Study on Strength and Self-Healing Behaviour of Bio-Concrete

Shashank B S[1]* Basavarj Dhannur[2] Dr. H N Ravishankar[3] Dr Nagaraj P S[4]
1.Assistant professor Dept of Civil Engineering R V college of EngineeringBengaluru Karnataka India
2.Student Dept of Civil Engineering R V college of Engineering Bengaluru Karnataka India
3.Associate Professor Dept of Bio Technology R V college of Engineering Bengaluru Karnataka India
4.Assosiate professor Dept of Civil Engineering UVCE Bengaluru Karnataka India

Abstract
Micro cracks are very commonly observed in concrete structures. Due to increased permeability through these micro cracks, durability of concrete structures reduces by the entry of chemical through these micro pores particularly in moist environments. In the field, crack repair is labour intensive. It is more advisable to restrict the early age small cracks the moment they appear instead of repairing after large cracks formed. In order to increase the durability of concrete against these commonly observed pores in concrete structures, autogenous pore refinement method can be adopted so that monitoring of the structure against these micro pores can be avoided. By using the principle of Biomineralization, Bacteria forms the Calcium precipitations which is usually called microbial induced calcite precipitation (MIC) .In the present work, the bacteria which will grow in the high alkaline media is chosen since concrete is highly alkaline material and cultured in the controlled medium to get the desired concentration of cells. In the present work, Un-identified and Bacillus sphericus bacterial broth is used for the study. It is observed that these bacteria when mixed with concrete at the concentration of 10^6 cells per ml, the compressive strength is increased by 36.36 % and 13.63 % and for 10^7 concentrations of cells, the un-identified bacteria show the increase of compressive strength as 29.56 %. Modulus of elasticity of concrete is increased by 23.78 % and 31 % for both bacteria at the concentration of 10^6 cells per ml of water and Split tensile strength is increased by 23.5 % and 28.5 % for concentration 10^6 and 107 cells of Bacillus sphericus. SEM and EDAX analysis reveals the deposition of calcium carbonate
Keywords: Self-healing, bio mineralization, strength

1.0 INTRODUCTION
Concrete is most widely used structural material because of its strength and durability. However, with low tensile strength, it is more vulnerable to cracks. Cracks will occur because of temperature stresses developed in concrete, plastic shrinkage, dry shrinkage, settlement, and corrosion environment [1] and there are different types of cracks such as structural, non-structural cracks, surface cracks, shallow and deep cracks, active and dormant cracks, flexural cracks, shear cracks torsion cracks, diagonal cracks, and Horizontal cracks. These cracks will become bigger under sustainable loading conditions and due to contraction and expansion of concrete under differential temperature [2].

1.1 About calcifying bacteria
Calcifying bacteria are obtained from the different sources like soil, water, ocean, caves, and concrete itself. Calcifying bacteria will produce an enzyme called urease which converts the urea into ammonia and carbon dioxide. The following reactions obtained are

$$CO(NH_2)_2 \rightarrow CO_2 + NH_4$$

The carbon dioxide obtained from urea will react with the calcium hydroxide of concrete as follows

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + H_2O\uparrow$$

1.2 Types of bacteria
1. Bacillus sphericus
2. Un identified bacteria

All these bacteria are best compatible with the concrete conditions and which are non-pathogenic in nature. These bacteria are isolated from soil and cultured in the laboratory at the minimum cost. The Un-identified bacteria is isolated and cultured in the Biotechnology department laboratory(yet to be identified), and it will survive in the pH of 13.

1.3 Objective of work
The main objective is to study the strength enhancement of M20 grade of concrete and comparison of strength with the controlled specimens strength and crack healing capacity using different concentration of cells of bacteria such as Bacillus sphericus, and un identified bacteria. and Concentration of cells used are 10^6, 10^7, cells per ml

1.4 PROPERTIES OF MATERIALS

1.4.1 Bacterial strain and nutrients

Bacillus sphericus brought from Gene Bank, CSIR-Institute of Microbial Technology, Chandigarh and Un-identified bacteria was developed in the Bio Technology Department.

Figure 1 Shows solution of calcium chloride and urea along with filtering unit.

Figure. 1 Shows solution of calcium chloride and urea along with filtering unit.

1.4.2 Cement

For present work, grade of cement considered is 53 grade and type of cement is OPC. Tests conducted and their result are shown in the Table 1.

Table 1 showing the tests results of cement

Sl.No.	Necessary tests of Cement	Results of tests	IS Code specifications
01	Fineness of Cement, %	2 %	< 10 %
02	Initial Setting Time, min	50 min	> 30 min
03	Final Setting Time of cement, min	420 min	< 625 min
04	Normal consistency, %	35%	–
05	Specific gravity of cement	3.10	–

1.5 Aggregate

Fine and coarse aggregates confirming to zone II of IS:383-1970 obtained from nearest source and basic tests were done in the laboratory. Basics tests results are shown in the table 2.

