SELF HEALING CONCRETE BY BACTERIAL AND CHEMICAL ADMIXTURES.

Asad Shaikh[1], Roshni John[2]

[1]P. G student, Saraswati College of Engineering, Kharghar, Maharashtra, India.
Shaikhasad1992@gmail.com
[2] Professor, Saraswati College of Engineering, Kharghar, Maharashtra, India.
roshnijohn@gmail.com

Abstract:

The objective of the present investigation is to compare the best effect of self-healing in concrete. One such thought has led to development of very special concrete known as Bacterial concrete where bacteria of bacillus subtilis (JC3) is used and other known as Super absrobant polymer concrete. The variation in compressive strength with respect to the different dosage was studied. From Scanning Electronic Method (SEM) it was found that pores were partially filled up by material growth due to addition of bacteria and Super absrobant polymer (SAP). Energy-Dispersive X-ray Spectrum test (EDM) gave us the percentage of calcite present in concrete sample which needed to repair the cracks. Durability study was carried out to determine the resistance offer by the bacteria and SAP mix from aggressive environment. Study reveal that bacterial concrete was more durable. It was also observed there was improvement in split tensile strength for cylinder with addition of bacteria.

Keywords: Bacterial concrete, bacillus subtilis, Super absorbant polymer, self -healing, self-sealing, Autogenous and, calcite crystallization.

I. INTRODUCTION

Concrete is the most commonly used building material, but it has few limitation. Cracks in concrete occur due to various mechanisms such as shrinkage, and tensile forces. Cracking of the concrete surface may enhance the deterioration of embedded steel bars. Self-healing concrete in general capable of solving these problems commonly associated with concrete. There are material in realm of self-healing concrete in development, now can solve many flaws related with concrete. This material are bacteria and super absorbant polymer (SAP).

Bacteria based self-healing concrete consist of mix with bacteria (Bacillus subtilis) induced into the concrete and calcium lactate food to support those bacteria when they become active. The bacteria feeding on provided food source, constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation. As bacteria feeds oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on cracked surface, thereby sealing it up.

Super abosorbant polymer (SAP) based self-healing concrete consist of mix with SAP introduced into the concrete. SAP are crossed-linked hydrogel networks consisting of water-soluble polymer. SAP (also called slush powder) are polymer that can absorb and retain extremely large amounts of a liquid relative to their own mass. They are highly pH sensitive. When added with fresh concrete due to high ion presence in water they are restrain from swelling thus remain in concrete unaffected. Note when concrete is prepared the water content in the matrix has very high ionic content as well as the ph value is around 12 which will not allow SAP to swell while preparing concrete. In future when cracks are occur in concrete SAP comes in contact with water which has low ionic strength they will start to swell and absorb all the water hence sealing the crack inside the concrete.

II. Literature survey:

S. Reddy et al (2010) carried out experimental investigation to obtain the performance of the concrete by Bacillus subtilis. M20 grade Concrete cubes with and without bacteria were tested. It was observed that compressive strength for cubes with addition of bacteria for a cell concentration of 10^5 cells/ml was increased upto 13.93% at 28 days, also there was an improvement in split tensile strength by 12.60% at 28 days for the cylinder. From durability studies percentage strength loss with 5% H_2SO_4 revealed that bacterial concrete was more durable. Percentage compressive strength loss in normal concrete after 105days was 14.66 as compared to bacterial concrete where percentage compressive strength loss was 8.64. From “Acid Durability Factor” calculation conventional concrete was 85.34% durable as compare to bacterial concrete which was 91.36% for 105 days studies. Bacillus subtilis was used to produce calcite as needed to repair crack and to survive in the concrete.

Srinivasa Reddy et al. (2012) they studied microbiologically induced calcite by bacteria subtilis which converted insoulable limestone which help to seal the crack. Addition of bacteria increase compressive strength of concrete by 23% at 28 days for ordinary, standard and high grades of concrete when compared to controlled concrete with addition of bacteria for a cell concentration of 10^5 cells/ml. Durability studies carried out in the investigation with 5% H_2SO_4 revealed that bacterial concrete is more durable than conventional concrete. Percentage compressive strength loss in normal concrete after 90days was 12.46, as compared to bacterial concrete where percentage compressive strength loss was 7.61 in immersion of H_2SO_4.

M. V. Rao et al. (2013) they studied Microbiological action done by bacillus subtilis to produce $CaCO_3$ precipitates. Improvement of compressive strength for cement mortar at cell concentration of 10^5 cells/ml for all ages. The study showed that 25% increase in 28 days compressive strength of cement mortar was achieved. The study also showed that for M20 grade of bacterial concrete 13.92% increase in 28 days compressive strength, and 12.60% improvement in 28 days split tensile test was achieved as compare to conventional concrete. The strength improvement is due to growth of filler material within the pores of the cement-sand matrix as shown by scanning electron microscopy (SEM). SEM also confirmed the role of microbiologically induced precipitation within the mortar matrix. More $CaCO_3$ precipitate higher is the healing effect.

