate

| Property | Values for Coarse Aggregate |
|---|---|
| Source | Sevaliya, Gujarat |
| Fineness modulus | 6.94 |
| Specific gravity | 2.81 |

### 2.5. Fine aggregate

As per IS 383:1970 an aggregate which is retain on IS 4.75mm sieve is called fine aggregate. Sand is shining yellow, off white, and rounded [10]. The construction cost of sand is nil due to its normal availability but its transportation cost is more. Figure 2(c) and table 5 shows the properties of fine aggregate which procured from the local market, Bodeli, Gujarat.

Table 5 Physical properties of fine aggregate

| Property | Values for Fine Aggregate |
|---|---|
| Source | Bodeli, Gujarat |
| Fineness modulus | 3.16 |

**2.6. Fly ash**

According to IS 10262:2019 code for concrete mix design while doing mix design of HSC additional cementitious material like Fly ash (FA), silica fume (SF), GGBS, metakaoline etc. has to be utilized. The utilization of fly ash as one of the admixture for the concrete not only because it improves the characteristics of concrete but moreover contributes to environmental pollution control. For this research work and for M70 grade fly ash is utilized having class C as one of cementitious material as partial replacement with cement based on IS 10262:2019 [8]. Figure 2(d) and table 6 shows characteristics of fly ash which procured from Vadodara, Gujarat.

Table 6 Chemical and physical properties of fly ash

| Chemical properties | Values for Fly ash (%) | Physical properties | Values for Fly ash |
|---|---|---|---|
| $SiO_2$ | 46.38 | Specific gravity | 2.07 |
| $Fe_2O_3$ | 8.26 | Fineness ($m^2$/kg) | 290 |
| $Al_2O_3$ | 13.9 | Bulk density (kg/$m^3$) | 1100-1200 |
| CaO | 15.1 | Colour (Visual observation) | Light grey |
| MgO | 6.68 | | |
| $SO_3$ | 4.26 | | |
| Free-CaO | 0.15 | | |

**2.7. Silica Fume**

According to IS 10262:2019 code for concrete mix design while doing mix design of HSC additional cementitious material like Fly ash (FA), silica fume (SF), GGBS, metakaoline etc [8]. Silica fume is an industrial by-product primarily delivered from ferrosilicon and silicon metal. Silica fume as substitution of cement not only makes the concrete more strong also its little angular particles improve workability, helping to diminish the water-cement ratio. For this research work and for M70 grade silica fume with 97% purity is utilized as one of cementitious material as partial replacement with cement based on IS 10262:2019. Figure 2(e) and table 7 shows characteristics of silica fume which procured from Surat, Gujarat.

Table 7 Chemical and physical properties of silica fume

| Chemical properties | Values for Silica fume (%) | Physical properties | Values for Silica fume |
|---|---|---|---|
| $SiO_2$ | 96.2 | Specific gravity | 2.26 |
| H2O (Moisture) | 1.2 | Specific surface (mw/gm) | 18 |
| $Fe_2O_3$ | 0.096 | Bulk density (kg/$m^3$) | 610 |
| Al2$O_3$ | 0.206 | | |
| CaO | 0.426 | | |
| MgO | 0.222 | | |
| $K_2O$ | 0.041 | | |
| L.O.I. | 1.6 | | |

**2.8. Superplasticizer**

Superplasticizer are very essential admixture for making HSC. It reduces the water/cement ratio of the concrete which is important for achieving high strength. Super plasticizing admixture based on selected sulfonated naphthalene polymers-based Superplasticizer supplied by FOSROC, under the brand name FOSROC Conplast SP-430. It is provided as a brown color solution which immediately disperses in water. Superplasticizer disperses the fine particles within the concrete mix, empowering the water substance of the concrete to perform more viably. Superplasticizer essentially progress the workability. Figure 2(f) and table 8 shows properties of Fosroc Conplast SP-430 Superplasticizer [7] which procured from Surat, Gujarat.

Table 8 Typical properties of Superplasticizer

| Typical properties | |
|---|---|
| Color | Brown liquid |
| Specific gravity | 1.20 @ 20°C |
| Chloride content | Nil to BS 5075 |
| Air entrainment | Less than 2% additional air is entrained at normal dosages. |
| Alkali content | Less than 72.0 g. $Na_2O$ equivalent/litre of admixture. |

**2.9. Water**

Ordinary portable water available locally was used for casting and curing of all specimen of this research. Water plays a vital role within the reaction with cement. Following figure 2 shows the various experimental material which are used in this research for making HSC.