Table 2 Showing the physical properties of fine aggregate

Sl. No	Test on aggregate	Results obtained Fine aggregate	Results obtained Coarse aggregate
1	Specific gravity	2.55	2.72
2	Fineness modulus, %	2.85	2.85
3	Water absorption, %	1	%

2. EXPERIMENTAL INVESTIGATION

2.1 Culturing of bacteria

Culturing of pure colony of bacteria was done in the laboratory while restricting the growth of other bacteria in the media and media was prepared from different chemical compositions.

2.2 Inoculation of bacteria

Once the media was transferred into Petridis plates and tubes, media was become solid because agar content. Bacteria was inoculated with the help of inoculating needle usually called nichrome and which is made of nickel and chromium, Figure. 2 and 3 shows Media for Bacillus sphericus and Un-identified bacteria and the bacterial growth respectively.

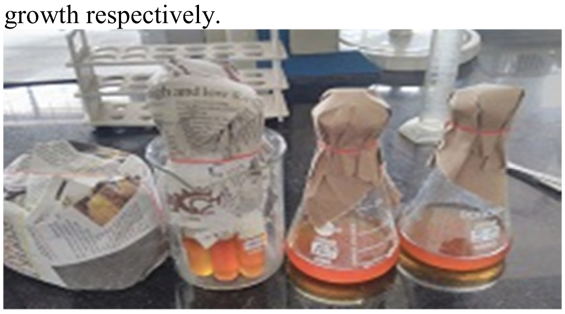


Fig. 2 Media of Bacillus sphericus and Un-identified bacteria

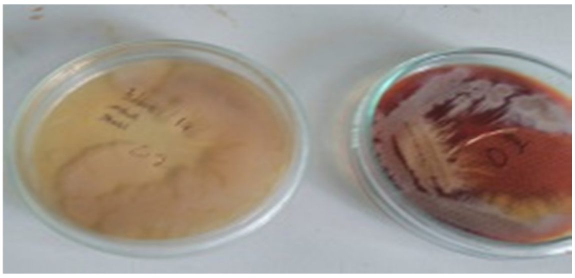


Fig. 3 Shows the bacterial growth

2.3 Preparation of broth

Preparation of broth involved the same nutrients except agar and broth will be in the liquid form because of not adding the agar. Figure 4 and 5 Shows the Broth before inoculation of bacteria and the growth of bacteria after inoculation of bacteria respectively.

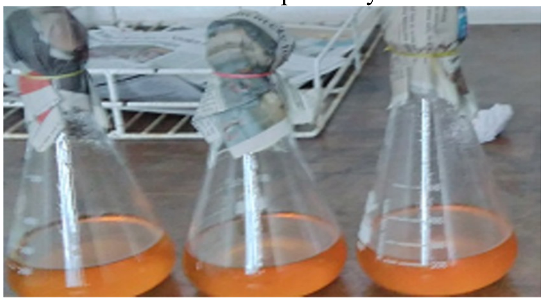


Fig. 4 Shows the Broth before inoculation of bacteria Fig. 5 Shows the growth of bacteria after inoculation of bacteria

2.4 Measurement of bacterial cells in broth

There are two ways to count the number of cells per ml solution

1. Hemo Cytometer
2. Serial Dilution

2.5 Mix Design

Mix design uses codes like IS 456-2000 and IS 10262-2009 and with using these codes mix design of M20 was done to find the proportion of coarse aggregate, fine aggregate, and cement. Obtained proportions are shown in the Table 3.

Table 3. Details of Mix design

Sl.No	Grade of concrete	Water, kgs	Cement, kgs	Fine aggregates, kgs	Coarse aggregate, kgs
01	M20	197	394	750	1037

3. RESULTS AND DISCUSSIONS

Results and comparison of various tests carried out on the specimens will be discussed

3.1 Slump test

Slump test was conducted on the fresh concrete of different grades like M20 values obtained from test are listed in the table 4.

Table 4. Slump values of different of concrete mixes

Sl.No.	Concrete grade	Value of slump, mm
01	M20	100
02	M20, 10^6 cells	96
03	M20, 10^7 cells	94

For RCC work, IS 456-2000 has specified the slump value of 90 - 100 mm and values got from the tests are within the limit and broth added while mixing was not affected the workability of mixes.

3.2 Compressive strength test

The compressive strength of different concentration of bacteria is compared with controlled specimens for 28 days and 56 days