Didier Snoeck et al. (2014) they studied Microfibre reinforced concrete is durable and provides reliable tensile ductility and crack controlling capabilities to prevent cracking failures. Super Absorbant Polymer (SAP) particles promote the self-healing ability by renewed internal curing upon crack formation and this lead to regain of mechanical properties. Optimum dosage of SAP was 1 % of cement weight.

Mignon et al. (2014) carried out an investigation to discuss addition of higher amount of Super Absorbant Polymer (SAP) result in a superior self-sealing effect. The addition of SAP of 0.5% of cement weight to cement mortar leads to significantly stronger sealing effect of cracks over period of 28 days compared to reference mortar without SAP. Water permeability test shown high sealing effect in SAP mortar when compare to mortar without SAP. Stalactites have been observed on samples in depth characterization showed the product forming around was CaCo3.

II. Materials:

Cement

Pozzolanic Portland cement of 53 grade is used in concrete. Cement used has been tested as per IS 4031-1988.

Crushed sand

Crushed sand having specific gravity of 2.70 and confirming to IS-383 II is used.

Course aggregate.

The maximum size of coarse aggregate should be 20 mm and minimum size should be 10 mm. The coarse aggregate with angular in shape and the rough surface texture is used.

Admixture

Sikament 610 UT (Sulfonated Nephthalien Formaldehyde Base) was used as a plasticizer.

Water

Locally available portable water confirming to standard specified in IS 456-2000 is used.

Super Absorbent Polymer.

A pH responsive super absorbent polymer used in chemical method. Water-absorbing polymers, which are classified as hydrogel when cross-linked, absorb aqueous solutions through hydrogen bonding with water molecules. A SAP's ability to absorb water is a factor of the ionic concentration of the aqueous solution. In deionized and distilled water, a SAP may absorb 300 times its weight (from 30 to 60 times its own volume) and can become up to 99.9% liquid, but when put into a 0.9% saline solution, the absorbency drops to maybe 50 times its weight. The presence of valence cations in the solution impedes the polymer's ability to bond with the water molecule.

Bacteria.

The bacteria of bacillus subtilis (JC3) were obtained from Agharkar Research Institute Pune.

Culture of Bacteria:

To prepare sub-colonies of the bacteria, the pure culture was isolated from the main sample and is maintained on nutrient agar plate. Agar plate is petri dish that contain a growth medium which is used to culture micro-organism. Whenever required a single colony of the culture is inoculated into nutrient bottle of 100ml conical flask and growth condition are maintained at 37 degree temperature.

Maintenance of Stock Culture:

Stock culture of bacillus subtilis were maintained on nutrient agar slants. The culture was streaked on agar slants with an inculating loop and slants were incubated at 37 degree Celsius. Growth slants culture were preserved under refrigerator until further use.

M25 grade of concrete mix design as per IS code 10262 (2009) given below in table no 1

Table 1: M25 grade of concrete mix design

Material	quantity	Avg. specific gravity	Water absorption %
Cement	405 kg	2.92	-
Crush sand	793 kg	2.70	4.48
10 mm aggregate	476 kg	2.83	1.59
20 mm aggregate	576 kg	2.85	1.37
Water	211	-	-
Admixture (sikament 610 ut)	4.05 kg	1.22	-

III. METHODOLOGY

Test on materials:

Compressive studies:
M25 concrete design mix was made as per I.S 10262: 2009.Cubes of size 150mm X 150mm X 150mm were casted with and without adding bacteria and super absorbant polymer. Dosage of 10^3, 10^5 & 10^7 cells/ml bacteria were added in 2nd mix design while 0.5%, 1.0% and 1.5% of Super Absorbant Polymer (SAP) were added with respect to cement weight in 3rd mix design. Cubes then tested for compressive strength at 3, 7, 28, 56, 90 days as per I.S 516:1959. The dosage at which high compressive test was achieved considered as optimum dosage.

Durability studies:
An experimental program was conducted on controlled mix and optimum dosage of bacterial and SAP concrete sample. Specimens were immersed in 5% solution of Sulphate attack (H_2SO_4). The specimen are arranged in the plastic tubs in such a way that the clearance around and above the specimen is not less than 30 mm. The solution has been changed for an interval of 15 days after taking the measurement. The response of the specimen to the solution was evaluated through changed in compressive strength. For determining resistance of concrete specimen to aggressive environment the durability factors are proposed by the philosophy of ASTM C 666_1997, as the basis. In present investigation "Acid Durability Factor" (ADF) is derived with respect to the strength.

