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Study on the compressive strength of steel fibre reinforced self-healing M20 concrete using a novel technique microbial induced calcite precipitation

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ABSTRACT

Aim : The objective of the study was to quantify the compressive strength of steel fiber reinforced self healing concrete using a novel technique called MICP(microbial induced calcite precipitation). **Materials and methods:** Sample size was calculated using clincalc software. The total sample size per group was 0 at a power of 95% and alpha value was 0.05. So for better understanding of the compressive strength, sample size was considered as 18 per group. Two groups consisting of 18 samples were prepared for the collection of data. One is prepared with the addition of steel fibre and other is without fiber. Bacteria *Bacillus subtilis* was prepared in the bioinformatics laboratory using a strain brought from the hi media laboratories. **Results :** The data was analysed using a statistical software SPSS, version 21. The mean compressive strength of steel fiber reinforced concrete was 37.7284 N/mm^2 and the compressive strength of bacterial concrete without fiber was 27.6445 N/mm^2. Independent samples t-test is performed to analyse the results. The significance of the events was $p=0.002$ ($p<0.05$). The standard deviation of steel fiber reinforced self healing concrete was 3.8819. **Conclusion:** The steel fiber reinforced concrete had more strength compared to bacterial concrete without fiber. The Percentage increase in strength of steel fiber reinforced concrete was 37.16%.

Keywords: Bacterial Concrete, Steel Fibre, Self Healing, Microbial Induced Calcite Precipitation, Novel Technique, *Bacillus Subtilis*, Compressive Strength.

INTRODUCTION

Bacterial concrete is a material, which is prepared using bacteria which can successfully remediate cracks in concrete. It uses a novel technique or new process called MICP(microbial induced calcite precipitation) to fill cracks automatically by producing calcium carbonate in the cracks (Ramakrishnan, Ramesh, and Bang 2001). In this process, if bacteria is exposed to air or moisture it starts reacting with calcium acetate present in the concrete and produces calcium carbonate and self heals the concrete. It also enhances the properties of concrete like pore density etc(Maqbool and Singh 2020). Today , in the world of growing population, there is a need for high performance concrete for high raised structures. The normal lifespan of concrete structures is 70-80 years. To improve the life span of concrete structures, bacterial concrete was a new solution by a novel technique called microbial induced calcite precipitation(Maqbool and Singh 2020; Wang et al. 2016). With the bacterial concrete, the lifespan of concrete structures can be improved. If the high raised structures produce any cracks, the maintenance and rehabilitation costs are high. If the load on the concrete structure applied is more than its limit, cracks will also occur especially in high raised structures due to uneven wind force. So in this case bacterial concrete reduces repair and rehabilitation costs(Babhor, Hingwe, and Raijiwala 2009). Bacterial concrete has a lot of advantages when compared to normal conventional concrete. Bacterial concrete increases the properties of concrete. It enhances the durability of cementitious materials. It prevents the cracks at the earliest stage and reduces maintenance and rehabilitation costs. By using this novel technique the corrosion in steel can be minimised. (Pasnur and Jain 2018)

Many researchers have done a lot of research on bacterial concrete. In the last five years , there have been around 90 plus publications in the area of self healing concrete. (Wiktor and Jonkers 2011), they investigated the crack healing capacity of bacterial concrete. They found that the crack healing capacity depends on the factors like type of bacteria used, amount of bacteria used, percentage of calcium acetate added, the concentration of bacteria etc. They found that the bacterial concrete has crack-healing capacity of up to 0.46mm wide cracks in bacterial concrete. And only up to 0.18mm wide cracks in bacterial concrete after 100 days submersion in water. (Krithika and Ramesh Kumar 2020; Ramesh Kumar and Rishab Narayanan 2020; Teja and Ramesh kumar 2020; Maurya, Sonker, and Rawat 2020; Khaliq and Ehsan 2016), investigated the chemical process to fix the crack by using bacteria. And found out the potential, possibilities, application of MICP(microbial induced calcite precipitation). (Krishnapriya, Venkatesh Babu, and G. 2015) found out the influence of bacteria on the compressive strength. Also found out the efficiency of bacteria towards crack healing. They used different bacteria of the Bacillus family and found out the compressive strength of bacteria and its influence on compressive strength. (Schlangen and Sangadji 2013) used hybrid fibre reinforced cementitious materials that can mechanically repair cracks when they occur. In all these papers, Paper published by HM Jonkers was the best paper.Previously our team has a rich experience in working on various research projects across multiple disciplines(Samuel et al. 2019; Johnson et al. 2020; Venu, Subramani, and Raju 2019; Keerthana and Thenmozhi 2016; Thejeswar and Thenmozhi 2015; Krishna and Babu 2016; Subashri and Thenmozhi 2016; Sriram, Thenmozhi, and Yuvaraj 2015; Jain, Kumar, and Manjula 2014; Menon and Thenmozhi 2016)

