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EFFECT OF BACILLUS SUBTILIS ON MECHANICAL BEHAVIOR OF BACTERIAL CONCRETE

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ABSTRACT

In the recent past bacterial concrete has been emerged as remedial measure of healing cracks in structures like bridges, RCC buildings, RCC pipes, Canal lining, pavement etc. Crack formation is incredibly common occurrence in concrete structure that permits the water and completely different sort of chemical into the concrete through the cracks and reduces their strength and that additionally have an effect on the reinforcement once it comes contact with water, carbon dioxide and different chemicals. For repairing the cracks occurred within the concrete, it needs regular maintenance and special sort of treatment which can be terribly expensive. So, to solve this problem Henk Jonkers introduced bacterial concrete to repair the cracks occurred in the concrete structures. This research has demonstrated that particular types of micro-organisms can really be useful method to repair cracks in the existing concrete structures. In this paper, experimental investigation done to arresting the cracks in the concrete using bacillus subtilis bacteria and calcium lactate. The selection of bacteria depends on its survival in alkaline environment. In this study bacillus subtilis bacterium with calcite lactate is used in different percentages such as 5%, 10%and 15% of cement weight for M20 and M40 grade concrete. An empirical relation between flexural strength and compressive strength is proposed in the form of $f_t = 0.66 \sqrt{f_{ck}}$.

Keywords: bacterial concrete, compressive strength split tensile strength, flexural strength, bacillus subtilis.

INTRODUCTION

Cement concrete has become an essential building construction material in the present modern era of infrastructural projects across the world. As this material is prone to crack due to its brittle and less resistant to straining demands the use of steel reinforcement or rebar in it. Since its bond with steel bars, concrete becomes most effective in resisting tension than when it does not contain any reinforcement, and the tensile strength of concrete is relatively lower than compressive strength. These cracks, whereas not compromising structural integrity now, do expose the steel reinforcement to the weather, resulting in corrosion that increases maintenance charges and compromises structural integrity over long periods of time. That being said, concrete may be a high maintenance material. It cracks and suffers serious wear and tear over the years of its predictable term of service [1]. It's not versatile and can't handle important amounts of strain. Ordinary concrete can tolerate to nearly zero to 1% strain before giving out. Self healing concrete normally seeks to repair these flaws, so as to increase the service lifetime of any given concrete structure. There's a material within the realm of self-healing concrete in development, now, which will solve several of the issues usually related to ordinary concrete. This material is micro-organism self-healing concrete. Self-healing concrete consists of a mixture with micro-organism (Bacillus subtilis) incorporated into the concrete and calcium lactate and nutrient broth food to support those micro-organisms once they become active [2]. The micro-organism, feeding on the provided food supply, heal the crack. This paper also will make a case for, in-depth, the method that extent part behind micro-organism self-healing in concrete and can describe the various parts that extent part enclosed within the process and the way they work severally and put together. This paper also will turn over into sensible applications of this self-healing technique, as well as real-world integrations in presently standing structures.

The biological self-healing process

It is vital to hustle what forms of bacteria can live in the concrete, however they exertion to amplify the long life of public communications, what the channel are that basis the substance process with in the micro-organism, what take place to the precise forms of specialized micro-organism once uncovered to the mechanism, and the mode they work along to not solely repair cracks earlier than they form, however additionally strengthen the overall structure they're incorporated into. just the once the bacteria is open to the elements to the atmosphere and therefore the "foodstuff," the micro-organism stand a action that reason them to freeze and blend, substantial within the fracture that has shaped, intensification the construction of the material, and hold on to the boundaries of the crack to fasten the cracks. This method extends the period of time of the structure whereas additionally fixing the cracks caused. The method of healing a crack will take as very little [3].

Concrete edifice is presently designed in keeping with set norms that enable cracks to create up to 2mm wide. Such small cracks are usually thought-about acceptable, as these don't directly impair the safety and strength of a construction. Moreover, small cracks generally repair themselves as several varieties of material quality an explicit crack-healing capability. However, owing to the unpredictability of crack remedial of material edifice, water run as a results of negligible crack creation in subway and underground structures will occur. The fundamental idea behind our specific version of self-healing material is utilizing sure kinds of bacteria (in this case Bacillus subtilis) and to fastentiny cracks surrounded by the material ahead of they breed into bigger and more durable to handle cracks. This biocalcification method involves many parts [6, 7].