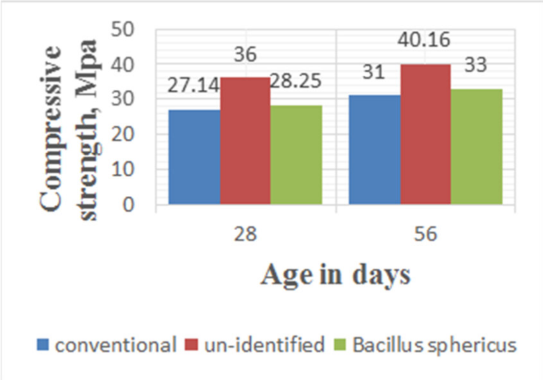


Fig.6 Compressive strength at 10^6 cells

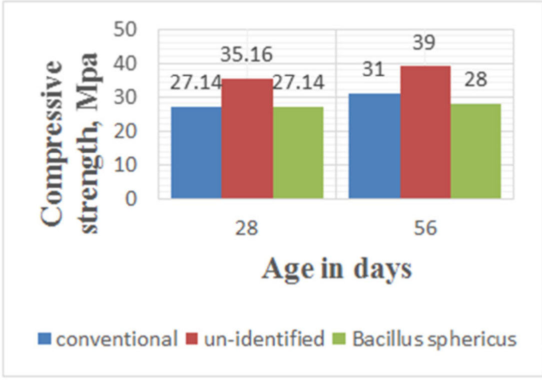


Fig.7 Compressive strength at 10^7 cells

Fig 6 shows the compressive strength at different days for M20 grade of concrete mix. The compressive strength of un-identified bacteria is increased by 32.6 % and 29.52 % for the concentration of 10^6 at 28 days and 56 days and there is increment of 4 % and 6.5 % of strength for Bacillus sphericus at 28 and 56 days.

From figure 7 shows the compressive strength at 10^7 cells per ml of water for 28 and 56 days and un-identified bacteria has gain strength by 29.55 % and 25.81 % at 28 and 56 days but there is no increase in the strength for bacillus sphericus at 10^7 concentrations.

3.3 Split tensile strength

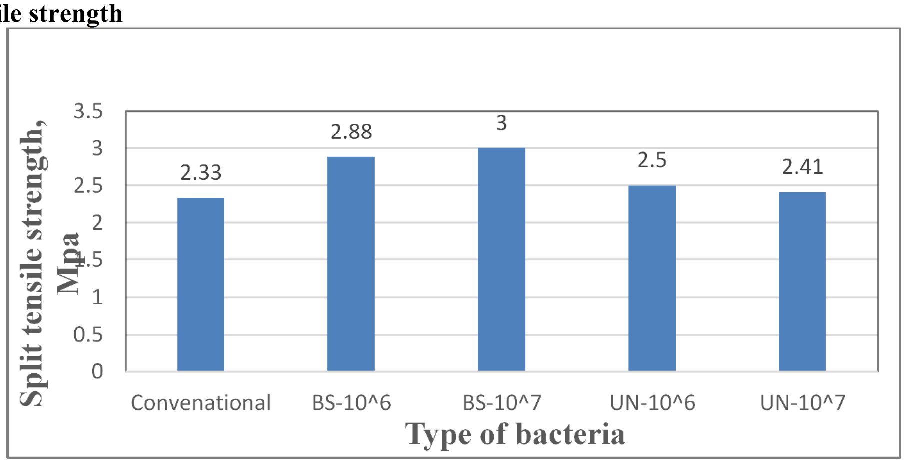


Fig. 8 Split tensile strength of different concrete mix at 28 days

Figure 8 represent test results got from different types of bacteria and bacterial concentration when added to concrete mix shows that there is no considerable increment in the tensile strength

3.4 Modulus of elasticity

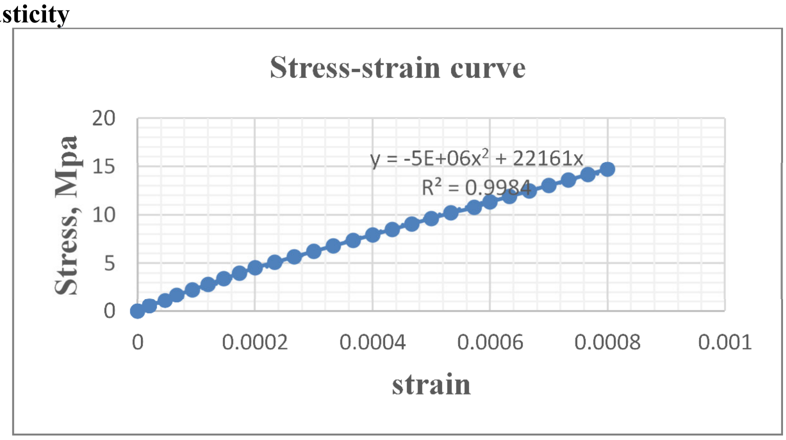
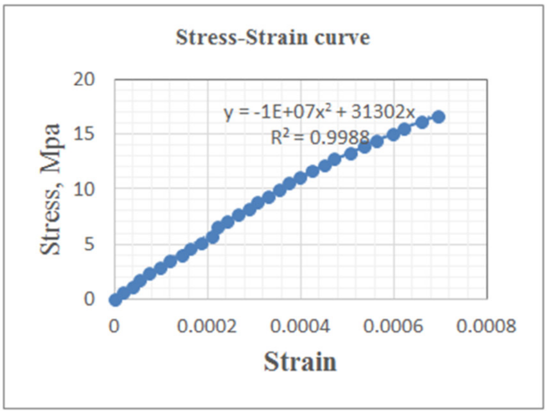