Figure 2 Various experimental materials used in HSC

## 3. Design Mix

The mix design for conventional HSC of M70 grade was prepared as per IS 10262:2019 code for concrete mix design [8]. As per IS code for mix design of HSC like M70 concrete grade there's necessary to use additional cementitious admixtures like GGBS, fly ash, metakaoline, silica fume etc. along with required dosage of superplasticizer to use help the concrete to lower its water/cement ratio, increase the workability and ultimately to achieve the strength. The proportions of assorted cementitious admixtures and dosage of superplasticizer were decided supported interactions with experts, various literatures and various codal provisions based on IS 10262:2019. During this research study for making M70 grade concrete 15% fly ash and 5% silica fume has been utilized as replacement of quantity of cement. The water/cement ratio was kept 0.263 to achieve dosage of superplasticizer was kept 0.5% of total quantity of cementitious materials utilized. The mix design for all concrete mix are prepared by volume method based on IS 10262:2019.

There is no codal provision for preparation of design mix for bacterial concrete. Based on the literature study in this research for making bacterial concrete the bacterial liquid is utilized as 10% replacement of total water required during concrete mixing [14,16,17]. The bacterial liquid has been prepared for three different bacterial concentrations $10^3$ cells/ml, $10^5$ cells/ml and $10^7$ cells/ml and has been utilized for making bacterial concrete. Following table 9 shows the nomenclature for various design mix adopted for HSC having grade of M70 and table 10 shows Design mix properties for 1 $m^3$ concrete mix.

Table 9 Nomenclature for various design mixes

| Concrete Mix | Description |
|---|---|
| A0 | Control Mix design for M70 grade of concrete |
| B1 | $10^3$ cells/ml bacterial concentration made with bacillus megaterium bacteria in concrete |
| B2 | $10^5$ cells/ml bacterial concentration made with bacillus megaterium bacteria in concrete |
| B3 | $10^7$ cells/ml bacterial concentration made with bacillus megaterium bacteria in concrete |

Table 10 Design mix properties in 1 $m^3$ concrete

| Concrete mixes | Design mix for concrete (Kg) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Cement** | **Fine Agg.** | **Coarse Agg.10 mm** | **Coarse Agg.20 mm** | **Water (lit.)** | **Bacterial Liquid (lit.)** | **Bacterial Food (g)** | **FA** | **SF** | **Superplasticizer (lit.)** |
| A0 | 429.08 | 521.35 | 722.73 | 481.82 | 152.72 | 0.00 | 0.00 | 80.45 | 26.82 | 2.67 |
| B1 | 429.08 | 521.35 | 722.73 | 481.82 | 152.72 | 15.27 | 171.8 | 80.45 | 26.82 | 2.67 |
| B2 | 429.08 | 521.35 | 722.73 | 481.82 | 152.72 | 15.27 | 171.8 | 80.45 | 26.82 | 2.67 |
| B3 | 429.08 | 521.35 | 722.73 | 481.82 | 152.72 | 15.27 | 171.8 | 80.45 | 26.82 | 2.67 |

## 4. Bacterial Cultivation

The very first process was to determine the growth and colony morphology of the bacteria for achieving required cell counts. It has been checked on various dilution factor [20]. The bacteria obtained good growth at $10^{-6}$ dilution factor after 24 hours. Also the optical density (OD) [21] has been determined at $OD_{600}$. Following figure 3 shows cell counts of the bacteria in bacterial plate which was counted manually by visual observation.