From all the papers published in the past five years, it can be seen that the influence of steel fiber in self healing concrete is not well understood. Among all the papers published on bacterial concrete focused on quantification compressive strength, crack healing etc. The influence of different fibres in the bacterial concrete was not very well understood. Our team had past experience of doing projects on bacterial concrete and published them in various journals.(Schlangen and Sangadji 2013; C. M. K. Reddy, Manvith Kumar Reddy, Ramesh, Macrin, et al. 2020; C. M. K. Reddy, Manvith Kumar Reddy, Ramesh, and Macrin 2020);(P. V. Y. Reddy et al. 2020). This paper quantifies the influence of steel fiber on the compressive strength of bacterial self healing concrete.

MATERIALS AND METHODS

This study on the influence of steel fiber on the compressive strength of self healing concrete was done in the concrete lab, Department of civil engineering, biotechnology lab, department of bioinformatics, Saveetha School of Engineering. The sample size calculation was done using clincalc software (Jagannathan et al. 2018). The sample size was considered as 18 per group. Since the value of sample size in software was 0 at 95% power and at an alpha value of 0.05. For better understanding the sample size was considered as 18 per group. Two different types of experiments were carried out. One group was prepared with the addition of steel fiber to the self healing concrete and the other one is the self healing concrete without fiber. One is for test purposes and the other for the comparison purpose.

Cubes of size 150x150x150 mm were prepared to find out the compressive strength of concrete. First was prepared with the addition of steel fibre . The steel fiber was brought from the nectar composites, poonamallee Chennai, Tamil Nadu and it has the following properties. The length of the fiber was 20mm. The shape of the fiber was wave cut. The colour of the fiber was black. The density of the fiber was 7900 Kg/m^3. The resistance to alkalis was good. The heat resistance of the steel fiber was also good. Young's modulus of the fiber was

$2.1x10^5$ N/mm^2. The specific gravity of the fiber was 7.90. The bacteria used for the preparation of steel fibre reinforced bacterial concrete was *Bacillus subtilis* which belongs to the family of Bacillus. The bacteria preparation was done in the bioinformatics laboratory. The strips of bacteria which consists of 10 spores on it were brought from the Hi-media laboratories, T-Nagar, Chennai. The materials used for the preparation of bacteria were Soyabean casein digest medium(tryptone soya bath), L-alanine($C_3H_7NO_2$), and manganous sulphate($MnSo_4.H_2O$) are shown in Fig.1.

After preparing the mother culture medium, the bacteria was first prepared in glass tubes. Then the grown bacteria was transferred to a glass container of 2L. 60gms of soybean casein digest medium, 0.4 grams of alanine, 0.2 grams of dissolved manganese sulphate in 200 ml water were used for growing 2L bacteria. The preparation of bacteria was done in the following sequence. The glass jar along with media was first sterilized in an autoclave. Then the glass jar was placed under a cooler for cooling. Then the bacteria prepared in tubes was transferred to a 2L jar. The jars were then placed in a shaking incubator. Then the bacteria was tested in a haecyometer to find the concentration of cells. The concentration was found to be $3x10^7$ cells/ml. Then the bacteria was centrifuged from the media using a centrifuge. The speerated bacteria was added to the concrete directly. The amount of bacteria added to concrete was 3% with respect to the water amount used for 1 cube. The materials used in this study were 53 grade and the size of coarse aggregate was 20mm. The amount of materials used for the preparation of 1 cube of M20 grade cement concrete were 1.3608kg cement, 2.26kg fine aggregate ,4.2525 kg coarse aggregate . The concrete was prepared manually. Water cement ratio was taken as 0.44. Water added per 1 cube of concrete was 0.6 liter. The grade of concrete used was M20. The bacteria which was centrifuged was added to the concrete along with calcium acetate. The amount of calcium acetate added was 30% with respect to the size of the cube. All the above were mixed along with the steel fiber, the steel fiber reinforced self healing concrete were casted 18 times and were casted separately. Similarly the other group of specimens werecement, fine aggregate and coarse aggregate and calcium acetate. The cement used prepared as group 1 but without the addition of fiber. The procedure of casting the second group of experiments was the same as group 1, the only difference was without the addition of steel fibre. All casted cubes were placed in water for curing for 28 days.

