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Experimental Investigations on Self-Healing Concrete with Pseudomonas Fluorescens Bacteria and Calcium Lactate

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Abstract

Bacterial concrete has recently developed as a therapeutic technique for mending fractures in constructions such as bridges, RCC buildings, RCC pipes, canal lining, pavement, and so on. Crack formation is a very common occurrence in concrete structures because it allows water and other types of chemicals to enter the concrete through the cracks and reduces its strength. It also has an effect on the reinforcement when it comes into contact with water, carbon dioxide, and other chemicals. Repairing cracks in concrete requires frequent maintenance and specialised treatment, both of which can be prohibitively expensive. So, to address this issue, Henk Jonkers developed bacterial concrete to mend fractures in concrete structures. This study indicated that specific types of microorganisms can be an effective way for repairing fractures in existing concrete buildings.In this paper, experimental investigation done to arresting the cracks in the concrete using Pseudomonas fluorescens bacteria and calcium lactate. The selection of bacteria depends on its survival in alkaline environment. In this study Pseudomonas fluorescens bacteria with calcite lactate is used in different percentages such as 5% ,10%and 15% of cement weight for M40 grade concrete. An empirical relation between flexural strength and compressive strength is proposed in the form of $f_t = 0.808\ f_{ck}^{0.443}$.

Keywords:*Bacterial Concrete, Compressive strength, Split tensile strength, Flexural strength, Pseudomonas fluorescens*

1. INTRODUCTION

In the current period of infrastructure projects across the world, cement concrete has become an essential building construction material. Because this material is fragile and prone to cracking, it requires steel reinforcement or rebar to be used in it. Because of its link with steel bars, concrete is more successful in resisting stress than when it does not include any reinforcement, and its tensile strength is lower than its compressive strength. While these fissures do not now jeopardise structural integrity, they do expose the steel reinforcement to the elements, resulting in corrosion that raises maintenance costs and jeopardises structural integrity over time. Having saying that, concrete may be a high-maintenance material.[1]. It is not adaptable and cannot withstand significant strain. Ordinary concrete can withstand approximately zero to one percent strain before failing. Self healing concrete often attempts to correct these defects in order to extend the service life of any particular concrete construction. There is now a material in the field of self-healing concrete in development that will alleviate some of the concerns commonly associated with regular concrete. This is self-healing microbe concrete. Self-healing concrete is made up of a combination that includes bacteria (Pseudomonas fluorescens) and calcium lactate and nutrition broth food to support those microorganisms once they become active. [2]. The microorganism, 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 microorganism 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.

1.1 The Self-healing Mechanism

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 microorganism, what take place to the precise forms of specialized microorganism 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 microorganism 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 materialquality an explicit crack-healing capability. However, owing to the unpredictability of crack remedial of materialedifice, 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 Pseudomonas fluorescens) and to fastentiny cracks surrounded by the materialahead of they breed into bigger and more durable to handle cracks. This biocalcification method involves many parts[4-7].
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 microorganism 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 microorganism spores.
When bacterium is combined with concrete, it enters an inert condition. When it is exposed to the environment (air), it stimulates all of its functions[10,11]. The limestone fills up gaps in concrete. The consumption of oxygen reduces corrosion of steel and the longevity of RCC constructions. The

following reaction happens during the chemical calcium carbonate reaction from dissolved calcium hydroxide [12]:

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O \quad \text{Eq. (1)}$$

$$Ca(C_3H_5O_2)_2 + 7O_2 \rightarrow CaCO_3 + 5CO_2 + 5H_2O \quad \text{Eq. (2)}$$

RESEARCH SIGNIFICANCE

There were many studies carried out in strength properties on self-healing concrete but no one used these type of special bacteria Pseudomonas fluorescens Bacteria and Calcium Lactate in concrete and also proposed empirical relation between compressive strength and flexural strength for bacterial concrete.