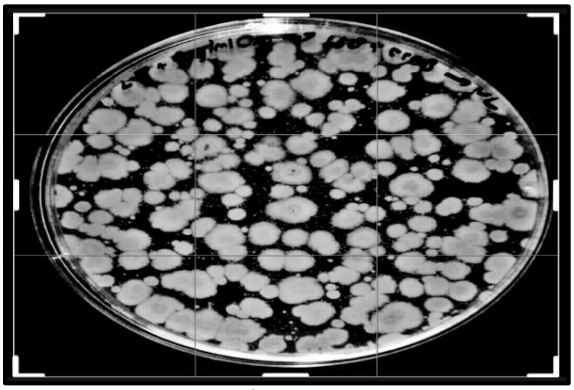

Figure 3 Cell counts of bacillus megaterium bacteria

For the growth of the bacteria in required concentration the nutrients is to be added in bacterial liquid as a food for the bacteria there are various nutrient are available. In this research 'nutrient broth (NB)' is utilized [1,13]. The quantity of NB is depends upon growth of bacteria and total amount of bacterial liquid required. After adding the NB bacterial liquid is placed in the incubator for growing the bacteria in required concentrations. Following figure 4 shows the prepared bacterial liquid before placing it into the incubator and figure 5 shows the nutrient broth with the bacterial liquid.

Figure 4 Preparation of bacterial liquid


Figure 5 Nutrient broth and bacterial liquid

## 5. PREPARATION OF BACTERIAL CONCRETE

As there is no particular code or guidelines are available for design of bacterial concrete based on literature study it has been determined that the inclusion of bacteria in concrete can be done by taking in to consideration two of the methods. Those methods are as follows [4]:

(a) Direct Application Method: In this method the bacterial liquid is mixed into concrete directly whenever the concrete mixing process is taking place.

(b) Encapsulation Method: In this method the bacteria along with its food like calcium source are kept inside the treated clay pellets and after that the pellets are mixed into the concrete. Approximately 6% of the clay pellets are mixed into the concrete along with bacteria while the process of concrete mixing.

In this research the direct application method is used for making of bacterial concrete of M70 grade of concrete. Various bacterial concrete mix were made by utilizing three different bacterial liquid with each liquid having different bacterial concentration in it. The bacterial concentration were kept $10^3$ cells/ml, $10^5$ cells/ml and $10^7$ cells/ml. Decided based on literature study the 10% of bacterial liquid of each concentration were utilized as the replacement of water used during concrete mixing process [14,16,17]. Following figure 6 shows the bacterial liquid and its direct application during the process of concrete mixing.

Figure 6 Addition of bacterial liquid during concrete mixing by direct application method

## 6. EXPERIMENTAL METHODOLOGY

The experimental study is performed on high strength bacterial concrete of grade M70 by 10% replacement of water with bacterial of three different concentration which are kept $10^3$ cells/ml, $10^5$ cells/ml and $10^7$ cells/ml. For all mixes, w/c ratio is 0.263. HSC contains cement, coarse aggregate 10mm and 20mm, fine aggregate, superplasticizer, fly ash, water, and silica fume.

### 6.1 Compressive strength test

Compressive strength (CS) is usually reported concerning a particular specialized standard. CS is most important engineering characteristic of concrete. It is a standard mechanical practice on the bases of that the concrete is classified into grades. The determination of compressive strength were done by casting three cubes for all concrete mix having mould size 150mm X 150mm X 150mm and the test were perfomed concerning to procedure given in IS: 516-1959 Method of Tests for Strength of Concrete [12]. Following figure 7 shows the concrete cube testing in universal testing machine which is conducted CS test at BVM Engineering College, V.V.Nagar, Gujarat. Also the equation for finding out CS is given below,

Compressive Strength (N/mm$^2$) = P / Δ ……… (1)
Where, P =Failure load of specimen (N)
Δ = Area of specimen (mm$^2$)


Figure 7 Compressive strength test

## 7. EXPERIMENTAL RESULTS AND DISCUSSION

The following figure 8 and table 11 shows the CS results for high strength bacterial concrete containing different bacterial concentration as compare to conventional HSC of M 70 grade. The results are shown determined for 7 and 28 days.