In the preparation of steel fibre reinforced self healing concrete, many equipment have been used for qunatificacaton of compressive strength and for the preparation of bacteria. The compression testing machine is shown in Fig.2 used for the qunatificacaton of compressive strength has the following properties. It has a maximum load capacity of 2000 KN. The equipment was electrically operated and it has an accuracy of plus or minus 1. In the process of preparation of bacteria, many equipment has been used to ensure that the bacteria was alive until the bacteria was mixed in the concerte. The bacterial content and the viability was confirmed using a light microscope at 60X magnification is shown in Fig.3. To protect the bacteria from contamination the culture bottles were sterilised in an equipment named autoclave. Autoclave Was an equipment that provides a physical method of sterilisation by killing bacteria, viruses, and even spores using steam under pressure. The autoclave was operated for a time period of 15 minutes at a temperature of 121°c and at a pressure of 15 lb/sec. The sterilised jars were then placed in a shaking incubator after the bacteria was added to the media. Shaking incubator was an equipment used to mix, blend or agitate substances in a tube or flask by shaking them. Shaking incubator was operated for a time.period of 4 days. The number of rotations per minute was 90. The temperature was 37°c. The concentration of cells was found using haecyometer. The concentration of the cells was found out to be $3x10^7$ cells/ml. After bacterial growth reached a constant stage, the bacteria was separated from the media using a centrifuge. Centrifuge is an equipment that uses centrifugal force to separate various components of a fluid is shown in Fig.4. Centrifuge was operated at an rpm of 4000/min. For a time period of 10 minutes. At a temperature of 29°c. The bacteria separated was added to the concrete along with calcium acetate. The casted cubes were then placed in water for curing for 28 days. The temperature of the water was 27°c +/- 2°c.

STATISTICAL ANALYSIS

The data was analysed with IBM's SPSS version 21 software. The study had no dependent variables, but the compressive strength, concrete grade, water/cement ratio, cement grade, and days of curing were all independent variables.The statistical significance between the study and control groups was determined using the Independent samples t-test in SPSS software version 21. Mean,standard deviation, standard error mean were calculated using this statistical tool.

RESULTS

The compressive strength of both the samples were analysed using SPSS software version 21. The compressive strength of bacterial concrete was 27.6445 N/mm^2. The compressive strength of steel fibre reinforced bacterial concrete was 37.7284 N/mm^2. The standard deviation of bacterial concrete was 2.05106 . The standard deviation of steel fibre reinforced self healing concrete was 3.88819. The significance of levene's test for equality of means was 0.002. The significance of compressive strength for levene's test for equality of variances was 0.002. Table 1 represents the compressive strength value of steel fibre reinforced self healing concrete. Table 2 represents the compressive strength values of self healing concrete without fiber. Particulars of group statistics were presented in Table 3 and independent samples t-test were presented in Table 4. The comparison of mean accuracy values for two groups of steel fiber reinforced self healing concrete and conventional self healing concrete with p-value 0.05 and error bar 95% with the effective prediction is shown in the Fig.5. The error bars with the mean accuracy detection +/- 1 SD.

DISCUSSION

The mean compressive strength of 18 specimens of bacterial concrete was 27.6445 N/mm^2. The mean compressive strength of 18 specimens of steel fibre reinforced bacterial concrete was 37.7284 N/mm^2. The percentage increase in compressive strength when compared to the bacterial concrete was 37.16%. The standard deviation of the steel fiber reinforced self healing concrete was found to be more compared to self healing concrete.It shows the deviation of compressive strength from its mean value. The significance of levene's test for equality of means was 0.002. The value is less than 0.005 . As our threshold value is less than 0.005, it shows some statistical significant difference.