Trendy techniques like X-ray diffraction tests and Scanning electron microscopy (SEM) analysis are used to quantify the study of stages of spar deposition on the surface and in cracks [8].

The bacterium to be used as self-healing agent in concrete should to be suited the task, i.e. they have to be ready to perform long effective crack protection, ideally throughout the overall constructions life time. The principle mechanism of bacterial crack remedial is that the bacterium themselves act mostly as a reagent and rework a precursor compound to an acceptable filler material. The freshly created compounds like calcium carbonate-based mineral precipitates ought to than act as a kind of bio-cement what effectively seals freshly shaped cracks [9].

Bacterium that may counterattack concrete matrix assimilation exist in nature, and these seem associated with a specialized cluster of alkali-resistant spore-forming bacterium. These spores part viable. However dormant cells and may stand up to mechanical and chemical stresses and stay in dry state viable for periods over fifty years. However, once micro-organism spores were directly supplemental to the concrete mixture, their lifespan perceived to be restricted to one-two months. Once embedded within the concrete matrix is also because of continued cement association leading to matrix pore-diameter widths generally a lot of smaller than the 1-μm sized micro-organism spores.

How does bacteria remediate cracks?

When the bacteria are mixed with concrete, the bacteria undergo inactive state. When it is exposed to the environment (air), then all their functions are stimulated [10, 11]. The limestone heals the cracks occurred in concrete. By consuming the oxygen, corrosion of steel decreases and the durability of RCC structures. The process of chemical calcium carbonate reaction from dissolved calcium hydroxide occurs according to the following reaction [12]:

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O \quad (1)$$

$$Ca(C_3H_5O_2)_2 + 7O_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O \quad (2)$$

RESEARCH SIGNIFICANCE

There were many studies carried out in strength properties on self-healing concrete but no one proposed empirical relation between compressive strength and flexural strength for bacterial concrete. In this paper, an empirical relation between compressive strength and flexural strength has been proposed.

MATERIALS AND TESTING METHODS

Cement

Ordinary portland cement (OPC) of 53 grade used in this experimental work. This OPC was tested as per IS 4031-1996[13] and the physical properties shown in below Table-1.

Table-1. Physical properties of portland cement (53 grade).

S. No.	Test property	Result	Requirements as per IS 12269-1987[14]
1	Fineness Sieve test Blaine	 2% 285m^2/kg	 Not more than 10% Min 225 m^2/kg
2	Normal Consistency	31.0%	-
3	Specific Gravity	3.01	-
4	Initial setting time	95minutes	Not less than 30 minutes
5	Final setting time	284minutes	Not more than 600 minutes
6	Compressive strength 3days 7days 28days	 28N/mm^2 41 N/mm^2 56N/mm^2	 27 N/mm^2(Min) 37 N/mm^2(Min) 53 N/mm^2(Min)
7	Soundness (Le-Chatlier Exp.)	2mm	Not more than 10mm

Fine aggregate

Local available river sand was used as fine aggregates in this experimental work. The particle size distribution curve of fine aggregate is shown in below Figure-1 and the specific gravity of fine aggregate used was 2.68

