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Experimental Studies on Self Healing Properties of Bacterial Concrete

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ABSTRACT
Concrete, a strong, durable material composed of cement, aggregate and water, is the most used building material in the world. Concrete has an ultimate load bearing capacity under compression but the material is weak in tension. That is why steel bars are embedded in the concrete for the structures to carry tensile loads. The steel reinforced bars take the load when the concrete cracks in tension. On other hand the concrete protects the steel reinforced bars from the environment and prevents corrosion. However, the cracks in the concrete form a major problem which affects the durability of the structures. Here the ingress of water and chloride ions takes place and deterioration of the structure starts with the corrosion of the steel. To increase the strength and durability of the structure either the cracks that are formed should be repaired conventionally using epoxy injection or latex treatment or by providing extra reinforcement in the structure during the design phase to ensure that the crack width stays within a permissible limit. Main reason to prevent cracks or limit crack width is to enhance the durability of the time and energy. Bacillus subtilis could be one of the answers to the long quest for crack free concrete.

1. INTRODUCTION
1.1CONCRETE
Concrete is a composite material composed mainly of water, aggregate, and cement. Often, additives and reinforcements are included in the mixture to achieve the desired physical properties of the finished material. When these ingredients are mixed together, they form a fluid mass that is easily moulded into shape. Over time, the cement forms a hard matrix which binds the rest of the ingredients together into a durable stone-like material with many uses Famous concrete structures include the Hoover Dam, the Panama Canal and the Roman Pantheon. The earliest large-scale users of concrete technology were the ancient Romans, and concrete was widely used in the Roman Empire. The Colosseum in Rome was built largely of concrete, and the concrete dome of the Pantheon is the world's largest unreinforced concrete dome.

1.2 IMPACT OF MODERN CONCRETE USE
Concrete is widely used for making architectural structures, foundations, brick/block walls, pavements, bridges/overpasses, highways, runways, parking structures, dams, pools/reservoirs, pipes, footings for gates, fences and poles and even boats. Concrete is used in large quantities almost everywhere mankind has a need for infrastructure. The amount of concrete used worldwide, ton for ton, is twice that of steel, wood, plastics, and aluminum combined. Concrete's use in the modern world is exceeded only by that of naturally occurring water. Concrete is also the basis of a large commercial industry.

1.3 PROPERTIES OF CONCRETE
Concrete has relatively high compressive strength, but much lower tensile strength. For reason it is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but a start decreasing at higher stress levels as matrix cracking develops. Concrete has a very low coefficient of thermal expansion and shrinks as it matures. All concrete structures crack to some extent, due to shrinkage and tension. Concrete that is subjected to long-duration forces is prone to creep. Tests can be performed to ensure that the properties of concrete correspond to specifications for the application. Different mixes of concrete ingredients produce different strengths, which are measured in psi or MPa. Different strengths of concrete are used for different purposes. Very low-

strength (2000 psi or less) concrete may be used when the concrete must be lightweight. Lightweight concrete is often achieved by adding air, foams, or lightweight aggregates, with the side effect that the strength is reduced. For most routine uses, 3000-psi to 4000-psi concrete is often used.

1.4 MERITS AND DEMERITS OF CONCRETE

Some Merits of concrete are given below in brief.

1. Concrete is economical when ingredients are readily available.
2. Concrete's long life and relatively low maintenance requirements increase its economic benefits.
3. It is not as likely to rot, corrode, or decay as other building materials.
4. Concrete has the ability to be molded or cast into almost any desired Shape.
5. Building of the molds and casting can occur on the work-site which reduces cost.
6. Concrete is a non-combustible material which makes it fire-safe and able to withstand high temperatures.
7. It is resistant to wind, water, rodents, and insects. Hence, concrete is often used for storm shelters.

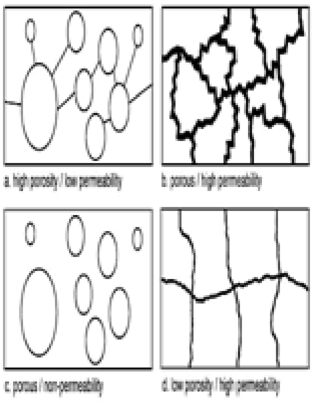

Fig. 1 Schematic diagram to distinguish porosity and permeability (EuroLightCon, 1998).