Fig. 9 Modulus of Elasticity of M20 grade of concrete mix



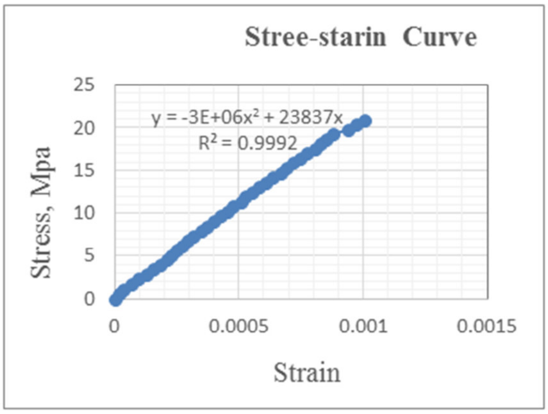
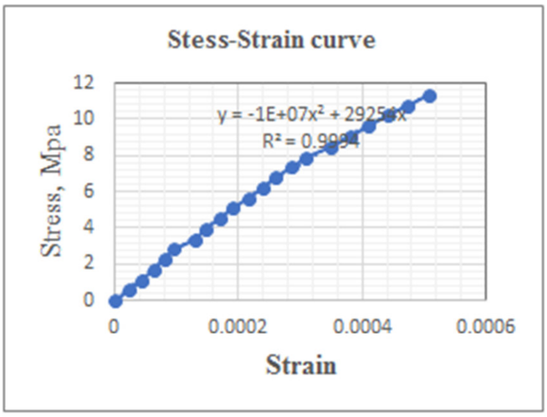


Fig. 10 Stress-Strain curve for Bacillus sphericus at 106 Fig11 Stress-Strain curve for Bacillus sphericus at 107



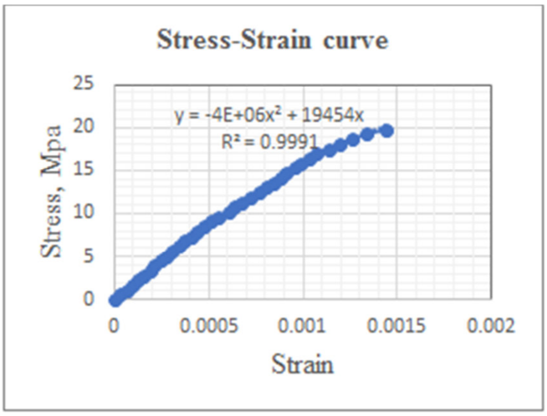


Fig. 12 Stress-Strain of un-identified bacteria for concentration of 10^6
Fig. 13 Stress-Strain of un-identified bacteria for concentration of 10^7

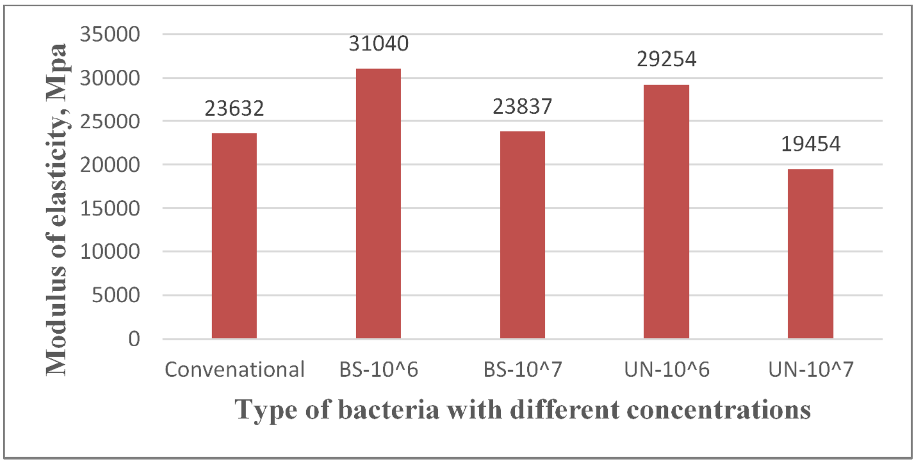


Fig. 14 Modulus of elasticity of M20 grade of concrete at different concentrations

From figure 9,10,11,12,and 13 Stress-Strain curve for different bacteria with different concentrations of cell and the modulus of elasticity for the same calculated and presented in figure 14

Figure 14 reveals the modulus of elasticity of cylindrical concrete specimens with and without bacteria. It is observed that modulus of elasticity at the concentration of 10^6 has been increased to 31.34 % and 23.78 % for BS and UN. For 10^7 concentrations, Bacillus sphericus shows the same elasticity as that of conventional concrete mix but there is decrease of modulus of elasticity at 10^7 concentrations for Un-identified bacteria.