2. MATERIALS AND TESTING METHODS

2.1 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 (a) Sieve test (b) 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 (a) 3days	 28N/mm^2	 27 N/mm^2(Min)

	(b) 7days (c) 28days	41 N/mm^2 56N/mm^2	37 N/mm^2(Min) 53 N/mm^2(Min)
7	Soundness (Le-Chatlier Exp.)	2mm	Not more than 10mm

2.2 Fine Aggregate

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

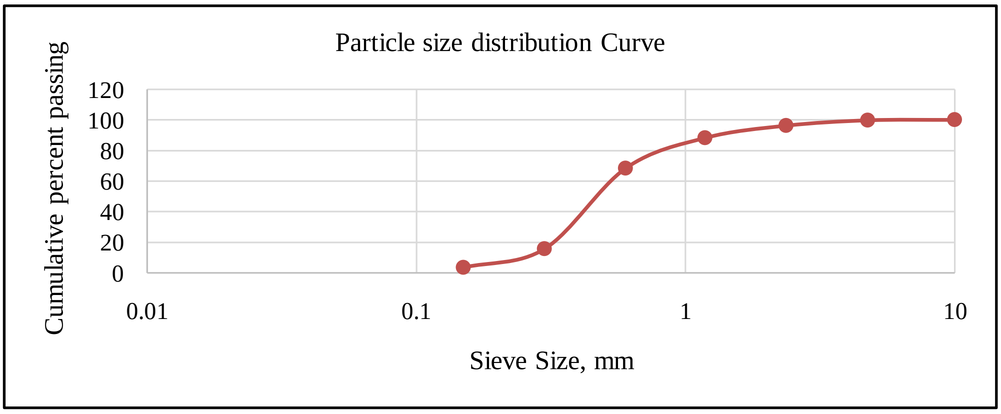

Figure. 1Particle Size Distribution Curve of Fine Aggregate

2.3 Coarse Aggregate

The particle size distribution curves of coarse aggregates were shown in below figure.2 and properties of coarse aggregates were shown in below table2.

Table 2. Properties of Coarse aggregate

S.No.	Property	Test Value
1	Specific Gravity	2.7
2	Water absorption	0.5%
3	Sieve Analysis Test results	Particle Size Distribution Curve shown in Fig.2

4	Aggregate Impact Value, %	21.50
5	Aggregate crushing value, %	20.40
6	Combined Flakiness & Elongation Value, %	21.90

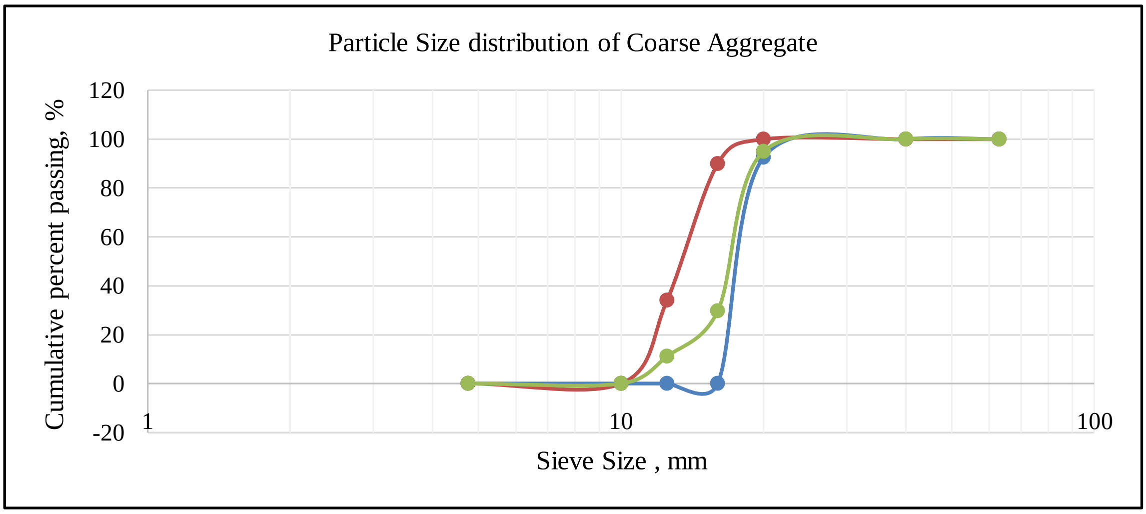

Figure 2 Particle Size Distribution Curve of Coarse Aggregate

2.4 Water

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

2.5 Microorganisms

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

Figure.3 Pseudomonas fluorescens bacteria

2.5.1 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^{o}C temperature and placed on orbital shaker at 125 rpm.