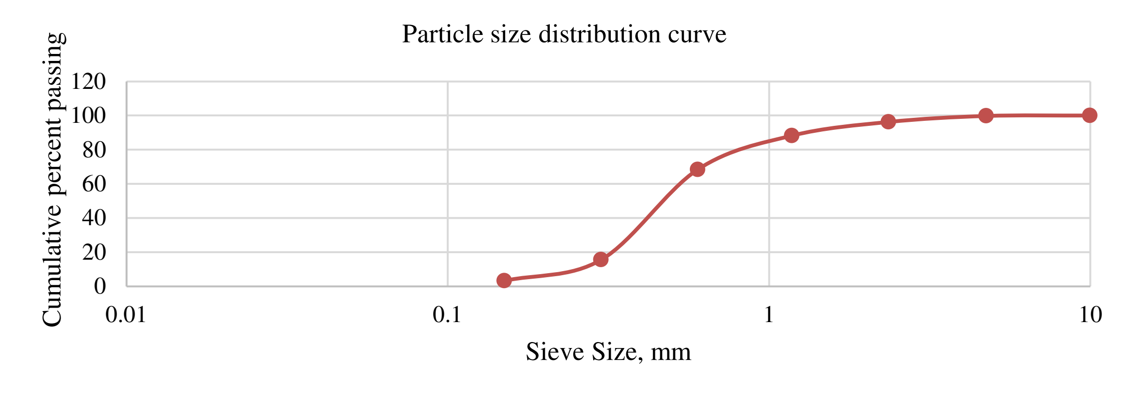

Figure-1. Particle size distribution curve of fine aggregate.

Coarse aggregate

Crushed granite broken stone of 20mm nominal size is used as coarse aggregate in this experimental work. The particle size distribution curves of coarse aggregates were shown in below Figure-2 and properties of coarse aggregates were shown in below Table-2.

Table-2. Properties of coarse aggregate.

S. No.	Property	Test value
1	Specific Gravity	2.71
2	Water absorption	0.5%
3	Sieve Analysis Test results	Particle Size Distribution Curve shown in Figure-2
4	Aggregate Impact Value, %	21.50
5	Aggregate crushing value, %	20.40
6	Combined Flakiness & Elongation Value, %	21.90

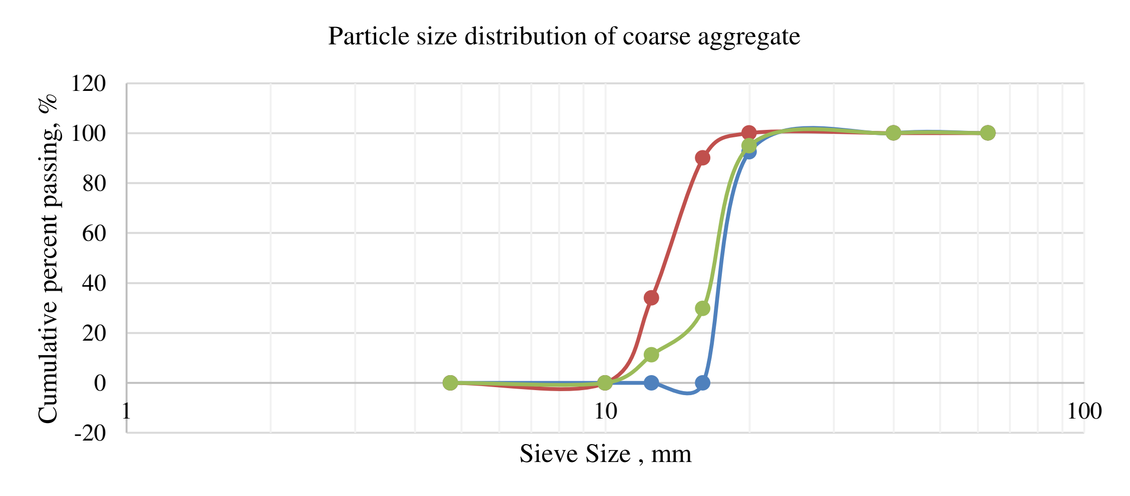

Figure-2. Particle size distribution curve of coarse aggregate.

Water

Locally available potable drinking water used in the experimental work for all mixes.

Micro-organisms

Bacillus subtilis bacteria used in this experimental work which is cultured at DVS Bio life Pvt Ltd Laboratory.

Culture of bacteria

The culture was isolated from DVS bio life pvt ltd laboratory and it was maintained on nutrient agar slants constantly. The irregular white colonies formed on the nutrient agar. When we require a single colony of the culture, it was inoculated into nutrient broth of 25ml in 100ml conical flask. This set up is maintained at 37°C temperature and placed on orbital shaker at 125 rpm.

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The medium composition required for growth of culture is

Peptone : 5 g/lt.

NaCl : 5 g/lt.

Yeast extract : 3 g/lt.

Figure-3 shows the preparation of bacterial solution.