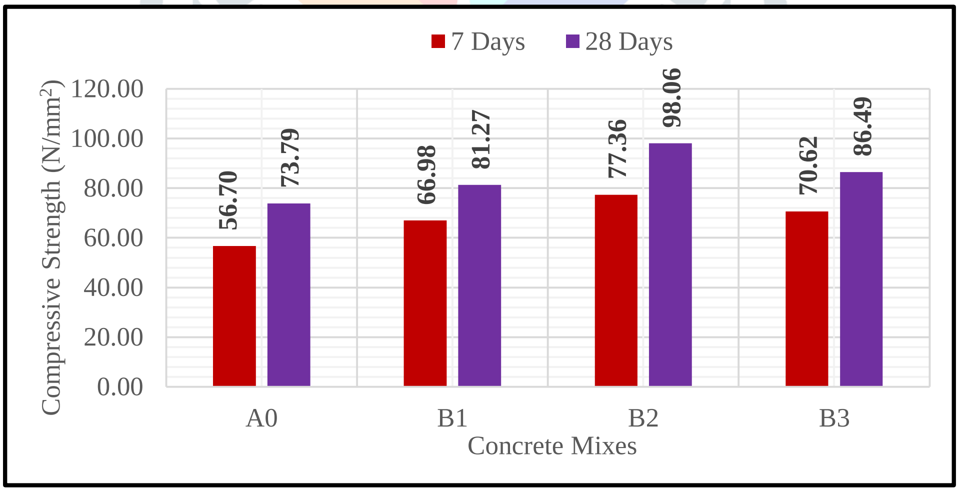


Figure 8 CS results for M70 grade concrete mixes with various bacterial concentrations

Table 11 CS and % change in CS at 7 and 28 days

| Concrete Mixes | Compressive Strength | | | |
|---|---|---|---|---|
| | 7 Days (N/mm$^2$) | % Change in Strength at 7 Days | 28 Days (N/mm$^2$) | % Change in Strength at 28 Days |
| A0 | 56.70 | 0 | 73.79 | 0 |
| B1 | 66.98 | (+) 18.13 | 81.27 | (+) 10.14 |
| B2 | 77.36 | (+) 36.43 | 98.06 | (+) 32.89 |
| B3 | 70.62 | (+) 24.55 | 86.49 | (+) 17.21 |

Table 11 represents the CS results of M70 grade concrete at 7 and 28 days for different HSC mix. A0 represents the conventional HSC with no inclusion of bacteria. At 28 days A0 concrete has gain 73.79 N/mm$^2$ strength. B1, B2 and B3 concrete mix represents the concrete made with different bacterial concentrations $10^3$ cells/ml, $10^5$ cells/ml and $10^7$ cells/ml respectively. B1 concrete mix has gain the strength of 81.27 N/mm$^2$ after 28 days which is higher than the conventional concrete which indicates that the calcite precipitation characteristics of bacillus megaterium is effectively participating in enhancing the strength parameters of concrete. B2 concrete mix has gain strength of 98.06 N/mm$^2$ after 28 days which shown the highest increase in the concrete strength. B3 concrete mix has gain strength of 86.49 N/mm$^2$ after 28 days which is lower than the B2 concrete mix. The decrease in the strength of B3 concrete mix can be because of the amount of bacterial food required is more in B3 concrete mix then the B2 concrete mix as the bacterial concentration is higher in B3 concrete mix then the B2 concrete mix. Based on literature study the observed contribution of bacteria to the CS in this study was higher then the lower grade of concrete [3,6,18]. The optimum bacterial concentration for the highest strength was observed $10^5$ cells/ml.

## 8. Cost Comparison

Based on literature study and interactions with experts it's determine that the cost of purchase of a bacterial culture is moreover the 'one time purchase' only. After that the bacterial culture can be preserved for many years (for about 200 years) [16] by storing it in its required condition and can be reused whenever it's necessary independent of the different bacterial concentrations. Following table 12 shows the cost of various experimental materials which has been utilized in this research for various concrete mix based on current market rates for different concrete mixes and table 13 shows the cost of various concrete mixes per $m^3$ including standard HSC of M70 concrete grade and various bacterial HSC.

Table 12 Cost of various experimental materials per unit

| Experimental Materials | Cost in Rupees |
|---|---|
| Cement (kg) | 6.40 ₹ |
| Fine aggregate (kg) | 0.45 ₹ |
| Coarse aggregate (kg) | 0.64 ₹ |
| Fly ash (kg) | 1.90 ₹ |
| Silica fume (kg) | 21.0 ₹ |
| Superplasticizer (ltr) | 38.0 ₹ |
| Bacterial culture | 2000 ₹ |
| Bacterial food – NB (g) | 5.0 ₹ |

Table 13 Cost of various concrete mixes per $m^3$

| Concrete Mixes | Cost of Concrete per $m^3$ in Rupees | % Change in Cost |
|---|---|---|
| A0 | 4569.17 ₹ | 0 |
| B1 | 6094.84 ₹ | (+) 33.39 |
| B2 | 6094.84 ₹ | (+) 33.39 |
| B3 | 6094.84 ₹ | (+) 33.39 |