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.

2.5.2 Calcium lactate

Calcium lactate ($C_6H_{10}CaO_6$) used for this experimental work along with Pseudomonas fluorescens Bacteria.

Figure.4 Calcium Lactate

2.6 Compressive strength

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

2.7 Tensile strength

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

2.8 Flexural strength

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

2.9 Mix Design

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

Table 3.Mix proportions for M40 grade concrete

Mixture No	**SHCR00**	**SHCR05**	**SHCR10**	**SHCR15**	**SHCM 00**	**SHCM 05**	**SHCM 10**	**SHCM 15**
Cement(kg/m^3)	395	395	395	395	395	395	395	395
River Sand(kg/m^3)	638	638	638	638	--	--	--	--
M-Sand(kg/m^3)	--	--	--	--	638	638	638	638
Coarse Aggregate (kg/m^3)	1270	1270	1270	1270	1270	1270	1270	1270
w/c ratio	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
Admixture (kg/m^3) (ECMAS)	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Bacterial Cells (cfu/ml)	--	10^5	10^5	10^5	--	10^5	10^5	10^5
Percent of bacterial solution	00	05	10	15	00	05	10	15

3. RESULTS AND DISCUSSIONS

3.1 Compressivestrength of bacterial concrete with curing age

The variation of compressive strength of bacterial concrete with curing age for M40 grade concrete graphically presented in fig. 5

As expected, the compressive strength of bacterial concrete for M40 grade increases with increasing curing age.From the below it was seen that the gain in compressive strength at 60 days and 90 days is more than the compressive strength at 28 days due to the fact that contribution of Pseudomonas fluorescens 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.

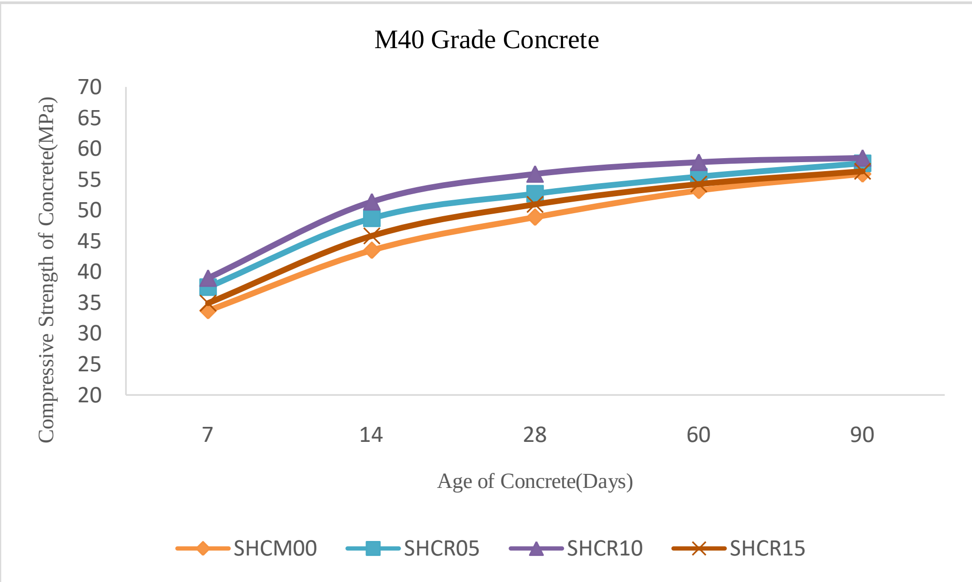

Figure.5 Variation of compressive strength with curing age

3.2 Split tensile strength of bacterial concrete with curing age

The variation of split tensile strength of bacterial concrete with curing age for M40 grade concrete graphically presented in fig. 6 and fig.7.

the split tensile strength of bacterial concrete for M40 grade increases with increasing curing age.