3.5 Flexural strength

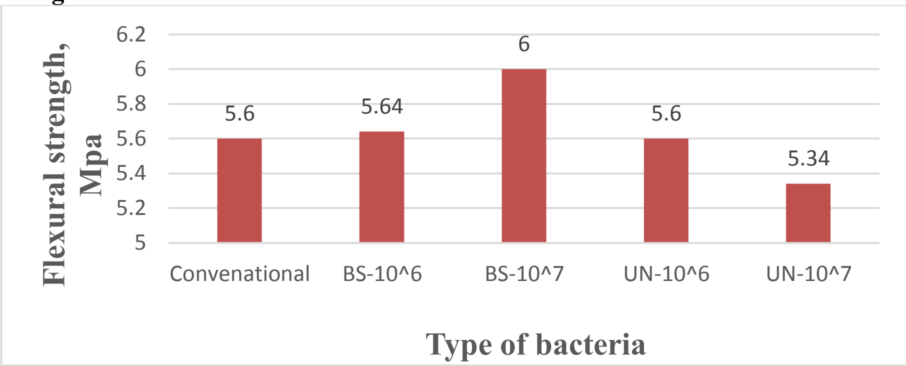


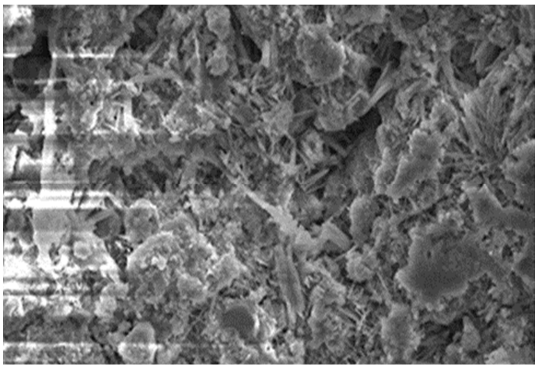
Fig. 15 Flexural strength for different concrete mix at 28 days

Figure 15 reveals the flexural strength of M20 grade of concrete mix at 28 days and the strength of Bacillus sphericus is more than Un-identified bacteria for the concentration of 10^7 cells per ml of water. The strength of un-identified bacteria is decreased compared to conventional concrete mix at the concentration of 10^7 concentrations.

4.0 Analysis of concrete microstructure by SEM and EDAX

In order to know the microstructure and elements of concrete mix, SEM and EDAX tests were conducted on all the samples of specimens and results of these are discussed below.

4.1Microstructure of controlled mix



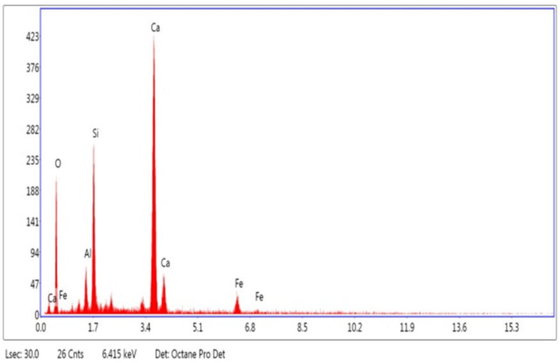
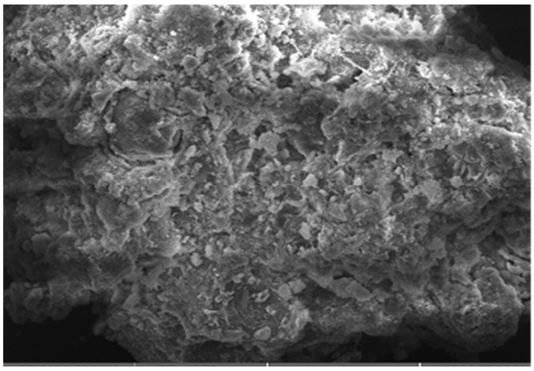


Fig. 16 SEM analysis of normal concrete mix Fig. 17 EDAX analysis of normal concrete mix

Figure 16 and 17 Reveals presence of large amount of C-S-H gel and ettringite in the normal mix.

4.1.1 Results of unidentified bacteria



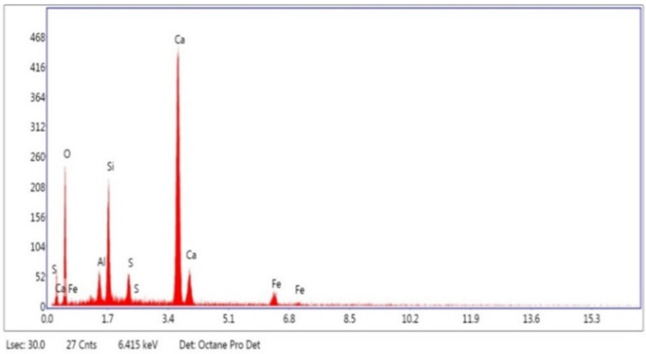
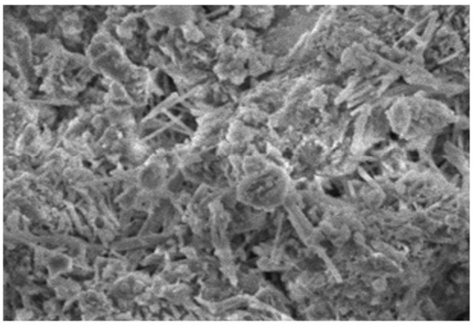


Fig. 18 SEM analysis of M20-10^6 cells Fig. 19 EDAX analysis of M20-10^6 cells

From figure 18, we can observe the gel which is Calcium Silicate Hydrate and rod like structures called ettringite. Figure 19 tells about different contents of sample of M20-10^6 and the main elements which contributes to strength are calcium and silicate. The ratio of Calcium to silicate is 3.68 which shows high strength.