Several bacteria have the ability to precipitate calcium carbonate. These bacteria can be found in soil, sand, natural minerals etc. Jonkers et al. used Bacillus cohnii bacteria to precipitate $CaCO_3$. Bacillussubtilis have been used by Santhoshand Ramakrishnan while Dick used Bacillus lentus and Bacillus sphaericus. In the present study the enhanced performance potential of bacteria B.subtilis is reported. De Muynck found that the influence of the calcium source is limited to the morphology of the crystals. By means of SEM observations, they proved that the presence of chloride ions resulted in rhombohedral crystals, while the presence of acetate ions resulted in spherical crystals[4].

2. EXPERIMENTAL PROGRAM

The present investigation is divided into two stages. In the first stage cement mortar blocks of mix proportion 1: 3 were casted with different concentrations of soil bacterium named "Bacillus Subtilis" like 0, 10^4, 10^5, 10^6, 10^7 and 10^8cells/ml. These blocks are then tested for 3days, 7days and 28days strength, to know the concentration of Bacillus subtilis which gives maximum strength for further investigations. In the second stage the performance of the above concentrated bacterial concrete is investigated by studying the various mechanical properties such as Compressive Strength, Split Tensile strength, Flexural strength for M20 grade concrete at 7 and 28 days of curing period.

2.1. CEMENT:

Ordinary Portland Cement of 53 Grade of brand name Ultra Tech Company, available in the local market was used for the investigation. Care has been taken to see that the procurement was made from single batching in air tight containers to prevent it from being effected by atmospheric conditions. The cement thus procured was tested for physical requirements in accordance with IS: 169-1989 and for chemical requirement in accordance IS:4032-1988. The following tests were carried out to determine the physical properties of the specified cement.

1. Specific Gravity (Density bottle method)
2. Normal consistency (using Vicat apparatus)
3. Initial setting time (using Vicat apparatus)
4. Final setting time (using Vicat apparatus)
5. Fineness (using 90µ sieve)

2.2.FINE AGGREGATES:

River sand locally available in the market was used in the investigation. The aggregate was tested for its physical requirements such as gradation, fineness modulus, specific gravity and bulk density in accordance with IS: 2386-1963. The sand was surface dried before use.

2.3. COARSE AGGREGATES:

Crushed aggregates of less than 10mm size produced from local crushing plants were used. The aggregate exclusively passing through 10mm sieve size and retained on 6.5mm sieve is selected.

The aggregates were tested for their physical requirements such as gradation, fineness modulus, specific gravity and bulk density in accordance with IS: 2386-1963.

Fig-2.1 Coarse aggregates

Fig 2.2: Bacillus subtilis

2.4 Bacterial solution:

The sample of "Bacillus subtilis", a soil bacterium was cultured and developed to the tune of requirements of investigations at Microbiology Laboratory, Sri Krishna Devaraya University, Anantapur by giving proper feed to the microorganisms.

2.5. WATER:

Water plays a vital role in achieving the strength of concrete. For complete hydration it requires about $3/10^{th}$ of its weight of water. It is practically proved that minimum water-cement ratio 0.35 is required for conventional concrete. Water participates in chemical reaction with cement and cement paste is formed and binds with coarse aggregate and fine aggregates. If more water is used, segregation and bleeding takes place, so that the concrete becomes weak, but most of the water will absorb by the fibers. Hence it may avoid bleeding. If water content exceeds permissible limits it may cause bleeding

Fig-2.3 Water

2.6 PRODUCTION OF CONCRETE

Concrete production is the process of mixing together the various ingredients, such as water, aggregate and cement, to produce the building material concrete. Concrete production is time-sensitive: Once the ingredients are mixed together, there is a limited amount of time during which the concrete may be formed into shape and placed where it is to harden.

2.6.1 CONCRETE MIXING:

Thorough mixing is essential for the production of uniform, high quality concrete. For this reason equipment and methods should be capable of effectively mixing concrete materials containing the largest specified aggregate to produce uniform mixtures of the lowest slump practical for the work.

High-energy mixed (HEM) concrete is produced by means of high-speed mixing of cement, water and sand with net specific energy consumption of at least 5 kilojoules per kilogram of the mix. The bacteria added to the water solution are then to the activated mixture, which can later be mixed with aggregates in a conventional concrete mixer. In this process, sand provides dissipation of energy and creates high-shear conditions on the surface of cement particles. This results in the full volume of water interacting with cement.