Acid Durability Factor (ADF) = Sr. (N/M)

Where, M= number of days at which the exposure is to be terminated.
N= numbers of days at which durability factor is needed
Sr. = relative strength at N days (%)

Scanning Electron Microscopy Test (SEM):
The test were conducted on powder of the broken sample and the results were compared with normal concrete. The images obtained from the result shows the limestone forming inside the cube which is essential for binding material.

Energy-Dispersive X-ray Spectrum (EDM):
The test is conducted by performing chemical analysis on the sample powder. The test shows the presences of calcite inside the cube. The results obtained are expressed as percentage of atom number present in the sample and spectrum chart.

Split Tensile Test.
M25 concrete design mix was made as per I.S 10262: 2009. Cylinder of size 300mm x 150mm were casted using with and without bacteria and super absorbant polymer. Cylinder were tested for split tensile test at 14 days as per ASTM C496/C4956M

IV. RESULT
COMPRESSIVE STRENGTH
The compressive strength results for 3, 7, 28, 56, 90 days are in Mpa for controlled mix, Bacterial mix, and SAP mix is shown in table 2

Table 2: Compressive Strength Results

Concrete	3 days	7 days	28 days	56 days	90 days
Conventional Concrete	14.4	21.8	36.5	41.9	42.3
Bacteria 10^3 cells/ml	16.4	25.8	44.6	51.7	53.3
Bacteria 10^5 cells/ml	17.4	27.8	46.4	54.3	57.0
Bacteria 10^7 cells/ml	14.6	24.5	40.6	46.9	47.8
SAP 0.5% Polymer of cement weight	14.1	21.3	35.7	40.8	41.2
SAP 1.0% Polymer of cement weight	10.5	16.4	28.7	32.6	33.2
SAP 1.5% Polymer of cement weight	9.3	14.1	24.2	27.1	27.4