Figure-3. Preparation of bacterial solution.

Calcium lactate

Calcium lactate ($C_6H_{10}CaO_6$) used for this experimental work along with bacillus subtilis bacteria as nutrient broth. It is in the form of powder having white colour.

Compressive strength

The compressive strength test was carry out on 15cm x 15cm x 15cm cubes as per IS: 516-1959 [15] specifications. Compressive strength of specimens was measured at 7, 14,28,60,90,180,270,365 days of curing age as per IS 516-1959.

Tensile strength

The split tensile strength test was conducted on 150mm diameter and 300mm long cylinder. Casting and testing was carried out in accordance with IS: 5816-1999[16].

Flexural strength

Flexural strength test was on 100 mm x 100 mm x 500 mm. all the specimens casting was carried out as per IS: 516-1959 specifications.

Mix design

The mix proportions for M20 and M40 grade concrete are designed using IS: 10262-2009 [17]. Materials required for 1 cubic meter of concrete is presented in Ttable-3.

Table-3. Mix proportions for M20 and M40 grade concrete.

Grade of concrete	**Cement** (Kg)	**Fine aggregate** (Kg)	**Coarse aggregate** (Kg)	**Water** (Kg)	**w/c ratio**
M20	340	736	1214	163.2	0.48
M40	390	642	1261	163.8	0.42

RESULTS AND DISCUSSIONS

Variation of compressive strength of bacterial concrete with curing age

The variation of compressive strength of bacterial concrete with curing age for M20 and M40 grade concrete graphically presented in Figure-4 and Figure-5.

As expected, the compressive strength of bacterial concrete for M20 and M40 grade increases with increasing curing age. However, the percent increase in compressive strength of M20 grade concrete at 28 days for BC-5%; BC-10% and BC-15% are 14.5%, 16.8% and 3.60% respectively. Similarly, the percent increase in compressive strength at 180 days is 20.27%, 21.25% and 2.27% respectively. At 365 days these percentages are

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18.34%, 21.48% and 3.72% respectively for BC-5%, BC-10% and BC-15%.

From the above it was seen that the gain in compressive strength at 180 days and 365 days is more than the compressive strength at 28 days due to the fact that contribution of bacillus subtilis bacteria along with calcium lactate to compressive strength is prominent at ages more than 28 days.

The percent increase in compressive strength of M40 grade concrete at 28 days for BC-5%, BC-10% and BC-15% are 8.98%, 17.02% and 4.65% respectively. Similarly, the percent increase in compressive strength at 180 days is 6.86%, 12.54% and 4.63% respectively. At 365 days these percentages are 6.88%, 11.22% and 3.84% respectively for BC-5%, BC-10% and BC-15%.

From the above it was seen that the gain in compressive strength at 180 days and 365 days is more than the compressive strength at 28 days due to the fact that contribution of bacillus subtilis bacteria along with calcium lactate to compressive strength is prominent at ages more than 28 days.

It was observed that as the percentage of bacterial concrete increased from 0% to 10% the compressive strength also increased, but at 15% the compressive strength is reduced, this is due to the fact that the hydration products are saturated at 10% bacterial solution, with further increase in bacterial solution does not contribute to strength and hence there is reduction in strength.

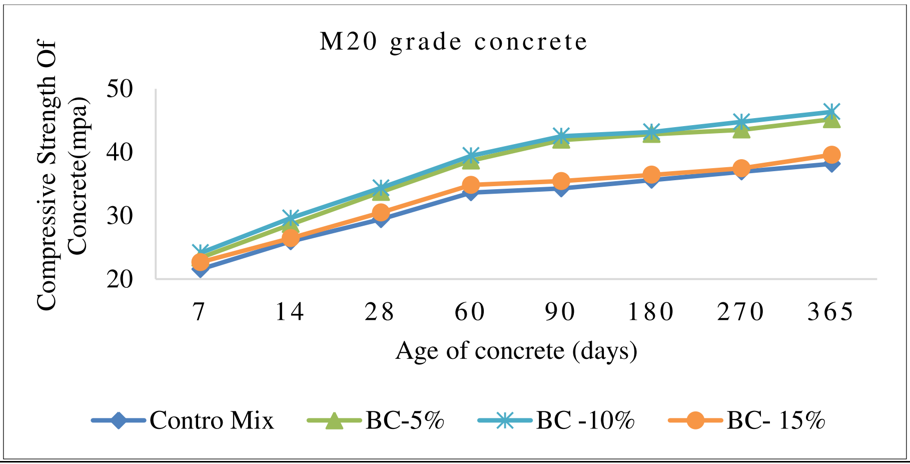

Figure-4. Variation of compressive strength with curing age.