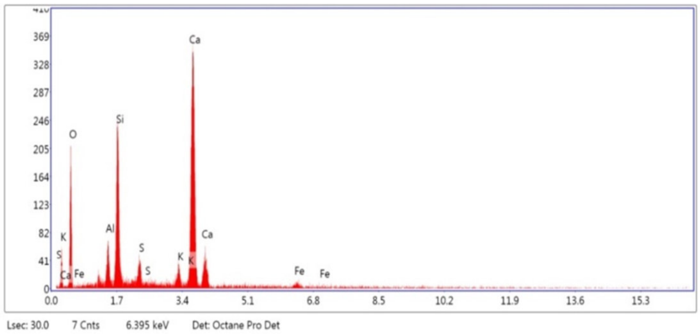
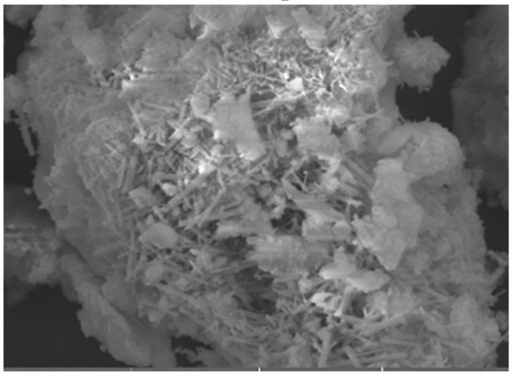


Fig. 20 SEM analysis of M20-10^7 cells Fig. 21 EDAX analysis of M20- UN-10^7 cells

Figure 20 shows the distribution of ettringite, C-S-H gel and $CaCO_3$. Figure 21 describes the compositions of concrete mix obtain from the EDAX analysis and Calcium to Silicate ratio is 2.60.

4.1.2 Results of bacillus sphericus



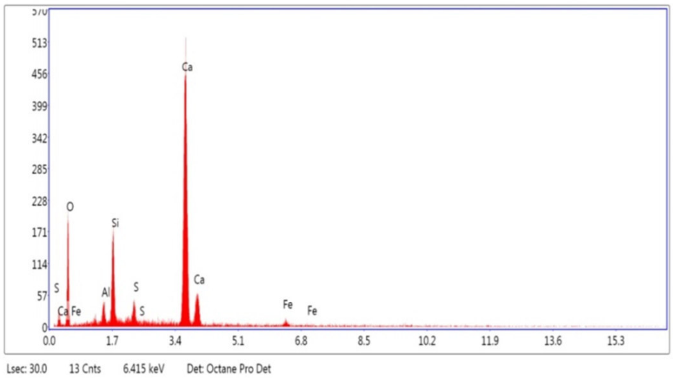
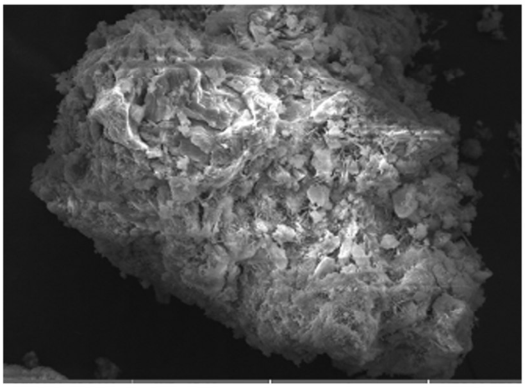


Fig. 22 SEM analysis of M20-10^6 cells Fig. 23 EDAX analysis of M20-10^6 cells

From figure 22, we can notice the presence of calcium deposition, C-S-H gel and the distribution of ettringite in the transition zone of concrete. Figure 23 is the results of M20-BS-10^6 sample obtained from the EDAX analysis which shows the Calcium to Silicate ratio as 4.85.



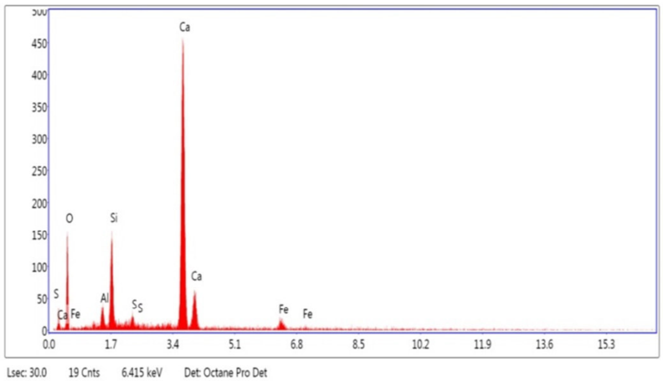


Fig. 24 SEM analysis of M20-10^7 cells Fig. 25 EDAX analysis of M20-10^7 cells

From fig 24, presence of large amount of C-S-H gel and Calcium deposition can be seen. Fig 25 and is results of M20-BS-10^7 sample got from the EDAX analysis and Calcium to Silicate ratio obtained is 5.4. Cao content obtained from the above table is 89.44 % and which is higher than OPC (66-70 %)

5. CONCLUSIONS

Based on the experimental investigations done on the controlled specimens, Un-identified bacteria, and Bacillus sphericus concrete mix, following conclusions drawn are listed below.