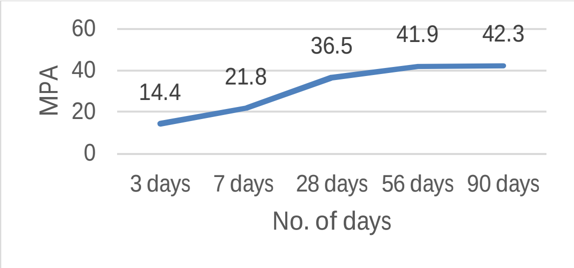

Figure 1: Compressive strength of Conventional Concrete

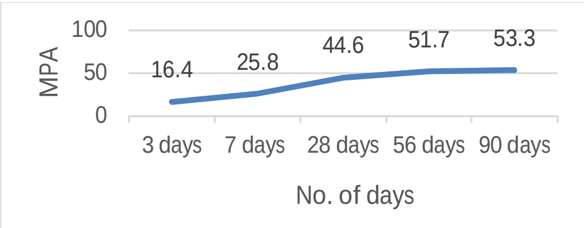

Figure 2: Compressive strength of Bacteria 10^3 cells/ml

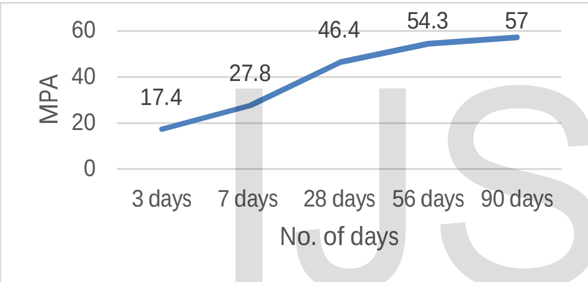

Figure 3: Compressive strength of Bacteria 10^5 cells/ml

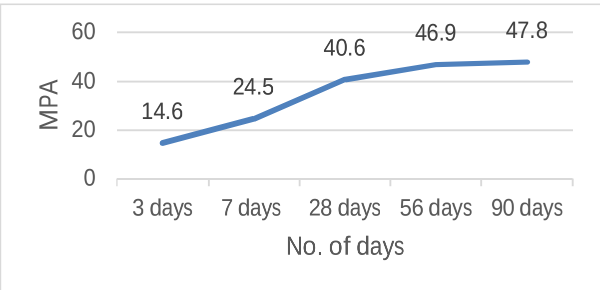

Figure 4: Compressive strength of Bacteria 10^7 cells/ml

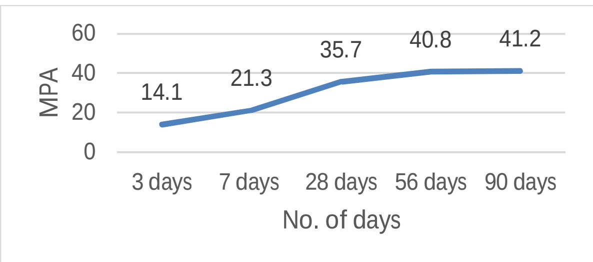

Figure 5: Compressive strength of SAP mix 0.5%

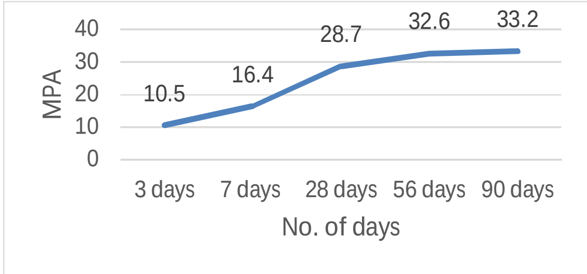

Figure 6: Compressive strength of SAP mix 1.0%

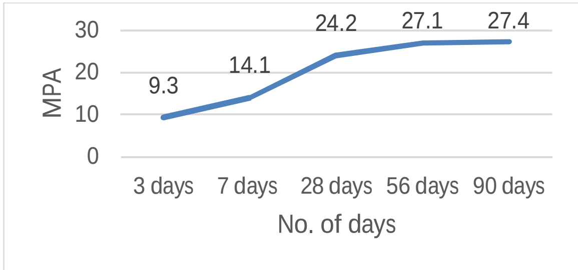

Figure 7: Compressive strength of SAP mix 1.5%

SPLIT TENSILE TEST

The tensile strength results for 14 days are in Mpa for controlled mix, Bacterial mix, and SAP mix is shown in table 3

Table 3: SPLIT TENSILE TEST

Type of Concrete	14 days	28 days
Conventional Concrete (N/mm2)	2.19	2.73
Bacteria 10^5 cells/ml (N/mm2)	2.48	3.56
SAP 0.5% Polymer of cement weight (N/mm2)	2.16	2.53

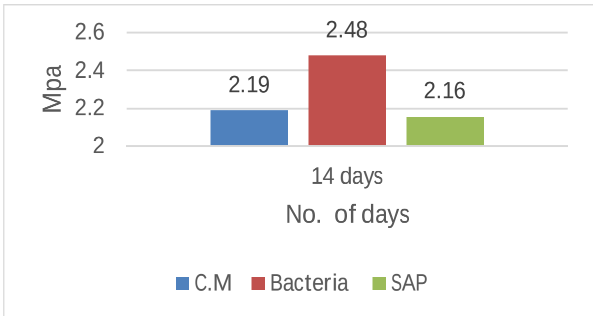

Figure 8: Tensile strength results for 14 days

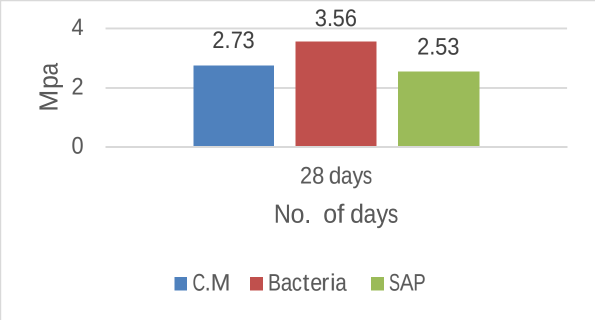

Figure 9: Tensile strength results for 28 days

DURABILITY TEST:

Specimens were immersed in 5% solution of Sulphate (H_2SO_4) is shown in tale 4

Table 4: Specimens immersed in 5% solution of H_2SO_4

Compressive strength of cube (N/mm^2)	28 days	56 days	90 days	120 days
Conventional Concrete				
Reference age at 28 days	36.5	36.5	36.5	36.5
At refined age	35.5	33.7	32	30.5
% loss	2.7	7.6	12.3	16.4
Bacterial concrete (10^5 cells/ml)				
Reference age at 28 days	46.4	46.4	46.4	46.4
At refined age	45.5	44	42.6	41.4
% loss	1.9	5.1	8.1	10.7
SAP concrete (0.5% Polymer of cement weight)				
Reference age at 28 days	35.7	35.7	35.7	35.7
At refined age	34.6	32.9	31.2	29.7
% loss	3.1	7.8	12.6	16.8