The research papers published on bacterial concrete in the past years have shown some mixed results about the compressive strength values. (Durga et al. 2019), they found that the bacterial concrete compressive strength has improved. The bacteria used was *bacillus subtilis*. The grade of concrete was M40. The concentration of cells was 10^8 cells/ml. The compressive of bacterial concrete after 28 days of curing was 64.25 MPa. The flexural strength after 28 days of curing was 5.96 MPa. (Jagannathan et al. 2018) research found that the compressive strength has been improved. The bacteria used was bacillus sphaericus. The grade of concrete was M20. The compressive strength and flexural strength of 10% fly ash+ bacteria bacillus sphaericus mix after 28 days of curing was 32.50 MPa and 3.50 MPa. The compressive strength and flexural strength of 20%+ bacillus sphaericus was 23.55 MPa and 2.17 MPa after 28 days of curing. The compressive strength and flexural strength of 30% fly ash+ bacillus sphaericus was 22.45 MPa and 1.85 MPa. As we can see that if the fly ash percentage increases, the strength starts decreasing. (Jagannathan et al. 2018; Andalib et al. 2016), the compressive strength was increased for a cell concentration of 10^5 cells/ml. The Garde of concrete was M25. The compressive strength was 37 Mpa after 28 days of curing. For another Garde of concrete i.e M35 and for a cell concentration 10 x 10^5 cells/ml the compressive strength for 7 and 28 days of curing was 19 and 35 MPa. And for cell concentration of 20x10^5 cells/ml the compressive strength for 7 and 28 days of curing was 19.5 and 36 MPa. Similarly for M35 Grade and for a cell concentration of 30x10^5 the compressive strength after 7 and 28 days of curing was 20 and 37 MPa. The compressive strength for a cell concentration of 40x10^5 cells/ml for a grade of concrete M35 the compressive strength was 18 and 35 MPa. Maheswaran et.al, 2014 in this research the bacteria used was bacillus pasteurii of wild strain CS-1. The compressive strength for a cell concentration of 10^5 cell/ml was 25.65 and 43.47 MPa after 7 and 28 days of curing. The compressive strength after 7 and 28 days of curing for a cell concentration of 10^6 cells/ml was 31.41 and 50.52 MPa. The compressive strength after 7 and 28 days of curing for a cell concentration of 10^7 cells/ml was 34.9 and 44 MPa. The above mentioned papers all showed positive responses regarding compressive strength of bacterial concrete. But the following mentioned papers showed opposing results. (Pei et al. 2013), in this study the compressive strength was slightly decreased. The concentration of cells used was 33.3mg/ml. (Bhavana, Raju, and Asadi 2017), research showed that the self healing concrete compressive strength was decreasing when the cement was replaced by fly ash. The bacteria used for the preparation of concrete was *bacillus subtilis*. Cubes were casted by replacing cement in the ratio of 0,10and 30%. The compressive strength of self healing concrete with 10% fly ash was increased when compared to normal self healing concrete. The self healing concrete with 30% fly ash compressive strength was decreased when compared to normal self healing concrete.The factors that affect the compressive strength of bacterial concrete were aggregate size, water/cement ratio, grade of cement, air voids, compaction during casting etc.

In this study, one type of fiber was used, that is steel fiber. In further, different fibres like steel, plastic, E waste, glass etc can be used. The grade of concrete used was M20, different grades of concrete can be used like M10, M15, M25, M30, M35, M40 etc. The bacteria used was *Bacillus subtilis* which belongs to the bacillus family. Different bacteria like megatherium, sphoracis etc from the Bacillus family can be used for further study and the compressive strength can be quantified. The Percentage of bacteria added to concrete was 3%. And calcium acetate added was 30% with respect to specimen size. In the future, many different types of concentration can be used.

In the further studies, Scanning electron microscope (SEM) and X- ray diffraction (XRD) analysis can be done to understand the fiber distribution and bacteria distribution and calcium carbonate production. The super plasticisers can be added to the concrete to quantify the compressive strength and comparison can be done with bacterial concrete. Crack healing analysis can be done . In this study one can study the crack depth and width of and how many days it takes to heal. Using an electronic microscope calcium precipitation distribution can be found. The bacterial concrete compressive strength can be analysed under different environment conditions like sea water curing, waste water addition to concrete etc.