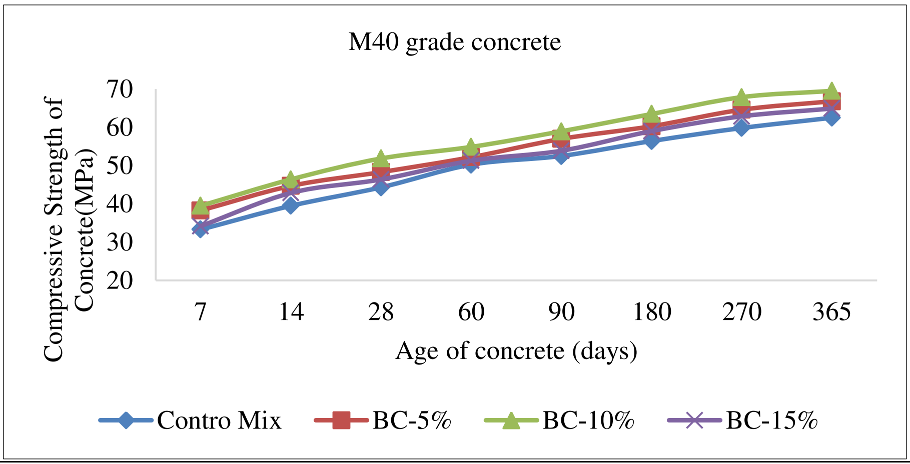

Figure-5. Variation of compressive strength with curing age.

Variation of split tensile strength of bacterial concrete with curing age

The variation of split tensile strength of bacterial concrete with curing age for M20 and M40 grade concrete graphically presented in Figure-6 and Figure-7 the split tensile strength of bacterial concrete for M20 and M40 grade increases with increasing curing age. The percent increase in split tensile strength of M20 grade concrete at 28 days for BC-5%, BC-10% and BC-15% are 4.69%, 19.46% and 2.68% respectively. Similarly, the percent increase in split tensile strength at 180 days is 16.58%, 25.12% and 3.51% respectively. At 365 days these percentages are 6.41%, 11.96% and 2.99% respectively for BC-5%, BC-10% and BC-15%.

From the above it was seen that the gain in split tensile strength at 180 days and 365 days is more than the split tensile strength at 28 days due to the fact that contribution of bacillus subtilis bacteria along with

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calcium lactate to split tensile strength is prominent at ages more than 28 days.

The percent increase in split tensile strength of M40 grade concrete at 28 days for BC-5%, BC-10% and BC-15% are 5.49%, 13.18% and 2.19% respectively. Similarly, the percent increase in compressive strength at 180 days are 10.34%, 13.79% and 3.87% respectively. At 365 days these percentages are 6.64%, 12.5% and 2.34% respectively for BC-5%, BC-10% and BC-15%.