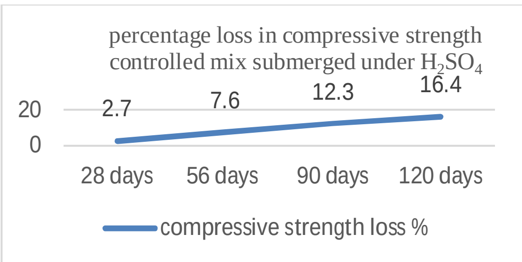

Figure 10: Percentage strength loss in controlled mix under H_2So_4

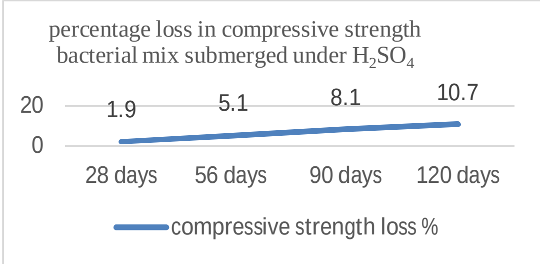

Figure 11: Percentage strength loss in bacterial mix under H_2So_4

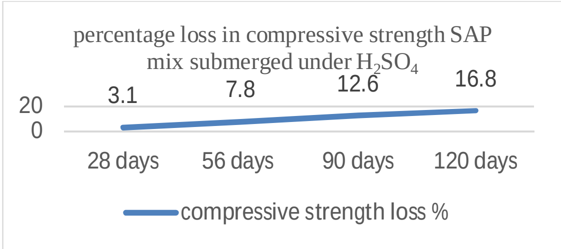

Figure 12: Percentage strength loss in SAP mix under H_2So_4

Acid durability factor (ADF) with sulphuric acid (H_2SO_4) is shown in tale 5

Table 5: Acid durability factor (ADF) with (H_2SO_4)

Period of immersion (days)	Relative strength (Sr.)	N	M	ADF
Controlled mix				
28	97.3	28	120	22.7
56	92.4	56	120	43.1
90	87.7	90	120	65.7
120	83.6	120	120	83.6
Bacterial concrete (10^5 cells/ml)				
28	98.1	28	120	22.8
56	94.9	56	120	44.2
90	91.9	90	120	68.9
120	89.3	120	120	89.3
SAP concrete (0.5% Polymer of cement weight)				
28	96.9	28	120	22.6
56	92.2	56	120	43.0
90	87.4	90	120	65.5
120	83.2	120	120	83.2

Scanning electron microscopy test (SEM):

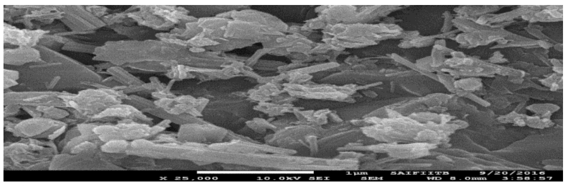

Figure 13: Magnified SEM Micrograph of controlled Concrete.

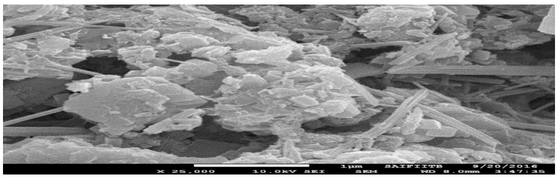

Figure 14: Magnified SEM Micrograph of bacterial Concrete.

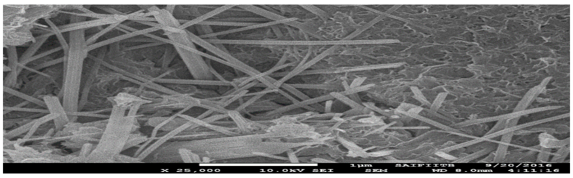

Figure 15: Magnified SEM Micrograph of SAP Concrete

Table 6: Percent of atom number present in sample By EDM

	Conventional Concrete	Bacterial Concrete	Super Absorbant Polymer Concrete
Element	Atomic %	Atomic %	Atomic %
$CaCO_3$	13.95	16.52	13.24
SiO_2	55.06	51.44	60.76
Albite	1.08	-	-
MgO	0.85	0.55	0.52
Al_2O_3	3.10	2.19	1.36
SiO_2	17.97	4.87	6.51
Wollastonite	5.97	11.61	16.22
Ti	0.23	0.12	-
FE	1.80	1.55	1.41
Total	100	100	100