CONCLUSION

The compressive strength steel fiber reinforced M20 Grade bacterial concrete was 37.7284 N/mm^2. The percentage increase in compressive strength compared to bacterial concrete was 37.16%.

Declarations

Conflict of Interests

No conflict of interest in this manuscript.

Author Contribution

Author MK is involved in data collection, experimental study and manuscript writing. Author RB involved in conceptualization, guidance and critical review of manuscript.

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TABLES AND FIGURES

Table 1. Represents the compressive strength values of steel fiber reinforced M20 grade bacterial concrete.

S.No	Weight (Kg)	Strength (KN)	Compressive strength (N/mm^2)
1	9.153	940	41.778
2	8.695	873	38.800
3	8.9	971	43.156
4	8.935	854	37.956
5	9.195	931	41.378
6	8.863	976	43.378
7	8.856	744	33.067
8	9.075	922	40.978
9	8.941	946	42.044
10	9.165	748	33.244
11	9.3	743	33.022
12	9.035	837	37.200
13	9.195	893	39.689
14	9.175	730	32.444
15	9.44	783	34.800
16	9.182	768	34.133
17	9.226	755	33.556
18	8.8	866	38.489

Table 2. Represents the compressive strength value of bacterial concrete without fiber addition.

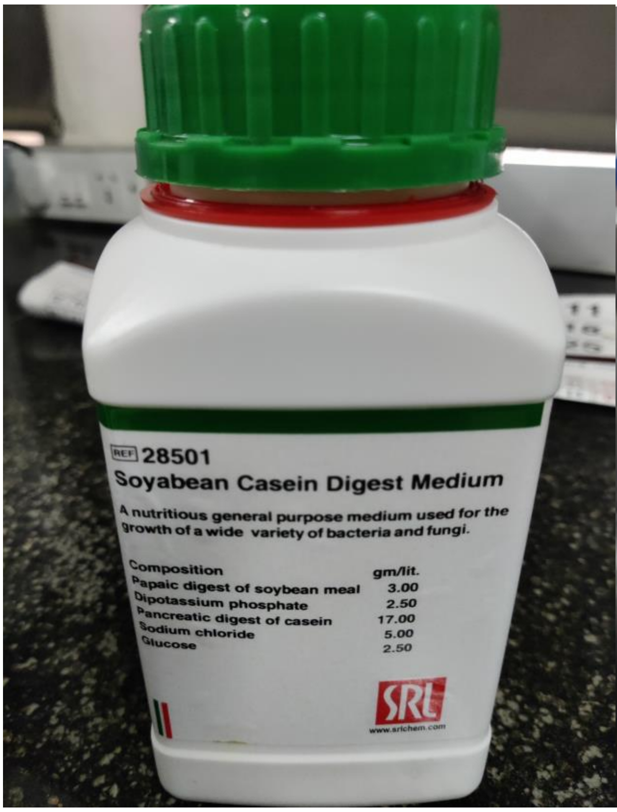
S.No	Weight(Kg)	Strength (Kn)	Compressive strength (N/mm^2)
1	9.155	562	24.978
2	8.773	572	25.422
3	8.89	579	25.733
4	9.09	698	31.022
5	8.726	647	28.756
6	9.33	645	28.667
7	9.075	527	23.422
8	8.951	589	26.178
9	9.05	583	25.911
10	9.067	643	28.578
11	8.963	645	28.667
12	9.162	623	27.689
13	8.974	672	29.867
14	9.065	642	28.533
15	9.032	634	28.178
16	8.892	675	30.00
17	8.948	593	26.356
18	9.036	667	29.644

Table 3. Represents group statistics for both sample groups. Mean (27.6445,37.7284), standard deviation(2.05106,3.88819), standard error mean (0.48344,0.91646).