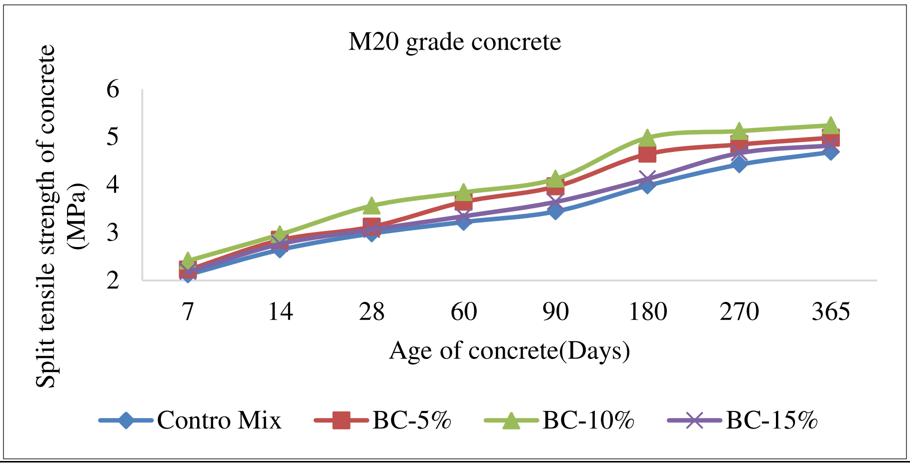

Figure-6. Variation of split tensile strength with curing age.

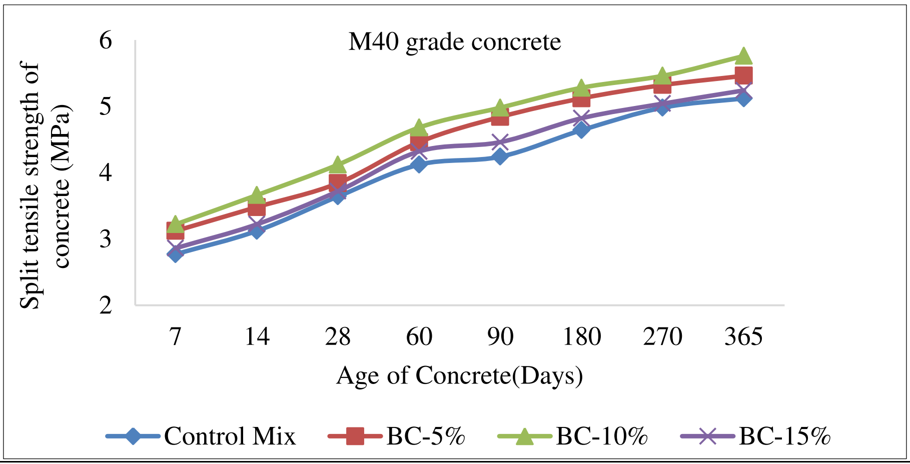

Figure-7. Variation of split tensile strength with curing age.

Variation of flexural strength of bacterial concrete with curing age

The variation of flexural strength of bacterial concrete with curing age for M20 and M40 grade concrete graphically presented in Figure-8 and Figure-9. The flexural strength of bacterial concrete for M20 and M40 grade increases with increasing curing age. However, the percent increase in flexural strength of M20 grade concrete at 28 days for BC-5%, BC-10% and BC-15% are 5.64%, 7.9% and 2.25% respectively. Similarly, the percent increases in flexural strength at 180 days are 4.43%, 10.34% and 1.97% respectively. At 365 days these percentages are 5.68%, 9.47% and 1.42% respectively for BC-5%, BC-10% and BC-15%.

From the above it was seen that the gain in flexural strength at 180 days and 365 days is more than the flexural strength at 28 days due to the fact that contribution of bacillus subtilis bacteria along with calcium lactate to flexural strength is prominent at ages more than 28 days. The percent increase in flexural strength of M40 grade concrete at 28 days for BC-5%, BC-10% and BC-15% are 4.97%, 9.04% and 2.26% respectively. Similarly, the percent increase in flexural strength at 180 days is 1.95%, 7.81% and 1.17% respectively. At 365 days these percentages are 2.89%, 3.98% and 1.08% respectively for BC-5%, BC-10% and BC-15%. It was observed that as the percentage of bacterial concrete increased from 0% to 10% the flexural strength also increased, but at 15% the flexural strength is reduced, this is due to the fact that the hydration products are saturated at 10% bacterial solution, with further increase in bacterial solution does not contribute to strength and hence there is reduction in strength.

