Development of Flexural Fatigue Model for Bacterial - Induced Concrete

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***Abstract* — Cement is the second largest material consumed after water. Now a day's concrete pavements are gaining popularity for its own good paving properties. Nowadays, the number of vehicle users is also increasing. Because of the maximum number of vehicles movements on the road, cracks will be formed. To overcome and avoid these cracks we need to increase the strength and durability of concrete. There are many ways to improve the strength of concrete. In that ways, inducing Bacteria in concrete is one of the Kind.**

In this research, extensive laboratory investigations have been undertaken to study the effect of inducing E coli bacteria on the mechanical properties such as compressive, tensile, flexural strengths and durability. BIC specimens were cast, cured and tested for 7, 14, 28 and 56 days and Plain concrete specimens were also cast and tested for reference purposes. With an addition to this Beams are Cast for fatigue test and the test was conducted for Plain concrete and BIC Beams for the stress ratio of 0.6, 0.7 and 0.8.

In this paper, the experimental results of BICP and plain concrete are discussed for M40 Grade of concrete. The results show that the strength and Fatigue properties of BICP with varying stress ratios for the flexural failure load. In this research, the results are proved that Bacterial concrete is 12.5% increasing compressive strength, 6.8% increasing Split tensile strength and 8.5% increasing in Flexural strength compared to conventional concrete.

Keywords* — *Concrete, Bacteria mineralization, Bio – Concrete, E - Coli, Strength & Fatigue Characteristics..

1. INTRODUCTION

In accordance with the desires of mankind, the civil engineering applications have been improving. Hence there is a need for more and more innovative materials. Worldwide, with an annual production of over seven billion tons, concrete is the most widely used structural material due to its ability to get casted in any form and shape. Concrete is strong under compression while it is weak under the tension. By making appropriate changes in its ingredients like binding materials, aggregates, water and special ingredients, the strength and the durability of the concrete can be changed. (Rahmani, et al., 2011) Durability is one of the most important aspects of concrete due to its fundamental incidence in the serviceability life of structures. (Krishna, 2016) The structures must be able to resist the mechanical actions, the physical and chemical aggressions they are submitted to during their expected service life. (Khan, et al., 2016).

Nowadays construction industries are mainly focused on the durability aspect of the structure. To overcome this need for contractors, bacteria have been introduced in the construction industry. Bacteria added into the concrete fills the pore spaces inside the concrete. It increases the durability of concrete. Bacterial concrete reduces the repair work which reduces the cement conception and also High-Volume Fly Ash was replaced to the cement. It leads to reduce the CO_2. Bacterial concrete makes the environment free from pollution. Microscopic analysis is used to evaluate the growth of bacteria inside the concrete specimens.

The current study has an overview that biotechnology can really be a supportive device to reduce microcracks in concrete structures by using Bacillus species of bacterial in concrete. This latest category of concrete, that is set to fix itself, shows a powerful improvement in community infrastructure's service-life, thereby considerably reducing the maintenance costs and lowering CO2 emissions. Several investigations are made of bacterial concrete in last few years. This paper covers the review of concrete based on the bacterial solution are discussed

2. MATERIAL AND EXPERIMENTAL STUDIES

In the present experimental work, studies on strength and fatigue properties of conventional and bacterial concrete with varying Bacteria dosages were carried out. The materials used for this experimental study are cement, fine aggregate (M-Sand), coarse aggregate (20mm & 10mm), water, admixture, superplasticizer (Forsoc Conplast 430) and E coli bacteria. The various tests were carried out on fresh and hardened concrete have been discussed in sections.

Cement: Ordinary Portland cement of 53 grades with a specific gravity of 3.10, normal consistency 29%, fineness 4%, initial and final setting times of 45 minutes and 540 minutes conforming to IS 12269-1987, Portland pozzolana cement with a specific gravity of 2.88 & Portland slag cement with the Specific gravity of 2.8.

Fine Aggregates: Locally available M-Sand with a specific gravity of 2.60, water absorption 7% and confirming to Zone II as per IS 383-1970 was used for the study.

Coarse Aggregates: Crushed granite stones of a 20mm size having a specific gravity of 2.7, water absorption 0.5% and fineness modulus 6.82 conforming to IS 383-1970 was used.

Water: Portable water was used to carry out the experimental studies.

Chemical Admixtures: Conplast SP 430 with a specific gravity of 1.12, for the concrete mix.