From the below it was seen that the gain in split tensile strength at 60 days and 90 days is more than the split tensile strength at 28 days due to the fact that contribution of Pseudomonas fluorescens Bacteria along with calcium lactate to split tensile 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 split tensile strength also increased, but at 15% the split tensile 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

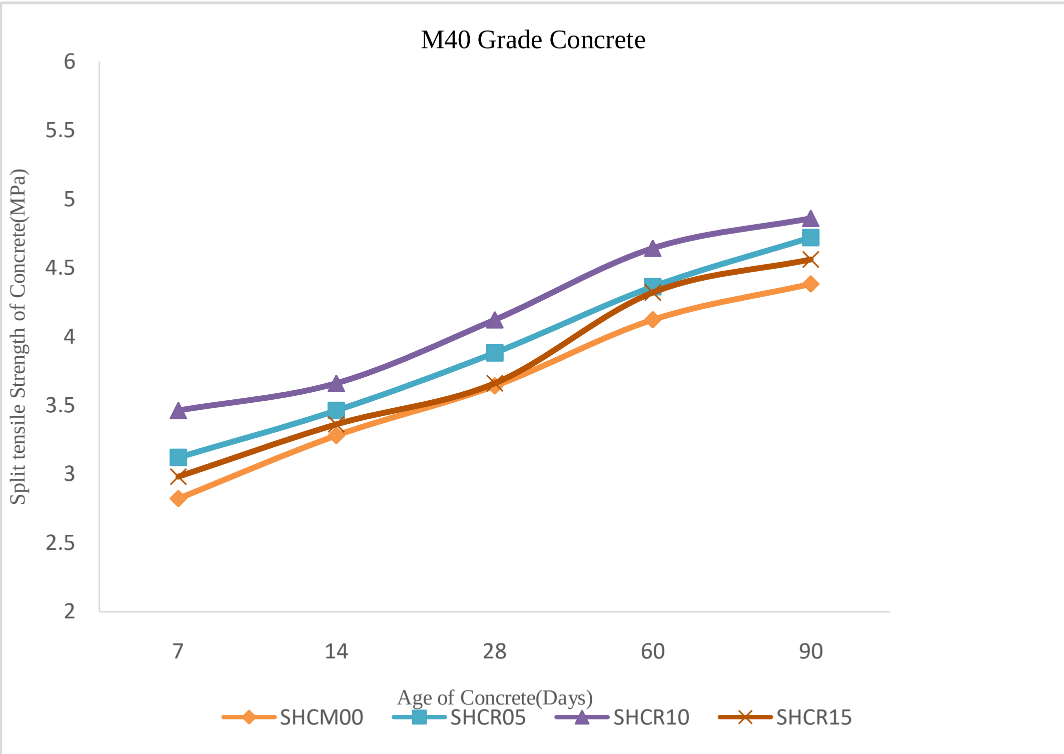

Figure.7 Variation of split tensile strength with curing age

3.3 Flexural strength of bacterial concrete with curing age

The variation of flexural strength of bacterial concrete with curing age for M40 grade concrete graphically presented in fig. 8The flexural strength of bacterial concrete for M40 grade increases with increasing curing age.

From the above it was seen that the gain in flexural strength at 60 days and 90 days is more than the flexural strength at 28 days due to the fact that contribution of Pseudomonas fluorescens Bacteriaalong with calcium lactate to flexural 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 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.