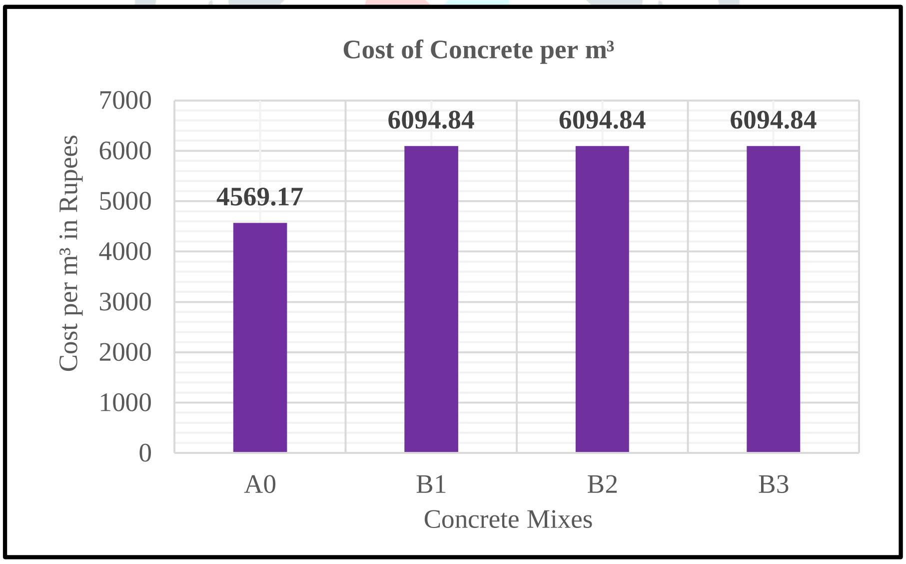


Figure 9 CS results for M70 grade concrete mixes with various bacterial concentrations

From above figure 9 it has been observed that the cost of high strength bacterial concrete denoted with B1, B2 and B3 is higher than the conventional HSC of M70 grade denoted by A0. The cost of high strength bacterial concrete is increased because of the inclusion of the bacteria and the bacterial food (NB). Here the quantity of food added is same in all bacterial concentrations. However the cost of bacteria is independent to the total quantity of concrete casted because the cost of bacteria is moreover the 'one time purchase cost'.If the cost of bacteria is neglacted then the cost of bacterial concrte will increse only about 18.80% instead of 33.39%. It has been also observed that the cost of the all bacterial concrete mix denoted with B1, B2 and B3 which contains different bacterial concentrations are also the same. Which means the cost of the high strength bacterial concrete is independent to the bacterial concentrations. The cost of high strength bacterial concrete will vary only if the quantity of bacterial food is changed.

## 7. Conclusion

The conclusions based on performed experimental investigation are as follows:

1. Bacillus megaterium bacteria is nonpathogenic organisms and harmless for humans.
2. The process of cultivating the bacteria in required concentration is relatively simple.
3. The calcite precipitation property of bacillus megaterium microbes are responsible for achieving additional strength as the calcite produced by the bacteria will fill up the micro pores which are there in the concrete and make the concrete less porous which will ultimately increases the CS of concrete.

4. The maximum increase in CS of concrete was observed at $10^5$ cell/ml bacterial concentration 36.43% at 7 days and 32.89% at 28 days as compare to M70 grade conventional concrete.
5. Furthermore increase in bacterial concentration reduces the concrete strength 24.55% at 7 days and 17.21% at 28 days. This happens due to lack of nutrients (bacterial food) at higher microbial load.
6. Based on experimental study it is determine that the benefaction of bacteria to the strength of the concrete is increase at higher grade of concrete.
7. The cost of bacterial concrete is higher than the standard concrete because of the inclusion of bacteria and its nutrients. However the cost of bacterial culture is moreover 'one time purchase cost' and its irrespective of the quantity of concrete as the lifespan of bacillus megaterium bacteria is more than 200 years so it can be stored for longer period time and can be reused effectively whenever its required.
8. The bacterial concrete has large potential to be utilized in construction industry as it significantly contributes to the mechanical properties of concrete.

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