Bacteria: In this study, E coli Bacterial concentration of 105 cells/ml were used. Bacteria was cultured by E coli pure culture and following components

- Urea 20 gm/lit
- Beef extract 1 gm/lit
- Ammonium chloride 10 gm/lit
- Sodium Bi carbonate 2.12 gm/lit
- Yeast extract 2 gm/lit
- Calcium chloride 25 gm/lit

Preparation of Bacteria

Primarily 12.5 grams of nutrient growth added to 500 ML conical flask containing distilled water. Then it is covered rubber band. Then it is sterilized using a cooker for 10 - 20 Min. Now solution is free from contamination and solution is clear orange in color before the addition of bacteria. Later flask is open up and 1 ML of bacterium is added to sterilized flask and kept in shaker at speed of 150 - 200 rpm overnight. After 24 hrs. bacterial solution was found to be Whitish Yellow Turbid solution.


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2.1 Mix design for Different types of cement

Table 1 Quantity of materials per cubic meter of concrete for OPC

Contents	Values (kg/m^3)
Cement	350
Water	140
Fine aggregates	770
Coarse Aggregates 20mm down	1209
Super plasticizer	2.25
Water-Cement ratio	0.40
E coli Bacteria	10^5 cells/ml or 30 ml/m^3

Table 1 Quantity of materials per cubic meter of concrete for PPC

Contents	Values (kg/m^3)
Cement	350
Water	140
Fine Aggregates	757.18
Coarse Aggregates 20mm down	1189.65
Super Plasticizer	2.25
Water-Cement ratio	0.40
E coli Bacteria	10^5 cells/ml or 30 ml/m^3

Table 2 Quantity of materials per cubic meter of concrete for PSC

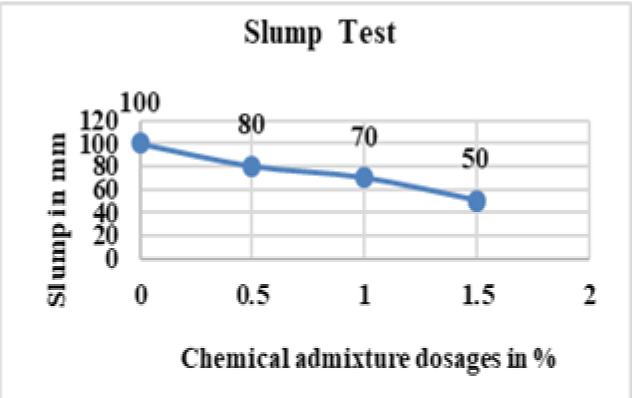
Contents	Values (kg/m^3)
Cement	350
Water	140
Fine Aggregates	746
Coarse Aggregates 20mm down	1218
Super Plasticizer	2.25
Water-Cement ratio	0.40
E coli Bacteria	10^5 cells/ml or 30 ml/m^3

2.2 Tests conducted on fresh concrete

Slump Test:

It is a laboratory test conducted to check the consistency of the fresh concrete which is very useful in detecting variations in uniformity of a mix of given nominal proportions. It was conducted in accordance with IS 1199-1959, with the use of slump cone of 30cm height, 10cm top opening and 20cm bottom opening.

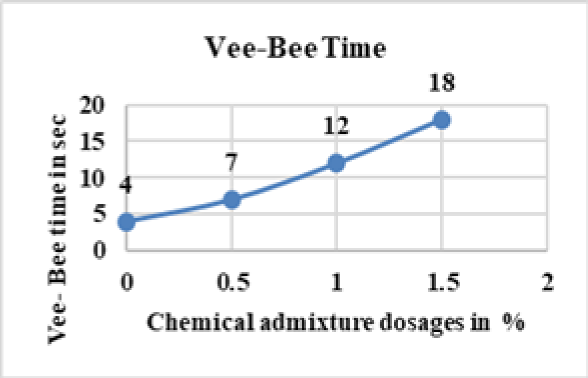
The results obtained from experimental tests conducted on Fresh Concrete for conventional and Bacterial induced concrete with varying Bacteria concentration of dosage of 0.25 %, 0.5% and 0.75% are plotted



Vee – Bee Consistometer Test:

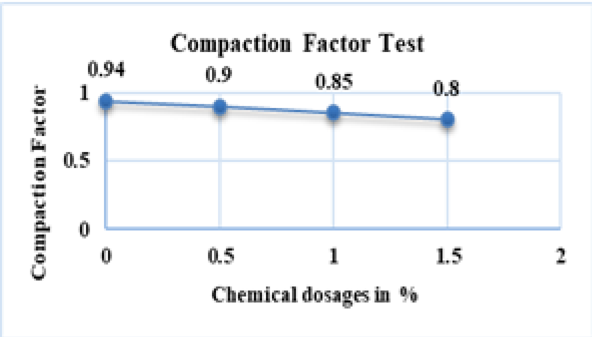
The Vee-Bee test gives an indication about the mobility and the compatibility aspects of the freshly mixed concrete. It measures the relative effort required to change the mass of the concrete from one definite shape to the other. The test was conducted in accordance with IS 1199-1959.

It was found that, the Vee-Bee time of the concrete mix increases with the proper percentage of chemical admixture adding into it. The Vee - Bee time for conventional concrete and Bacterial induced concrete with varying chemical admixture dosages of 0.25 %, 0.5% and 0.75% were found to be 8 secs, 4.2 secs, 3 secs respectively.



Compaction Factor Test:

Compaction factor is nothing but the degree of compaction and it is measured as ratio of the partially compacted and fully compacted densities. The compaction factor test is more sensitive at low workability. It was conducted in accordance to IS 1199-1959.



2.3 Tests conducted on Hardened concrete

Compressive Strength :

A total of 24 cubes of dimension 150 x 150 x 150mm for compression test and 24 cylinders 200mm long and 100mm in diameter for split tensile test were casted and tested on a digital compression testing machine as per IS 516-1959.

Split tensile strength :

Total 24 cylinders 200mm long and 100mm in diameter for split tensile test were casted and tested .

Flexural Strength:

Beams of dimensions 100 x 100 x 500mm were casted and tested in Flexural testing machine in accordance with IS 516-1959 to determine the flexural strength of concrete with under three-point loading.

Fatigue test :

Beams of dimensions 100 x 100 x 500mm were casted and tested in Fatigue testing machine in accordance with ASTM E606 to determine the no of repetitions for the cyclic load with varying stress ratio for the flexural failure load under three-point loading.

3. RESULTS AND DISCUSSION

3.1 Compressive strength

It was observed that, there was a considerable increase in the compressive strength due to the addition of Bacteria when tested for 7, 14 and 28 days of age. The compressive strengths of conventional concrete and Bacterial concrete with proper concentration of E coli bacteria, when tested for 7days were found to be 24.08 MPa, 26.48 Mpa for conventional and Bacterial concrete respectively and when tested for 14 days were found to be 34.42 MPa, 36.25 Mpa & finally when tested for 28 days 39.85 MPa and 48.16 Mpa respectively.

Table 3 Compressive strength of Conventional and Bacterial concrete

Sl no	Cement	Age (No of days)	Conventional concrete (Mpa)	Bacterial concrete (Mpa)
1	OPC	7	24.08	26.48
	PPC		18.01	20.25
	PSC		17.25	19.25
2	OPC	14	34.42	36.25
	PPC		29.58	31.42
	PSC		29.02	30.68
3	OPC	28	39.85	42.16
	PPC		33.12	35.65
	PSC		32.15	34.48