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Fig-2.4 Concrete mixing

3. EXPERIMENTAL INVESTIGATIONS

Apparatus:

1. Vicat apparatus (confirming to IS: 5513 – 1968) with plunger (10 mm diameter).
2. Vicat mould
3. Gauging trowel
4. Measuring jar
5. Balance
6. Tray

Figure 3.1 Vicat apparatus

Procedure:

1. Take 400 g of cement and prepare a paste with about 28% (by weight of cement) water by taking care that the gauging time is from 3 to 5 minutes. The gauging time is counted from the instant of adding of water to dry cement until the mould is filled.
2. Fill the vicat mould by placing it on a non-porous plate with the cement paste prepared. After completely filling the mould, smooth off the surface with a single movement of the trowel, making it level with the top of the mould.
3. Shake the mould slightly to remove any air bubbles as their presence may affect the penetration of the plunger.
4. Place the specimen along with the non-porous plate under the vicat plunger and lower it gently so that it just touches the surface of the specimen.
5. Quickly release the plunger and allow it to sink. Note the reading.
6. Prepare the paste with varying percentages of water and repeat the experiment until the plunger stops penetrating at a level 5 to 7 mm from bottom and tabulate the results.

3.2 INITIAL SETTING TIME OF CEMENT:

Apparatus:

Vicat apparatus (confirming to IS: 5513 – 1968) with needle (1.13 mm diameter).

1. Vicat mould
2. Gauging trowel
3. Measuring jar
4. Balance
5. Tray
6. Stop watch

Figure 3.2 Vicat apparatus in initial setting time of cement

Procedure:

1. Prepare a neat cement paste by gauging 400 g cement with 0.85P water, where P is the normal consistency of the given sample of cement.

2. The gauging time is between 3 and 5 minutes. The gauging time is counted from the instant of adding of water to dry cement.
3. Fill the vicat mould with the prepared paste and level it to the top of the mould. The cement block thus prepared is known as the test block.
4. Place the test block on a non-porous plate and set it below the vicat needle. Lower the needle to make contact with the surface of the test block.
5. Quickly release the needle and allow it to sink. Note the reading.
6. Repeat the experiment until the needle fails piercing the block at a level 5 to 7 mm from bottom.

3.3 FINAL SETTING TIME OF CEMENT:

Apparatus:

1. Vicat apparatus (confirming to IS: 5513 – 1968)
2. Vicat needle with annular attachment
3. Vicat mould
4. Gauging trowel
5. Measuring jar
6. Balance
7. Tray
8. Stop watch

Figure 3.3 Vicat apparatus in final setting time of cement

Procedure:

1. Prepare a neat cement paste by gauging 400 g cement with 0.85P water, where P is the normal consistency of the given sample of cement.
2. The gauging time is between 3 and 5 minutes. The gauging time is counted from the instant of adding of water to dry cement.
3. Fill the vicat mould with the prepared paste and level it to the top of the mould. The cement block thus prepared is known as the test block.
4. Place the test block under the vicat needle with the annular attachment and lower the needle just to make contact with the surface of the test block.
5. Quickly release the needle allowing it to penetrate into the test block.
6. The cement is said to be finally set when the needle makes an impression on the test block and the attachment fails to do so.
7. The time elapsed between this stage and the instant when the water was added to the cement is called the final setting time.

The period elapsing between the time when water is added to the cement and the time at which the needle penetrates the test block to a depth equal to 5 to 7 mm from the bottom is taken as initial setting time and the needle makes an impression on the test block is taken as final setting time.

Table 1: Chemical Composition of Cement

SI.NO	Constituent	Percentage
1	Cao	64.00
2	Sio_2	22.00
3	Al_2o_3	4.10
4	Fe_2o_3	3.60
5	Mgo	1.53
6	So_3	1.90

3.3 Specific gravity of fine aggregate:

Weight of empty Pycnometer =W1 gm.
Weight of Pycnometer + coarse aggregate =W2 gm.
Weight of Pycnometer + coarse agg + water =W3 gm.
Weight of Pycnometer + water =W4 gms
1) Dry weight of aggregate =W2-W1
2) Weight of equivalent volume of water = (W2-W1)-(W3-W4)
Specific gravity = (W2-W1)/(W2-W1)-(W3-W4)

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4. MIX DESIGN OF CONCRETE:

The strength is mainly influenced by water cement ratio, and is almost independent of the other parameters the properties of concrete with a compressive strength of 20MPa,are influenced by the properties of aggregate in addition to that of water cement ratio. To obtain good strength, it is necessary to use the lowest possible w/c ratio which affects the workability of the mix. In the present state of art, concrete which has a desired 28days compressive strength of minimum 20 MPa, can be made by suitable proportion of the ingredients using normal methods for compacting the mixes.