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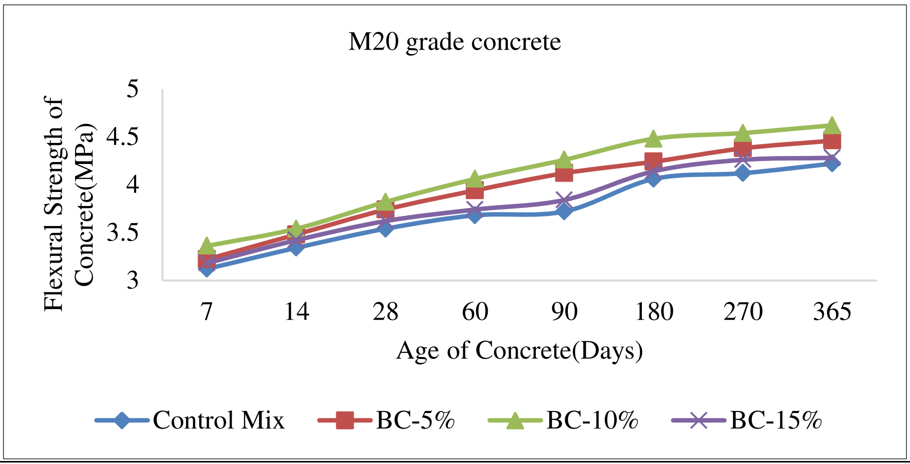

Figure-8. Variation of flexural strength with curing age.

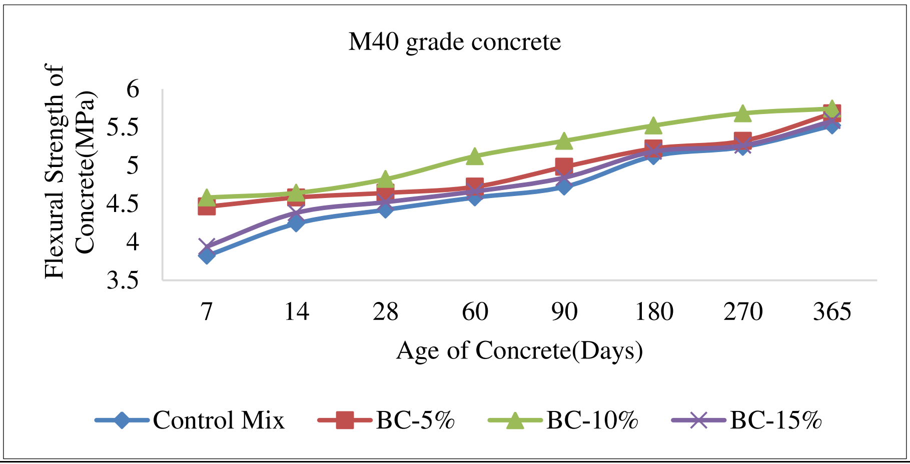

Figure-9. Variation of flexural strength with curing age.

Proposed empirical relation between compressive strength and flexural strength of bacterial concrete

Empirical relations are proposed by various standards between cube compressive strength and flexural strength are as follows:

$fr=0.7\sqrt{fc}$ as per Indian code IS 456-2000[18] (3)

$fr=0.62\sqrt{f_c}$ as per American code ACI- 318-2002[19] (4)

$fr=0.60\sqrt{f_c}$ as per new Zealand NZS - 3101-2006[20] (5)

$fr=0.30(fc)^{0.67}$ as per The Euro-Code (EC-02-) [21] (6)

$fr=0.60\sqrt{f_c}$ as per Canadian Code of Practice (CSA 23.3-1994)[22] (7)

where,

fr : Flexural of concrete in Mpa
fc : Cube compressive strength at 28 days in Mpa
f'_c : Cylinder compressive strength at 28 days in Mpa

From the literature review [23, 24], there is no definite relation was existing between compressive strength and flexural strength of bacterial concrete. Hence a relationship between compressive strength of bacterial concrete with different bacterial percentages and flexural strength of bacterial concrete with different bacterial percentages has been developed.