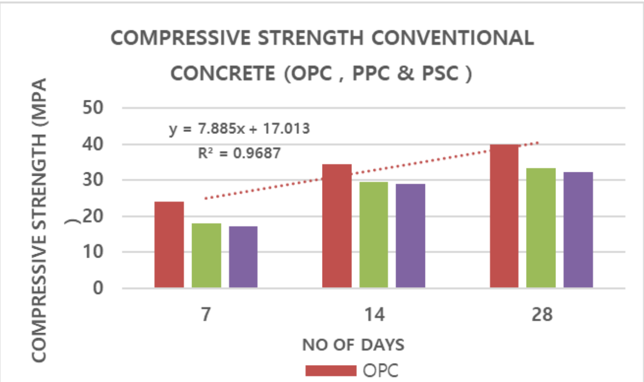


Figure 1 Comparison of Conventional concrete for the OPC, PPC & PSC

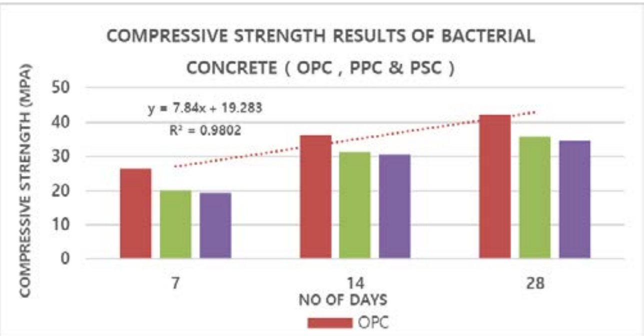


Figure 2 Comparison of Conventional concrete for the OPC, PPC & PSC

3.2 Split tensile strength

There was a considerable increase in the compressive strength due to the addition of Bacteria when tested for 7, 14 and 28 days of age. The compressive strengths of conventional

concrete and Bacterial concrete with proper concentration of E coli bacteria, when tested for 7days were found to be 2.87 MPa, 2.98 Mpa for conventional and Bacterial concrete respectively and when tested for 14 days were found to be 3.18 MPa, 3.35 Mpa & finally when tested for 28 days 4.16 MPa and 5.12 MPa respectively.

Table 4 Split tensile strength of Conventional and bacterial concrete

Sl no	Cement	Age (No of days)	Conventional concrete (Mpa)	Bacterial concrete (Mpa)
1	OPC	7	2.87	2.98
	PPC		2.38	2.54
	PSC		2.35	2.49
2	OPC	14	3.18	3.35
	PPC		2.95	3.2
	PSC		2.75	3.15
3	OPC	28	4.16	5.26
	PPC		4.25	5.12
	PSC		4.19	5.01

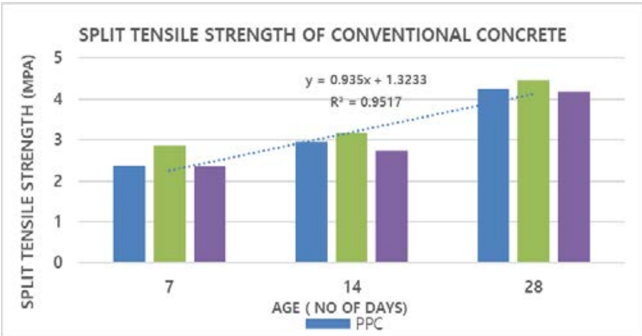


Figure 3 Comparison of Conventional concrete for the OPC, PPC & PSC

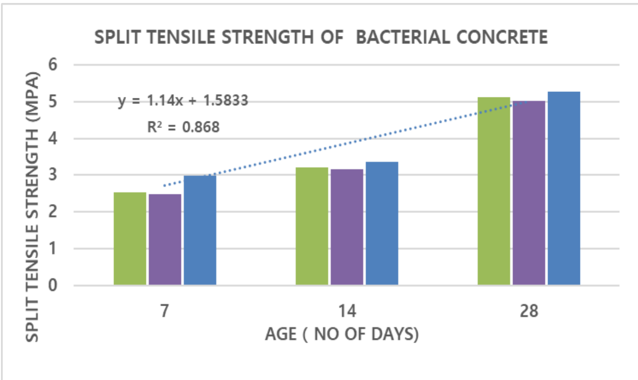


Figure 4 Comparison of Conventional concrete for the OPC, PPC & PSC

3.3 Flexural strength

It was observed that, there was a considerable increase in the compressive strength due to the addition of Bacteria when tested for 7, 14 and 28 days of age. The compressive strengths of conventional concrete and Bacterial concrete

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with proper concentration of E coli bacteria, when tested for 7 days were found to be 1.2 MPa, 1.7 Mpa for conventional and Bacterial concrete respectively and when tested for 14 days were found to be 6.0 MPa, 6.25 Mpa & finally when tested for 28 days 7.5 MPa and 7.85 MPa respectively.