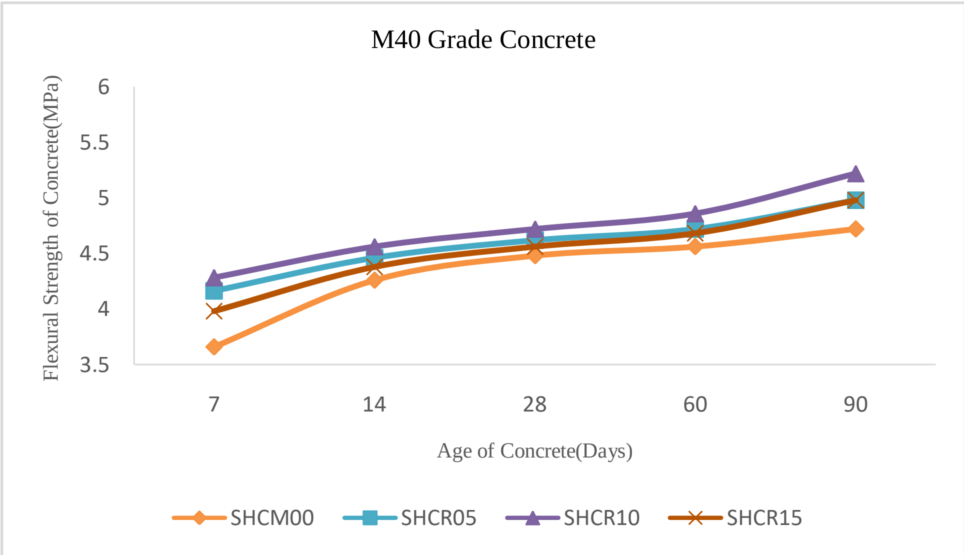

Figure.8 Variation of flexural strength with curing age

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

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

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

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

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

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

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

Eq. (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, 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.

Fig.9 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. Fig. 9 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. $f_t = f_t = 0.808\ f_{ck}^{0.443}$ - M40 grade concrete Eq. (8)

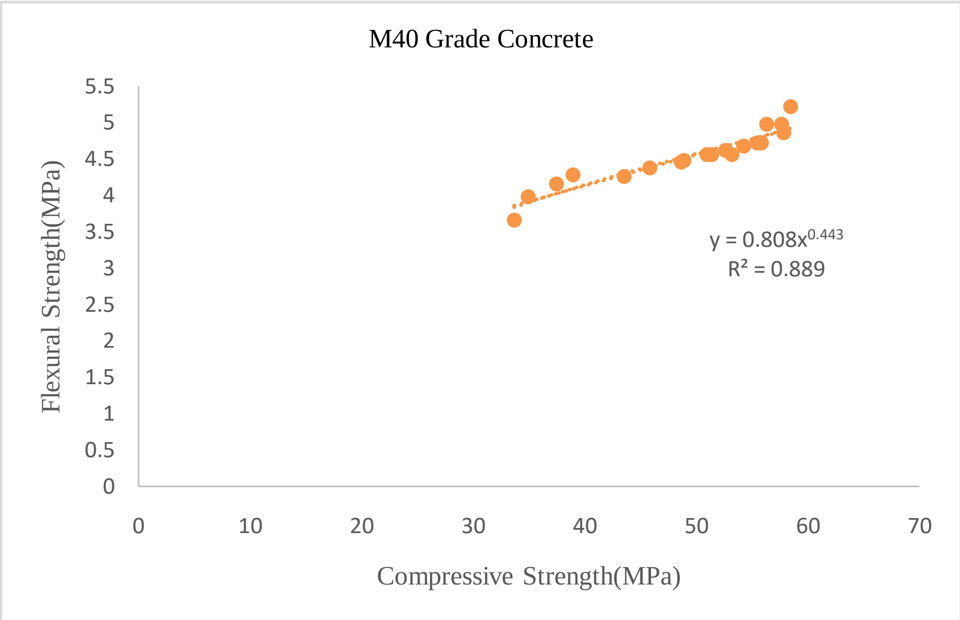

Figure.9 Empirical relation between compressive strength and flexural strength

4.CONCLUSIONS

Following are the conclusions drawn from the experimental work.

1. The compressive strength, flexural strength and split tensile strength of bacterial concrete for 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.

2. There is increase in compressive strength at 10% bacterial solution for M40 grade concrete at 28 days of curing in comparison with control mix concrete.
3. The addition of bacteria in concrete has significantly improved the split tensile strength at all ages.
4. Based on test results, the optimum dosage of bacterial solution to improve strength at any age has been 10% by weight of cement.
5. An empirical relation exists between compressive strength and flexural strength of bacterial concrete and it can be presented in the form $f_t = 0.808\ f_{ck}^{0.443}$.

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