Figure-10 & Figure-11 shows the relationship between compressive strength of bacterial concrete with different bacterial percentages (BC-5%,BC-10% and BC-15%) and flexural strength of bacterial concrete with different bacterial percentages (BC-5%,BC-10% and BC-15%) at all ages. Figure-10 & Figure-11 can be used to access the compressive strength of contril mix (BC-0%) and bacterial concrete (BC-5%, BC-10% and BC-15%) at any age of concrete. From the experimental results, exponential relation between compressive strength and flexural strength of control mix (BC-0%) and bacterial concrete mixtures containing 5%,10% and 15% bacterial solution respectively has been proposed as under:

i. $f_t = f_t = 0.66\sqrt{f_{ck}}$ for M20 and M40 grade concrete (8)

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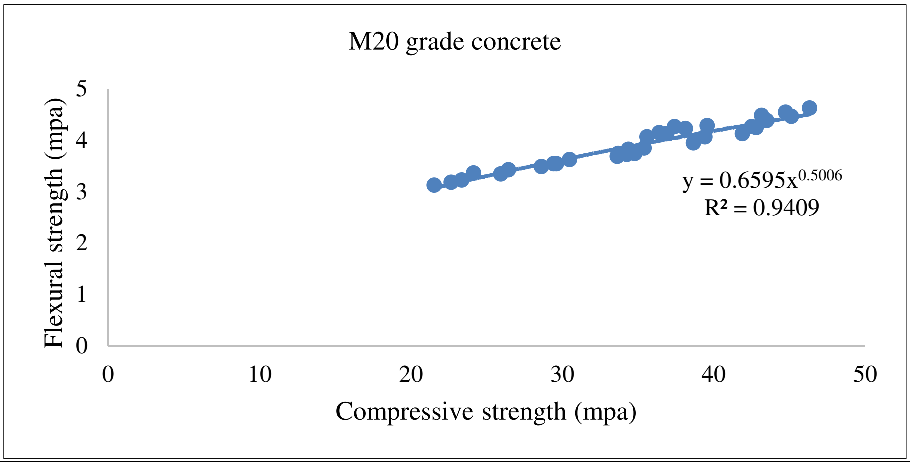

Figure-10. Empirical relation between compressive strength and flexural strength.

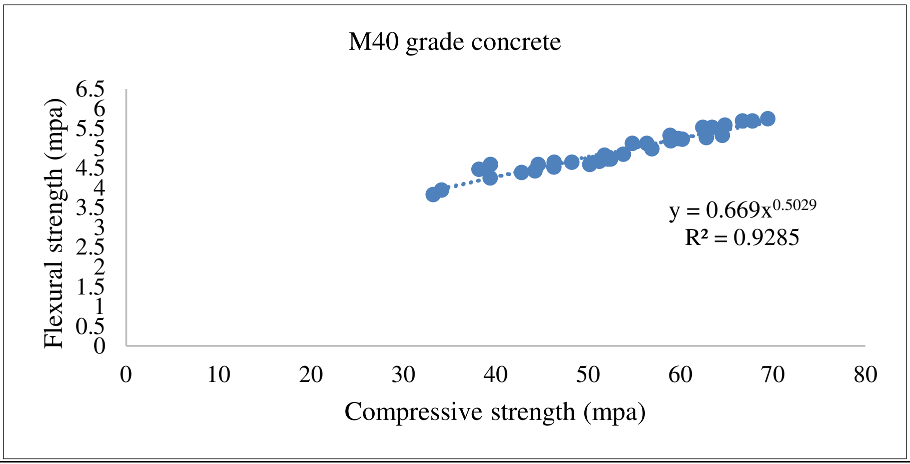

Figure-11. Empirical relation between compressive strength and flexural strength.

4. CONCLUSIONS

Following are the conclusions drawn from the experimental work.

a) The compressive strength, flexural strength and split tensile strength of bacterial concrete for M20 and M40 grades reaches a maximum value at 10% bacterial solution. It is due to the formation of calcium carbonate crystal and its precipitation inside the gel matrix.
b) The increase in compressive strength at 10% bacterial solution for M20 and M40 grade concrete at 28 days of curing is 16.80% and 17.02% respectively in comparison with control mix concrete.
c) The addition of bacteria in concrete has significantly improved the split tensile strength at all ages.
d) Based on test results, the optimum dosage of bacterial solution to improve strength at any age has been 10% by weight of cement.
e) An empirical relation exists between compressive strength and flexural strength of bacterial concrete and it can be presented in the form $f_t = 0.66\sqrt{f_{ck}}$.

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