Table 5 flexural strength of conventional and Bacterial concrete

Sl no	Cement	Age (No of days)	Conventional concrete (Mpa)	Bacterial concrete (Mpa)
1	OPC		2.5	2.95
	PPC		2.3	2.45
	PSC		2.1	2.3
2	OPC	14	6	6.25
	PPC		4.9	5.2
	PSC		4.75	5
3	OPC	28	7.5	7.95
	PPC		6.53	6.9
	PSC		6.5	6.85

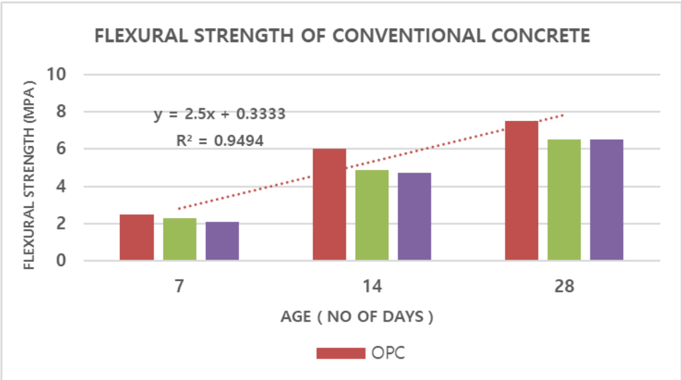

Figure 5 Comparison of Conventional concrete for the OPC, PPC & PSC

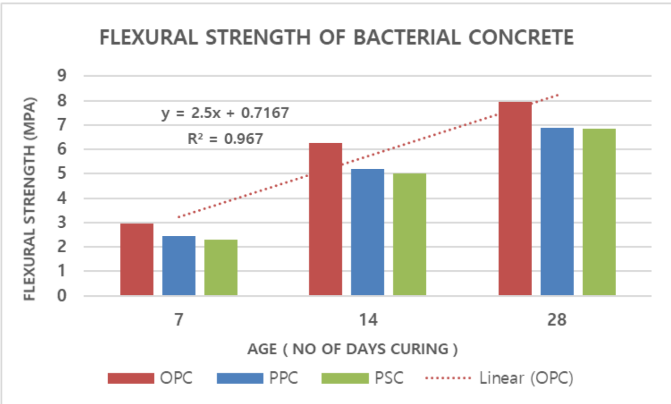

Figure 6 Comparison of Conventional concrete for the OPC, PPC & PSC

3.4 Failure model of Beam

Beam model

Data:

Dimension: 100 X 100 X 500 MM

Density of concrete: 2398.77 KG/m^3

Poisson's ratio: 0.15

Young's modulus: 5000√Fck

Fck = 40 N/mm^2

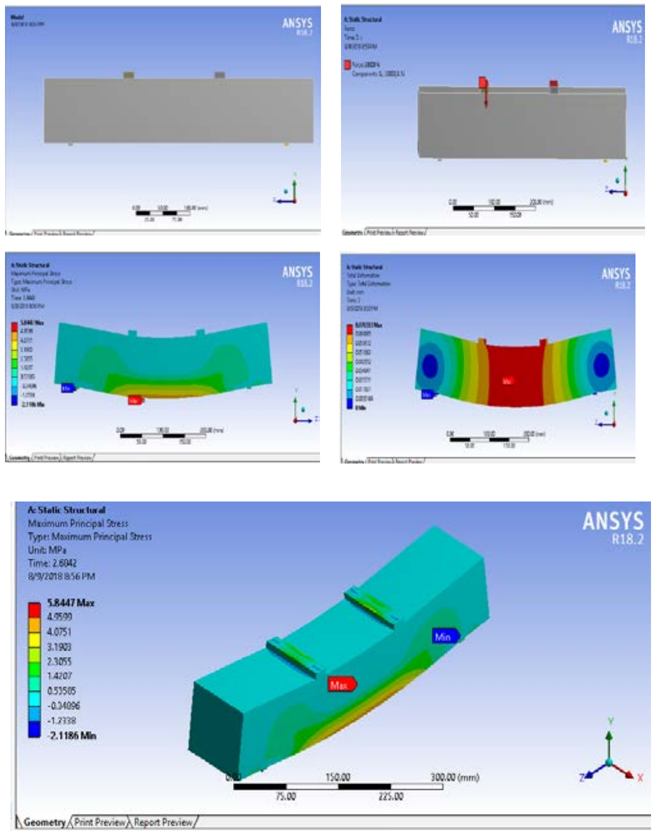

Figure 7 Failure model of a Beam by Ansys analysis

Stress obtained from the Analysis done by Ansys Software = 5.8447 Mpa

Stress obtained from the experiment = 7.5 Mpa

In the above observation, stress obtained from the experiment is more compared to Software analysis. This is because Youngs modulus of concrete (Ec) value for concrete. In the software analysis we assumed E value as 5000i/fck but in the actual condition E value will be different.