4.1 MIX DESIGN PROCEDURE:

1. The strength of the cement as available in the country today has greatly improved since 1982. The 28-day strength of A, B, C, D, E, F. Category of cement is to be reviewed.

2. The graph connecting, different strength of cements and W/C is to be reestablished.

3. The graph connecting 28-day compressive strength of concrete and W/C ratio is to be extended up to 80Mpa, if this graph is to be cater for high strength concrete.

4. As per the revision of 456-2000, the degree of workability is expressed in terms of slump instead of compacting factor. This results in change of values in estimating approximate sand and water contents for normal concrete up to 35Mpa and high strength concrete above 35Mpa. The table giving adjustment of values in water content and sand % for other than standard conditions requires appropriate changes and modifications.

5. In the view of the above and other changes made in the revision of IS456-2000, the mix design procedure as recommended in IS 10262-82 is required to be modified to the extent considered necessary and examples of mix design is worked out.

4.2 MIX DESIGN FOR BACTERIA MIXED CONCRETE

a) Design stipulations

Characteristic compressive strength required in the field at 28 days : 20Mpa
Maximum size of aggregate : 20mm
Degree of quality control : Good
Type of exposure

b) Tested data for materials

Specific gravity of cement : 3.14
Comp Strength of cement at 7 day : Satisfies the requirementIS:269-1989
Specific gravity of Coarse aggregates : 2.63
Specific gravity of Fine aggregates : 2.75
Water absorption of Coarse aggregates : 1%
Free moisture in CA & FA : Nil

c) Target mean strength of concrete

The target mean strength for specified characteristic cube strength is

$$20+1.65*4=26.6 N/mm^2$$

d) Selection of water - cement ratio

The free w/c ratio required for the target mean strength of 26.6 N/mm^2 is 0.50

The maximum free water-cement ratio for mild exposure is 0.55

The free w/c ratio is taken as the minimum of the above two values, i.e.,

w/c ratio = 0.50

e) Estimation of air content:

For maximum size of aggregate of 20mm,the air content is take as 2.0%

f) Selection of water and sand content

From IS method for 10mm max size of aggregate, Sand conforming to grading ZoneII. Water content per cubic meter of concrete = 186kg and sand content % of total aggregate by absolute volume = 35%.

Water =186kg/m^3 of concrete

Sand = 35% of total aggregate by absolute volume

For change in value in W/C ratio, compacting factor and sand belonging Zone II, following adjustment required.

Therefore, Required water content = 186+(186×3)/100

= 186+5.58

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=191.6 lit/m^3

Therefore, Required sand content as percentage of total aggregate by absolute volume,

P=35-2.0 =33%

Table 2. Mix design

Change in condition	adjustment required	
	Water content %	Percentage sand in total aggregate
For decrease in water-cement ratio(0.60-0.50) that is 0.10 Therefore, 0.10/0.05×1=2.0	0%	-2.0
For increase in compacting factor (0.9-0.8) =0.1 Therefore, 0.1/0.1×3=3.0	+3	0
Total	+3	-2.0

g) Determination of cement content

W/C ratio =0.50

Water = 191.6 lit

Cement = 191.6/0.50 =383kg/m^3

Formula for fine aggregate:-

V = [W+C/Sc+1/P×fa/Sfa]×1/1000

0.98 = [191.6+(383/3.14)+{f_a/(0.33×2.5)}]×10^{-3}

=> f_a = 605.2kg

f_a= Content of Fine aggregate

Formula for coarse aggregate:-

V =[W+C/Sc+1/(1-P)×Ca/Sca]×1/1000

0.98 =[191.6+383/3.14+1/(1-0.33)×Ca/2.63]×10^{-3}

=> C_a= 1190.04kg

C_a = Content of Coarse aggregate

The mix proportion becomes

Water	**cement**	**Fine agg.**	**Coarse agg.**
191.6 lit	**383kg**	**605.2kg**	**1190.04kg**
0.50	**1**	**1.58**	**3.10**