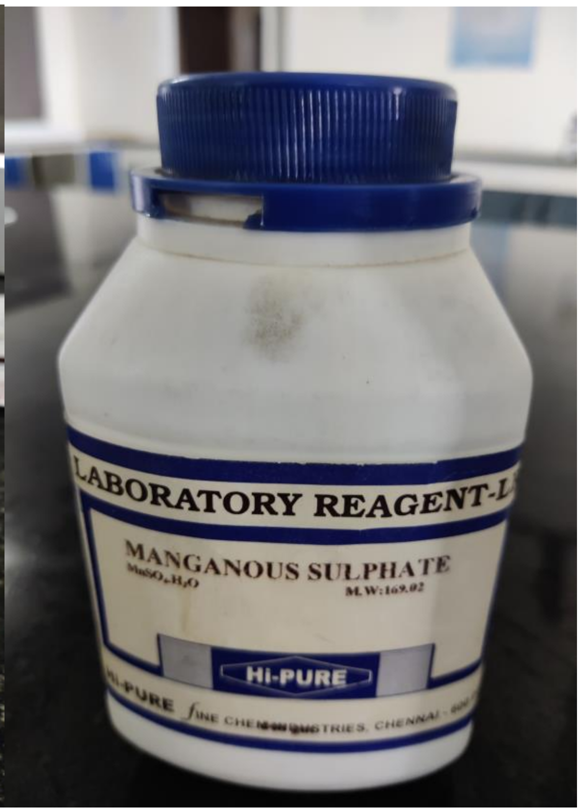
	Group	**N**	**Mean**	**Std.deviation**	**Std.Error mean**
Compressive strength	Conventional concrete	18	27.6445	2.05106	0.48344
	Glass fiber reinforced concrete	18	37.7284	3.88819	0.91646

Table 4. Result of independent T-test using SPSS tool. It includes levene's test for equality of variances, T-test for equality of means, and 95% CI of the difference for accuracy for the two groups in Compressive strength. The p-values obtained are p<0.05.

Independent-samples-t-test									
	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Compressive strength Equal Variances Assumed	11.867	0.002	-9.732	34	0.000	-10.0839	1.03615	-12.189	-7.978
Equal Variances Not Assumed			-9.732	25.781	0.000	-10.0839	1.03615	-12.214	-7.95



(a)

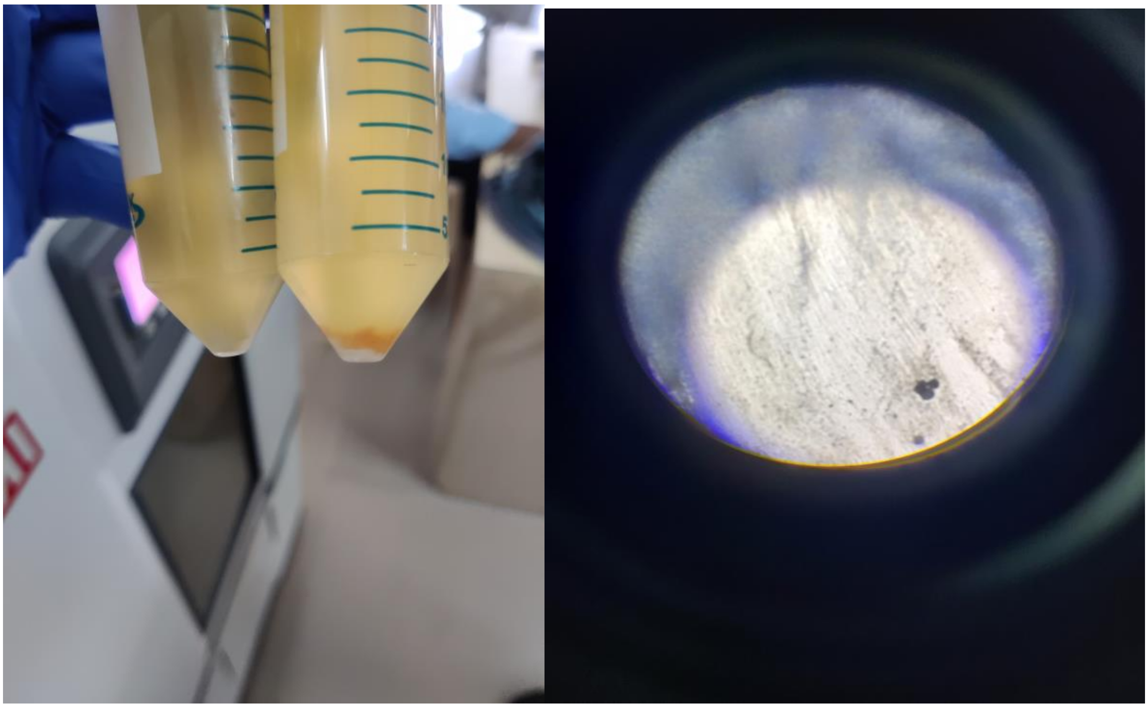


(b)