3.5 Fatigue test

The present investigations are proposed for conducting the flexural fatigue studies on controlled (m1) and bacterial concrete beams of size 100 mm x 100 mm x 500 mm. The specimen is subjected to accelerated half sine wave form of cyclic loading tests at two stress levels 60%, 70% and 80% of static flexural strength with frequency of load application i.e. Two cycles per seconds. Prediction of fatigue life by a direct linear relationship between stress ratio and log (n) values models is attempted and the results are presented in this study. To get realistic value, half sine wave form of loading at two cycles per second is applied. The number of repetitions to failure is shown in table 4.1

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SAMPLES	CONTROLLED CONCRETE			BACTERIAL CONCRETE		
	Stress Ratio			Stress Ratio		
	0.6	0.7	0.8	0.6	0.7	0.8
1	12450	6251	1620	12890	6720	1700
2	11520	7250	1298	11780	7520	1420
3	10250	6758	1425	11985	6952	1435
4	12250	6785	1352	12015	7250	1625
5	12584	6524	1568	12854	6850	1750
Avg	**11810.8**	**6713.6**	**1452.6**	**12304.8**	**7058.4**	**1586**
1	10256	5252	1105	10350	5420	1150
2	9952	4985	1209	9900	5015	1268
3	9856	5120	1265	10100	5210	1125
4	10242	5365	1025	10100	5009	1035
5	10153	5685	986	10800	5690	1010
Avg	**10091.8**	**5281.4**	**1118**	**10250**	**5268.8**	**1117.6**
1	9589	4958	1152	9600	5005	1205
2	10250	5325	1025	10300	5450	1100
3	9756	4852	1184	9852	5150	1052
4	9625	5500	995	10150	4995	1189
5	9856	5789	925	9958	5890	1025
Avg	**9815.2**	**5284.8**	**1056.2**	**9972**	**5298**	**1114.2**

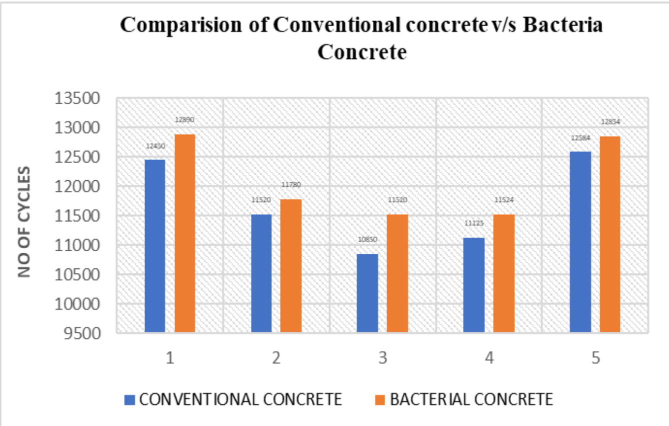

Figure 10 Fatigue life of Pavement for conventional and Bacterial concrete

3.6 To Develop a Failure Prediction Model by Regression analysis

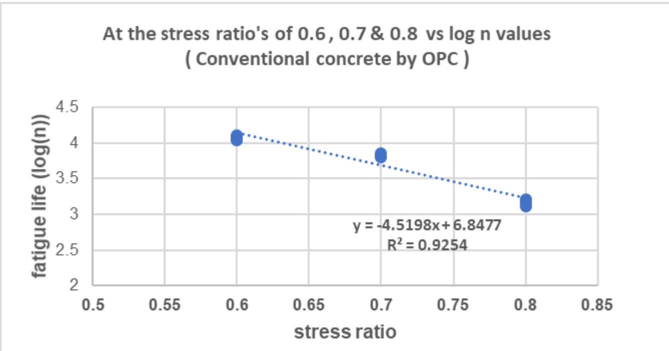

Figure 8 Stress ratio& 0.8 vs log(n) values (Conventional concrete by OPC)