- By using Un-identified Bacteria the percentage increase in compressive strength for 10^7 concentrations of cells is 29.55 %, 25.58 % for M20 grade of concrete and 7.05%, 22.54% for M25 grade of concrete at 28 and 56 days and for Bacillus sphericus for 10^6 concentrations of cells, the compressive strength is increased by 4.08 %, 6.45 % for M20 grade of concrete mix and 8 %, 13.63 % for M25 grade of concrete at 28 and 56 days.
- By using Un-identified Bacteria the percentage increment in split tensile strength for 10^6 and 10^7

concentrations of cells is 7.29 %, 3.43 for M20 grade of concrete and 3.265 %, 1.632 % for M25 grade of concrete at 28 days.

- By using Un-identified Bacteria the percentage increase of modulus of elasticity for concentration of 10^6 is 23.78 %.
- By using Bacillus sphericus the improment of modulus of elasticity is occurred at 10^6 concentrations of cells by 31%.
- By using Bacillus sphericus the percentage increase of flexural strength for 10^6 and 10^7 concentrations of cells is 4 %, 7.14 % for M20 grade of concrete
- There is no appreciable increase in the flexural strength but achieved the target strength for both concentrations.
- Healing of cracks by injection of different concentrations of cells could not give the proper results.
- SEM and EDAX analysis are basis for the increment of strength for different concentrations.

6. REFERENCES

[1] Varenyam. A., Abhijit. M., and Sudhakara, R., "Microbial Concrete: Way to Enhance the Durability of Building Structures", *Journal of Materials in Civil Engineering Journal of materials in Civil Engineering*, Vol.23(6), 2011, 730-734.

[2] Virginie Wiktor, Henk M. Jonkers., "Quantification of crack-healing in novel bacteria based Cement and concrete composite 33(2011) 763-770.

[3] Harn, W., and Gupta.S., "Encapsulation Technology and Techniques in Self-Healing Concrete" *ASCE publications* No. ISSN0899-1561.

[4] Navneet, C., Rafat Siddique., and Anita, R., "Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of fly ash concrete", *Construction and Building Materials*, Vol.28,2012, pp. 351–356.

[5] Kim Van, Nele De Belie., "Acoustic emission analysis for quantification of autonomous Crack healing in concrete" *Construction and Building material*, Vol.28, 2012, pp. 333-341.

[6] J.Y. Wang a,b, H. Soens c, W. Verstraete b, N. De Belie, "Self-healing concrete by use of microencapsulated bacterial spores", *cement and concrete research* , Vol.56, 2014, pp. 139-152.

[7] James, G., Marwa, Hassan, M., Tyson, R., Michele, B., "Dicyclopentadiene and Sodium Silicate Microencapsulation for Self-Healing of Concrete", *Journal of materials In Civil Engineering*, Vol.26, 2014, pp.886-889.

[8] Jing, X., Wu Yao, and Zhengwu, J., "Non-Ureolytic Bacterial Carbonate Precipitation as a Surface Treatment Strategy on Cementitious Materials", *Journal of Materials in Civil Engineering, Vol. 26, 2014,* 983-991.

[9] Kostera, S. A. L., Morsb, R. M., Nugterena, H., Jonkersb, M., and Nugterena, G. M. H., "Geopolymer coating of bacteria-containing granules for use inself-healing concrete", *The 7th World Congress on Particle Technology (WCPT7), Procedia Engineering, Vol.* 102, 2015, pp. 475 – 484.

[10] Filipe Bravo da, S., Nele, D. B., Nico. B., Willy V., "Production of non-axenic ureolytic spores for self-healing concrete applications" *Construction and Building Materials, Vol.* 93, 2015, pp. 1034–1041.

[11] Yusuf Cag˘atay Ers, Filipe Bravo Da Silva, Nico Boon, "Screening of bacteria and concrete compatible protection materials", *Construction and Building Materials*, Vol.88, 2015, pp. 196-203.

[12] Krishnapriya, S., Venkatesh B., Prince, A., "Isolation and identification of bacteria to improve the strength of concrete", *Microbiological Research, Vol.*174 2015, pp 48–55.

[13] Mian Luo and Chun Xiang Qian., "Factors affecting crack repairing capacity of bacteri based self-healing concrete" *Construction and Building Material, Vol.* 87, 2015, pp. 1-7.

[14] Huaicheng Chen, Chunxiang Qian, Haoliang , "Self-healing cementitious materials based on bacteria and nutrients immobilized respectively", *Construction and Building Material, Vol.* 126, 2016, pp. 297-303.

[15] Wasim Khaliq, Muhammad Basit Ehsan, "Crack healing in concrete using various bio- influenced self-healing techniques", *Construction and Building Materials,* Vol.102, 2016, pp.349-357.

[16] Arezou Shafagh.at, Nasiru Zakari Muhammad., "Tests and Methods of evaluation of self -Healing efficiency of concrete" *Construction and Building Materials*, Vol.112, 2015, pp. 11-23.

[17] Mian.L., and Chun, X. Q., "Performance of Two Bacteria-Based Additives Used for Self-Healing Concrete", *J. Mater. Civ. Eng,* Vol. 28, 2016, pp. 1-6.