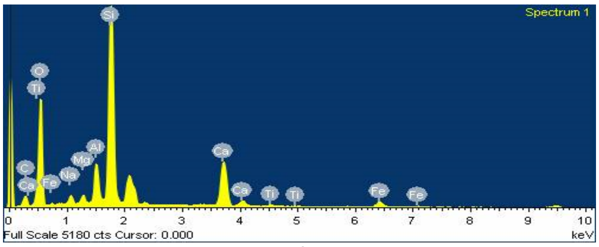

Figure 16: Spectrum Chart of Conventional Concrete

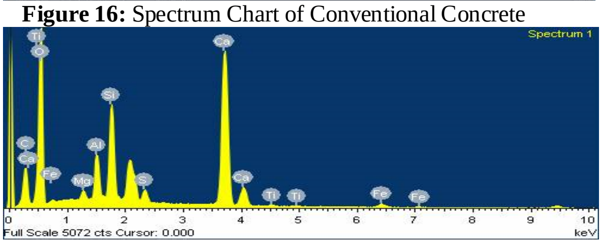

Figure 17: Spectrum Chart of bacterial Concrete

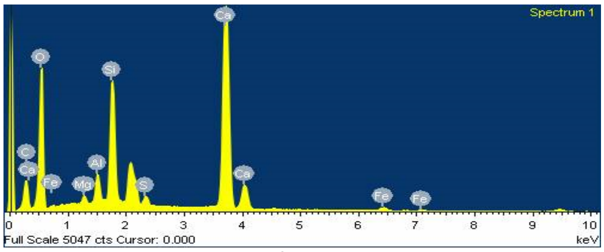

Figure 18: Spectrum Chart of SAP Concrete

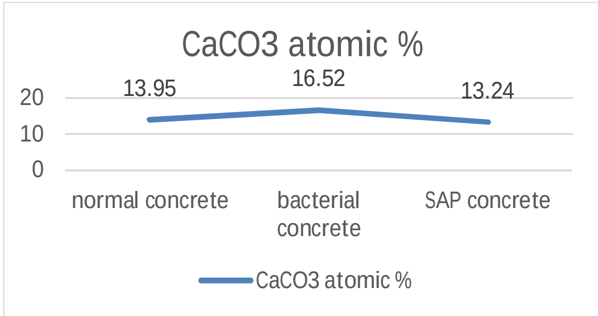

Figure 19: $CaCO_3$ atomic %

The amount of calcite present in conventional and SAP concrete is almost same however in spite of showing pH reactivity property by SAP, it still got swell up when added in concrete. Though the swelling was less but it still retain certain amount of water and affect the heat of hydration in small amount. Due to which the strength of conventional and SAP mix was different. Because of retaining of water there was always a future scope for heat of hydration to take place. It was De-swelling of SAP which produce calcite in SAP concrete. De-swelling of SAP can be occurred due to coming in contact with alkaline nature or sudden application of load. Again SEM and EDM test were conducted after a week on sample powder to have more detail regarding Calcite formation in SAP Concrete. This time test was conducted in place were there was less amount SAP available.

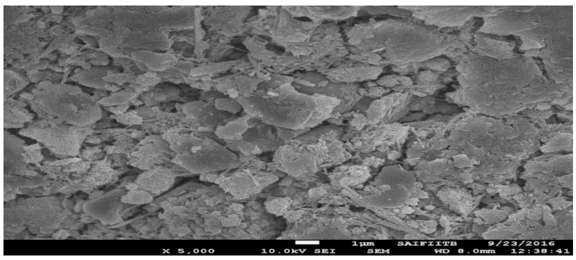

Figure 20: Magnified SEM Micrograph of controlled Concrete.

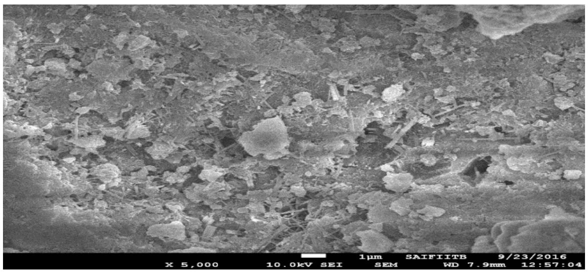

Figure 21: Magnified SEM Micrograph of bacterial Concrete.

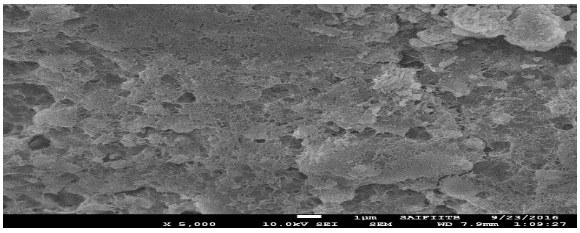

Figure 22: Magnified SEM Micrograph of SAP Concrete

Table 7: Percent of atom number present in sample By EDM

	Conventional Concrete	Bacterial Concrete	Super Absorbant Polymer Concrete
Element	Atomic %	Atomic %	Atomic %
$CaCO_3$	10.59	21.02	6.15
SiO_2	56.34	57.68	70.47
Albite	0.25	-	0.47
MgO	0.87	0.57	0.98
Al_2O_3	3.34	2.11	2.12
SiO_2	8.78	5.52	7.14
Wollastonite	16.56	11.90	10.95
Fe	0.347	0.56	1.14
Other element	2.93	0.64	0.57
Total	100	100	100