Hence the Mix is **1:1.58:3.10** (Designed for M20)

Bacterial solution:

The sample of "Bacillus Subtilis" a soil bacterium was cultured and development to the tune of requirements of investigation at microbiology laboratory

We are using 10^5 cells/ml

We are using 15ml of bacterial solution for one liter of water

We are using 363.5ml of bacterial solution

4.3. CASTING:

4.3.1 CUBE CASTING

Weight of 1 cube mould of concrete = volume × density

= 0.15×0.15×0.15×2400=8.1kg

Mix design ratio = 1:1.58:3.1

Sum of proportions = 1+1.58+3.1

=5.68

=8.1÷5.68

= 1.426kg i.e. wt. of cement

=1.426×1.58

= 2.253kg i.e. wt. of f.a

=1.426×3.1

= 4.4206kg i.e. wt. of c.a

Fig 4.1 Cylinder mould casting

PRISM CASTING:

Weight of concrete in 1 prism mould = Volume × density

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= 0.15×0.15×0.7× 2400

= 37.8kg

Mix design ratio = 1:1.58:3.1

Sum of proportions = 1+1.58+3.1=5.68

37.8÷5.68 = 6.65kg i.e. wt. of cement

6.65×1.58 = 10.507kg i.e. wt. of f.a

6.65×3.1 = 20.615kg i.e. wt. of c.a

Water to be added = 3325 ml

From, water/cement ratio = 0.5

W/6.65= 0.5

Weight of water,

W = 0.5×6.65

= 3.325 liters

= 3325 ml

Total number of prisms casted = 1

5.TESTING OF CONCRETE SPECIMENS

5.1 COMPRESSION TEST AND SPLIT TENSILE TEST

a) Remove the specimens from water after specified curing time and wipe out excess water from the surface.
b) Leave the specimen in the atmosphere for 24hours before testing.
c) Place the specimen in the machine in such a manner that the load shall be applies to the opposite sides of the specimen cast.
d) Align the specimen centrally on the base plate of the machine for a cubic or cylindrical specimen.
e) Rotate the movable portion gently by hand so that it touches the top surface of the specimen.
f) Apply the load gradually without shock and continuously at the rate of $140 kg/cm^2$ /minute till the specimen fails.
g) Increase the load until failure and note the maximum load.

Figure 5.1 Compression testing machine

5.2 Flexural Test

a) Remove the specimens from water after specified curing time and wipe outexcess water from the surface.
b) Leave the specimen in the atmosphere for 24hours before testing.
c) The specimen is then placed in the machine in such a manner that the load is applied to the uppermost surface as cast in the mould, along the two lines spaced 20.0 cm apart. The axis of the specimen is carefully aligned with the axis of loading device.
d) The load is then applied without shock and increasing continuously at a rate of 400kg/minute.

Fig 5.2 Flexural Testing Machine with Prism mould

Fig 5.3 Universal Testing Machine with Prism mould

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Fig 5.4 Universal testing machine after testing the prism mould

Calculations & Results:

Compression Test:

Size of the cube=15cm×15cm×15cm

Area of the specimen (calculated from the mean size of the specimen) = 225cm^2

Compressive strength at 28 days =……N/mm^2

Compressive strength = (Load in N/ Area in mm^2) =……….. N/mm^2

Split Tensile Test:

Size of the specimen = 15cm in diameter and 30cm long

Tensile Strength = 2P/πDL =……… N/mm^2

Tensile Strength at 28 days = …….. N/mm^2

Flexural Test:

Size of the specimen = 15cm×15cm×70cm

Flexural Strength = p×l/b×d×d=……. N/mm^2

Flexural Strength at 28 days = ……… N/mm^2

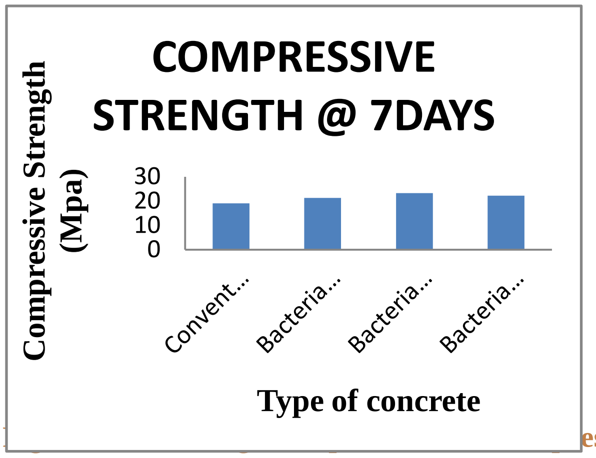
6. TEST RESULTS

6.1 COMPRESSIVE STRENGTH

Compressive strength of concrete at 7 days

COMPRESSIVE STRENGTH OF CONCRETE @ 7 DAYS

Type of Concrete	Mix Designation	Percentage of Addition	Average Compressive Strength of 3 cubes (Mpa) @ 7 days
Conventional Concrete	M0	0	19.10
Bacterial Concrete	M1	5ml	21.30
	M2	10ml	23.31
	M3	15ml	22.21



essive strengths of Plain concrete and Bacterial concrete at 7 Days

TABLE:COMPRESSIVE STRENGTH OF CONCRETE @ 28 DAYS

Type of Concrete	Mix Designation	Percentage of Addition	Average Compressive Strength of 3 cubes (Mpa) @ 28 days
Conventional Concrete	M0	0	25.3
Bacterial Concrete	M1	5ml	29
	M2	10ml	30.1
	M3	15ml	28.8

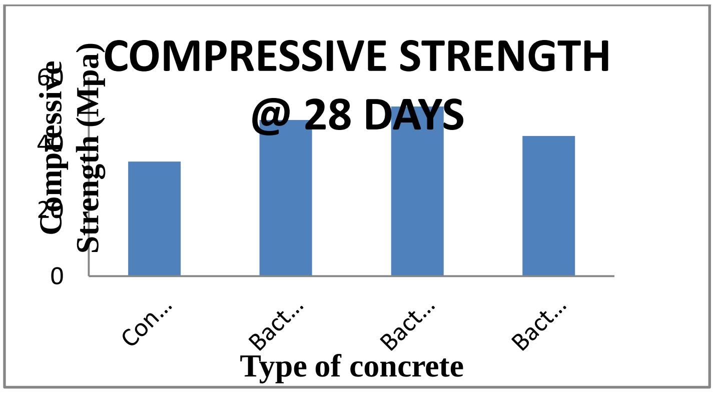


Figure6.2 showing comparison of compressive strengths of Plain concrete and Bacterial concrete at 28 Days

TABLE:COMPRESSIVE STRENGTH OF CONCRETE @ 90 DAYS

Type of Concrete	Mix Designation	Percentage of Addition	Average Compressive Strength of 3 cubes (Mpa) @ 90 days
Conventional Concrete	M0	0	34.60

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COMPRESSIVE STRENGTH

- The compressive strength of Bacteria concrete& conventional concrete at 7 days, 28 days, & 90 days are found & results are tabulated.
- It is observed that with the addition of 10ml of Bacterial solution the compressive strength of concrete showed an increase by 48% at 180Days
- The percentage of compressive strength increases with an addition of 5ml to 10ml Bacterial solution and the strength decreases with increase in the percentage of Bacteria solution to 15ml
- With the addition of 5ml ,10ml & 15ml Bacterial solution the average Compressive strength increased by 11% ,22% & 16% at 7 Days
- With the addition of 5ml ,10ml & 15ml Bacterial solution the average Compressive strength increased by 14% ,18% & 13% at 28 Days
- With the addition of 5ml ,10ml & 15ml Bacterial solution the average Compressive strength increased by 36% ,47% & 22% at 90 Days
- With the addition of 5ml ,10ml & 15ml Bacterial solution the average Compressive strength increased by 37% ,48% & 26% at 180

7.CONCLUSIONS

1. Upto 10ml dosage of Bacterial concrete the average compressive strength of concrete increased rapidly at a large dosage of Bacterial solution the average compressive strength of concrete decreased
2. Upto 10ml dosage of Bacterial concrete the Tensile strength of concrete increased gradually at a large dosage of Bacterial solution the Tensile strength of concrete decreased
3. Upto 10ml dosage of Bacterial concrete the Flexural strength of concrete increased marginally at a large dosage of Bacterial solution the Flexural strength of concrete decreased.

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