[18] Poonam., I. Modi, Chirag N. Patel., "Repair and Rehabilitation of concrete structures" *PHI Learning Private Limited Delhi*-110092@2016.

[19] T.S. Qureshi, A. Kanellopoulos, A.Tabbaa, "Encapsulation of expansive powder mineral within a concentric glass capsule system for self-healing concrete", *Construction and Building Material*, Vol. 121, 2016, pp. 629-643.

[20] Jianyun, W., Jan, D., Veerle, C., Sandra Van Vlierberghe., "X-ray computed tomography proof of bacterial-based self-healing in concrete", *Cement & Concrete Composites, Vol.* 53, 2014, pp- 289–304.
[21] Biqin, D., Yanshuai, W., Guohao, F., Ningxu, H., "Smart releasing behavior of a chemical self-healing microcapsule in the stimulated concrete pore solution", *Cement & Concrete Composites.* Vol. 56, 2015, pp. 46–50.
[22] Yu Zhu1, Zhao, C. Zhang., Yan, y., Xue, M. G.,and Ying, Z. Y., "Analysis of Crack Microstructure, Self-Healing Products, and Degree of Self-Healing in Engineered Cementitious Composites", *J. Mater. Civ. Eng., Vol. 28, 2016,* pp. 1-10.
[23] Jing, X., Yao, W., "Multiscale mechanical quantification of self-healing concrete incorporating non-ureolytic bacteria-based healing agent", *Cement and Concrete Research, Vol.* 64, 2014 1–10.
[24] Belie, D.N., "Stony materials versus Microorganisms: a love – hate relationship", *Materials and Structures* (2010) 43:1191-1202 DOI 10.1617/s 11527-010-9654-0.
[25] Sarda, D., Lele, S.S., Sarode, D.D., "Biocalification by Bacillus pasteurii: a novel application", *Jind microbiail biotechnol* 2009, 36,1111-1115.
[26] Jonkers, H.," Self-Healing Concrete: A Biological Approach", *Springer Series in Materials Science*, 2008, Volume 100, 195-204.
[27] Ghosh, P., Mandal, S., Chattopadhyay, B.D., and S. Pal, "Use of microorganism to improve the strength of cement mortar", *Cement and Concrete Research* 35 (2005) 1980 – 1983.
[28] Johnna, K., Galinat, Shannon, S., Sookie, S., "Microbiological precipitation of CaCO3," *Soil Biology and Biochemistry Volume* 31, Issue 11, October 1999, Pages 1563–1571.
[29] Whiffina, Victoria, S., Leon, A., Paassenb, V., Marien, P., Harkesa, "Microbial Carbonate Precipitation as a Soil Improvement Technique", *Geomicrobiology Journal Volume* 24, Issue 5, 2007 pages 417-423.
[30] Jonkers & Erik, S., Henk, M.,"A two component bacteria-based self-healing concrete", *Concrete Repair, Rehabilitation and Retrofitting II – Alexander et al (eds) 2009 Taylor & Francis Group, London*, ISBN 978-0-415-46850-3.
[31] Rafat S., Anita, R., Navneet, C., "Calcium carbonate precipitation by different bacterial Strains", *African Journal of Biotechnology* Vol. 10(42), pp. 8359-8372, 8 August, 2011.
[32] Sasikala, Ch., Jyothi, K.S., Seshagiri Rao, , Srinivasa, R.V., "Studies on Permeability of Self-Healing Built-In Bacteria Concrete", *International Journal of Recent Technology and Engineering* (IJRTE) ISSN: 2277-3878, Volume-1, Issue-6, January 2013.
[33] Varenyam Achal, Abhijit Mukherjee, Shweta Goyal, and M Sudhakara reddy, "Corrosion prevention of reinforced concrete with microbial calcite precipitation", *materials journal,* vol 109, 2012, issue 2, pg 157-164.
[34] V. Ramakrishnan, R. K. Panchalan, and S. S. Bang, "Bacterial Concrete-A Concrete for the Future", vol 225 Pages: 37-54, 2005.
[35] QingFeng, P., & WANG, R., ChunXiang, Q.," Cementation of sand grains based on carbonate precipitation induced by microorganism", *Technological Sciences*, August 2010 Vol.53 No.8: 2198–2206.
[36] Crack Repairing in Concrete by Bacterial Calcite Precipitation", *M Tech Project Report, Civil, DSCE* 2010-2012.
[37] Siddique,.R., Anita R., Gurdeep, K., "Micro-structural and metal leachate analysis of concrete made with fungal treated waste foundry sand", *Construction and Building Materials* 38 (2013) 94–100.
[38] Okwadha, Jin Li, George, D.O., "Optimum conditions for microbial carbonate precipitation", *Chemosphere* 81 (2010) 1143–1148.
[39] IS 456: 2000, code of practice for plain and reinforced concrete.
[40] IS 12269: 1987, Specification for 53 Grade Ordinary Portland Cement.
[41] IS 10262: 2009, Concrete mix proportioning.
[42] IS 383: 1970, Specification for coarse and fine aggregates from natural sources for concrete.