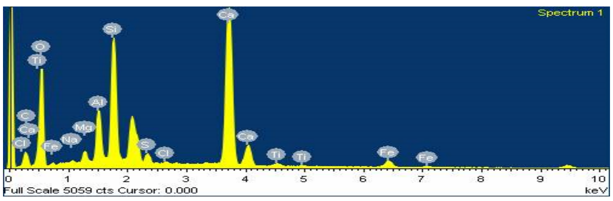

Figure 23: Spectrum Chart of Conventional Concrete

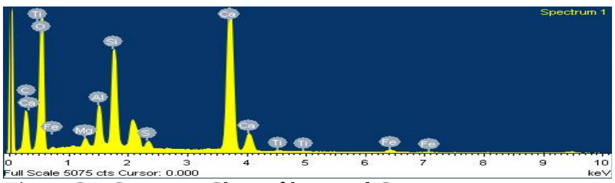

Figure 24: Spectrum Chart of bacterial Concrete

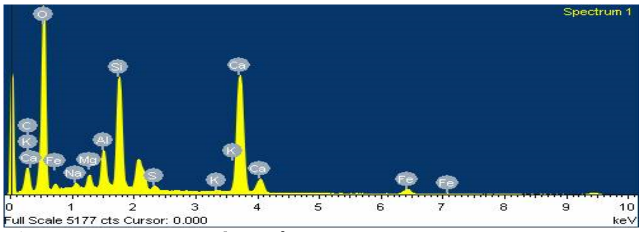

Figure 25: Spectrum Chart of SAP Concrete

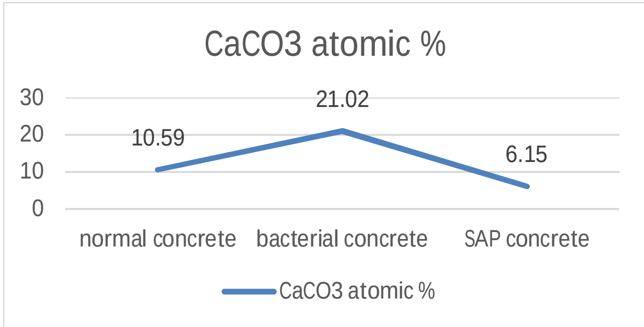

Figure 26: $CaCO_3$ atomic %

Now from SEM and EDM test we can conclude that due to less amount of SAP available the quantity of calcite was found to be low. It happens due to unavailability of water to trigger C-S-H reaction in future. For bacterial concrete it can be safely assumed that, the region where SEM and EDM test were conducted the presence of bacteria was found to be in high quantity and it is due to the micro biological process which result in formation of calcium carbonate that deposited in form of calcite.

CONCLUSION

The performance of Bacterial concrete and Super Absorbant Polymer concrete was investigated. These are the conclusion drawn from the analysis:

- Bacteria Bacillus Subtilis plays a significant role in increasing compressive strength of normal concrete by 21.33% for 28 days and 25.78% after 90 days.
- When the bacteria cells concentration was increased more than optimum level i.e. 10^5 cells/ml the reduction in strength start to occur.
- Addition of SAP beyond the dosage of 0.5% Polymer of cement weight will start to have a negative impact on concrete strength.
- From the durability studies the percentage strength loss with 5% H_2SO_4 revealed that Bacteria concrete has less strength losses than the SAP or Conventional concrete.
- Durability studies carried out in investigation through acid attack test with 5% H_2SO_4 revealed that bacterial concrete is more durable in term of "Acid Durability Factor".

- From SEM & EDM test it can be concluded that bacteria concrete produce extra amount of calcite in the concrete which help in improving compressive strength of concrete and formation of impermeable calcite layer over the surface of an already existing concrete layer, can seal the cracks in concrete structure and also decrease permeability of water and other liquids in concrete.
- For SAP concrete, SEM & EDM test shows that SAP can sustain hydration by yielding their absorbed water and provide water for precipitation of $CaCO_3$. For self-healing in concrete if the crack width is less than 50 to 100 micrometre healing through adding SAP as an ingredient can be achieved. Whereas to make sure that the width of crack always remain smaller we can add microfibers inside the matrix with SAP to have reliable tensile ductility and crack controlling capability to prevent localised cracking failure.
- From above it can be concluded that Bacteria Bacillus Subtillis can be easily cultured and safely used in improving the performance characteristic of concrete.
- SAP promote self-healing ability by renewing internal curing upon deswelling however if the amount of calcite formation is compared between SAP and bacteria which is essential for cracks repair, it is bacterial concrete which look more promising for autonomic healing in concrete.