(c)

Fig.1 : (a) tryptone soybean bath, (b) manganous sulphate, (c) L-Alanine . Represents the materials used for the preparation of bacteria.

Fig.2 : Compression testing machine used to collect the compressive strength data.



(a) (b)

Fig.3 : (a) represents the presence of bacteria under the microscope, (b) represents the growth of bacteria in the 100 ml tube.

(a)

(b) (c)

Fig.4 : (a) represents the centrifuge device used to separate the bacteria from media, (b) represents the bacteria after separation from media, (c) Represents the equipment used for the sterilization of equipment (Autoclave).

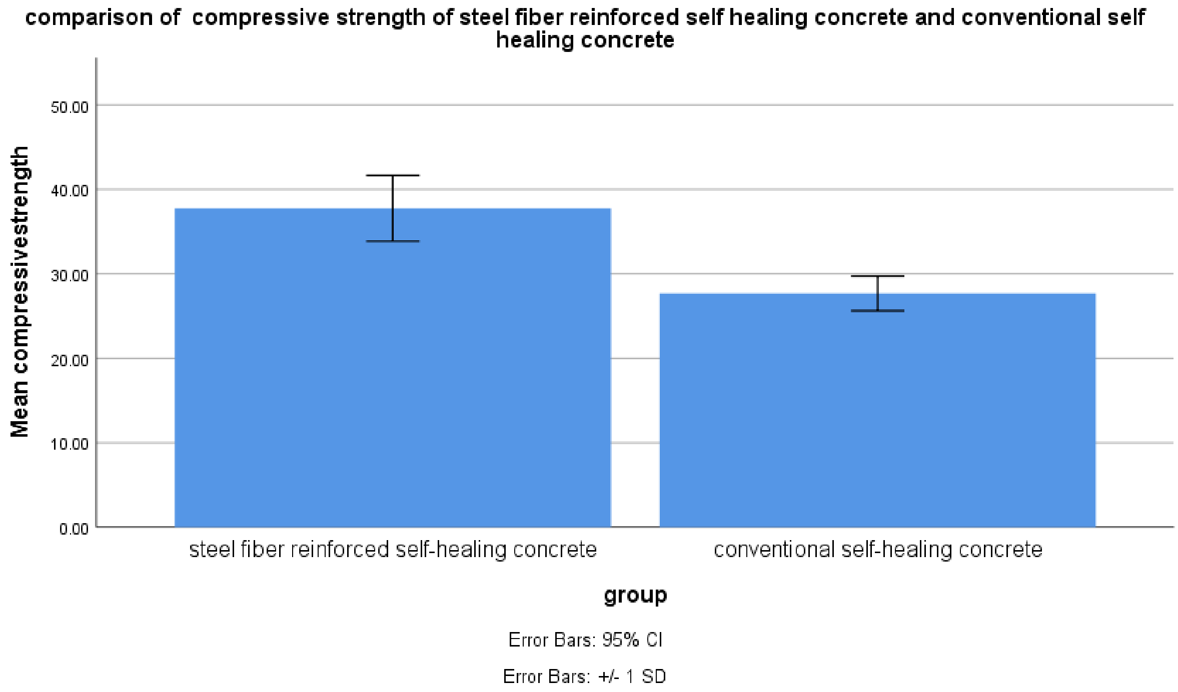


Fig.5 : Bar chart represents the analysis of mean compressive strength of steel fiber reinforced bacterial concrete and bacterial concrete. Steel fiber reinforced concrete shows better accuracy compared to bacterial concrete. Mean compressive strength(N/mm^2)+/- 1 SD, X axis represents steel fiber reinforced concrete and bacterial concrete groups, Y axis represents mean compressive strength(N/mm^2).