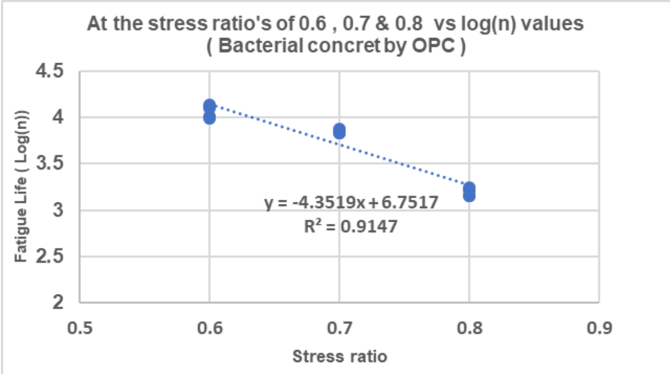

Figure 9 Stress ratio vs log(n) values (Bacterial concrete by OPC)

Table 6 Comparison of fatigue life of Bacterial and conventional concrete with IRC values

S R	IRC		Conventional concrete		Bacterial concrete	
	Log(n)	No of repetitions	Log (n)	No of repetitions	Log(n)	No of repetitions
0.55	5.09	1.24×10^5				
0.6	4.49	3.09×10^5	4.406	3.05×10^5	4.56	3.18×10^4
0.65	3.87	7.70×10^5				
0.70	3.3	1970	3.754	7265	3.85	7680
0.75	2.7	477				
0.8	2.07	119	3.206	1520	3.11	1856
0.85	1.48	30				

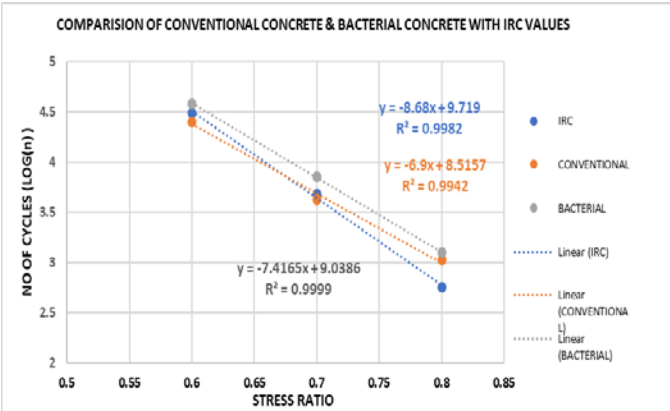

Figure 11 Comparison of Fatigue life of Pavement for conventional and Bacterial concrete

4. DISCUSSION

The following important conclusions were drawn based on the results obtained from the experimental studies:

- With an increase in chemical admixtures dosages, the workability decreases. This problem of workability and flow property of concrete can be overcome by adding superplasticizers
- It was also observed that by adding Bacteria there was an increase in compressive strength of BICP for varying dosages of 103, 105 & 107 cells/ml and were found to be 12.87%, 13.25% & 12.8% more than that of conventional concrete. The maximum percentage increase in compressive strength was achieved at 105 cells/ml of fiber dosage.

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- It was also observed that by adding Bacteria there was an increase in split tensile strength of BICP for varying dosages of 103, 105 & 107 cells/ml and were found to be 12.87%, 13.25% & 12.8% more than that of conventional concrete. The maximum percentage increase in compressive strength was achieved at 105 cells/ml of fiber dosage.
- It was also observed that by adding Bacteria there was an increase in flexural strength of BICP for varying dosages of 103, 105 & 107 cells/ml and were found to be 12.87%, 13.25% & 12.8% more than that of conventional concrete. The maximum percentage increase in compressive strength was achieved at 105 cells/ml of fiber dosage.
- The Flexural Strength of Bacterial Concrete increases by 6.5% at 28 days curing when compared to Controlled Concrete at 28 days curing. Hence BICP can be used for construction of new pavements.

5. CONCLUSION

With the results obtained from the tests conducted on Bacterial concrete and Conventional concrete, the following conclusions can be drawn.

- The optimum dosage of super plasticizer for Controlled and Bacterial concrete is found to be 0.5 % of the total cementitious material in concrete, which improves the workability in terms of slump and Compaction factor.
- As the number of repetitions to failure in Bacterial Concrete is more when compare to conventional pavement quality concrete, it can be advantageously used in pavement construction.
- Due to higher flexural strength there will be reduction in thickness of pavements and hence Bacterial Concrete pavements are more economical. It will be particularly beneficial when gain in early strength is not the criteria for pavement construction
- The model developed in this study can be used for estimating the cumulative fatigue life while designing Bacterial concrete pavements.
- The Flexural Strength of Bacterial Concrete increases by 6.5% at 28 days curing when compared to Controlled Concrete at 28 days curing. Hence BICP can be used for construction of new pavements.

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