REFERENCES

[1] IS: 10262-2009, Recommended Guidelines for concrete Mix. Bureau of Indian Standards, New Delhi.

[2] IS: 456-2000, Plain and reinforced concrete. Bureau of Indian Standards, New Delhi.

[3] De Muynck W., De Belie N. and Verstraete W., Microbial carbonate precipitation in construction materials: A review, Ecological Engineering Vol. 36(2), pp.118-136, 2010.

[4] Gavimath, C, Mali, M, Hooli, R, Mallpur, D, Patil, B, Gaddi, P, Ternikar, R and Ravishankera, E, Potential application of bacteria to improve the Strength of cement concrete, International Journal of Advanced Biotechnology and Research, 3(1): 541-544, 2012.

[5] Ghosh, P., Mandal, S., Chattopadhyay, B. D. and Pal, S., Use of microorganism to improve the strength of cement mortar. Cem. Concr. Res., 2005, 35(10), 1980–1983.

[6] Ghosh, S. N., IR spectroscopy. In Handbook of Analytical Techniques in Concrete Science and Technology, Principles, Techniques, and Applications (eds Ramachandran, V. S., Beaudoin, J. J.), Noyes Publications, William Andrew Publishing, New York, pp. 174–200, 2001.

[7] Hammes F. and Verstraete W., Key roles of pH and calcium metabolism in microbial carbonate precipitation, Reviews in Environmental Science and Biotechnology, 1, 3-7, 2002.

[8] Meldrum F.C. “Calcium carbonate in biominerilisation” Biomimetic chemistry, 48, 187-224, 2003.

[9] Park, S. J., Yu-Mi, P., Chun, W. Y., Kim, W. J., Ghim, S.-Y., Calcite-forming bacteria for compressive strength improvement in mortar. J. Microbiol., Biotechnol., 20(4), 782–788, 2010.

[10] Ramachandran, S. K., Ramakrishnan, V. and Bang, S. S., Remediation of concrete using micro-organisms. ACI Mater. J., 98, 3–9, 2001.

[11] Senthilkumar, V, Palanisamy, T, Vijayakumar, VN, Comparative Studies on Strength Characteristics of Microbial Cement Mortars, International Journal of ChemTech Research, 16(1): 578-590, 2001.

[12] Willem, D. M., Debrouwer, D., Belie, De, Verstraete, W., Bacterial carbonate precipitation improves the durability of cementitious materials. Cem. Concr. Res., 38, 1005–1014, 2008.

[13] Hughes, B. P., and Guest, J. E., "Limestone and Siliceous Aggregate Concretes Subjected to Sulphuric Acid Attack," Magazine of Concrete Research (London), V. 30, No. 102, Mar. 1978, pp. 11-18.

[14] Fattuhi, N. I., and Hughes, B. P., "Effect of Acid Attack on Concrete with Different Admixtures or Protective Coatings," Cement and Concrete Research, V. 13, No.5, Sept. 1983, pp. 655-665.

[15] Raju, P. S. N., and Dayaratnam, P., "Durability of Concrete Exposed to Dilute Sulfuric Acid," Building and Environment, V. 19, No.2, 1984, pp. 75-79.

[16] Yonkers, H. M., and E. Schlangen. "Crack Repair by Concrete-immobilized Bacteria." Proc. of First International Conference on Self Healing Materials, Delft University of Technology, Noordwijk Aan Zee. Springer, 2007. Print.

[17] Joseph, C., A. D. Jefferson, and M. B. Cantoni. "Issues Relating to the Autonomic Healing of Cementitious Materials." Proc. of First International Conference on Self Healing Materials, Delft University of Technology, Noordwijk Aan Zee. Springer, 2007. Print.

[18] Kessler, M.R., N.R. Sottos, and S.R. White. "Self-healing Structural Composite Materials." Composites Part A: Applied Science and Manufacturing 34.8 (2003): 743-53. Print

[19] Santhosh KR, Ramakrishnan V, Duke EF, and Bang SS, “SEM Investigation of Microbial Calcite Precipitation in Cement”, Proceedings of the 22nd International Conference on Cement Microscopy, pp. 293305, Montreal, Canada, 2000.

[20] SHETTY M. S. “Concrete Technology THEORY AND PRACTICE”, revised edition, S. CHAND TECHNICAL, Page numbers: 234, 237, 324, 456, 463.