A Comparative Study of Self Healing Concrete by using Bacteria and Silica Fume

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Abstract:- **Nanotechnology is one of the leading scientific fields today since it combines knowledge from the fields of Physics, Chemistry, Biology, Medicine, Informatics, and Engineering. It is an emerging technological field with great potential to lead in great breakthroughs that can be applied in real life. Nanotechnology or Nanoscaled Technology is generally considered to be at a size below 0:1 _m or 100 nm (a nanometer is one billionth of a meter,10_9 m). The concrete structures have various durability issues due to the different physiological conditions and it results to irretrievable damage to the structure and eventually reduction in the strength of concrete structure. In the recent years MICCP (microbiologically induced calcium carbonate precipitation) by the bacteria considered as an environment friendly method to enhance the properties of concrete, also for the repair of concrete structure and to consolidate different construction materials. One of the strategies employed for the self-healing of cementitious material is using mineral admixtures like silica fume. This research outlines the method of preparation, testing procedure and salient results on compressive test SEM analysis also the eco-friendly concrete that is manufactured using the waste products of coal industries. The effects of self-healing on normal concrete by adding small amounts of silica fume and bacteria to concrete is studied. M25 mix design is being done as per the Indian Standard Code IS: 10262-1982. A uniaxial compression load was applied to generate micro cracks in concrete where cube specimens were pre-loaded up to 70% and 90% of the ultimate compressive load determined at 28 days. After pre-loading, concrete specimens are stored in water for a month, the mechanical and permeation properties are monitored every weeks and increase or decrease in strength and durability properties are studied.**

Key words: Nanotechnology, bacteria, silica fume, self healing concrete

1.INTRODUCTION

Cracking is an inevitable phenomenon in structures and is one of the inherent weaknesses. Water and other salts seep through these cracks; corrosion initiates, and thus reduces the life of structures. Any structure with cracks looses its structural integrity and, is structurally unsafe. The bacterial remediation technique can be used for repairing structures of historical importance to preserve its aesthetic value, as conventional techniques like epoxy cannot be used to remediate cracks in those structures. The application of concrete is rapidly increasing worldwide and therefore the development of bacterial mediated concrete is urgently needed for environmental reasons. As presently, about 8% of atmospheric carbon dioxide emission is due to cement production, mechanisms that would contribute to longer service life of concrete structures would make the material not only more durable but also self repair, i.e., the autonomous healing of cracks in concrete. The potential of bacteria to act as self healing agent in concrete has proven to be a promising future. This field appears to be more beneficial as bacterial concrete appears to produce more substantially more crack plugging minerals than control specimens (without bacteria). A promising sustainable repair methodology is currently being investigated and developed in several laboratories, i.e., a technique based on the application of mineral producing bacteria. The application for ecological engineering purposes is becoming increasingly popular as is reflected by recent studies where bacteria were applied for removal of chemicals from waste water streams , for bioremediation of contaminated soils and removal of green house gases from landfills . The applicability of specifically mineral producing bacteria for sand consolidation and limestone monument repair and filling of pores and cracks in concrete have been recently investigated. This technique is highly desirable because the mineral precipitation induced, as a result of microbial activities, is pollution free and natural. As the cell wall of bacteria is anionic, metal accumulation (calcite) on the surface of the wall is substantial: the mineral crystals grow with time and eventually plug the pores and cracks in structures. Many types of bacteria are efficient at extracting the nitrogen the require to live from urea (the nitrogenous component of urine, produced by many microorganisms), which process produces carbon dioxide and ammonia as byproducts. If water is also present, that ammonia will react with it to form ammonium hydroxide; if calcium is also present, that ammonium hydroxide will react with it to form crystals of calcium carbonate. Calcium carbonate (CaCO3) is better known as limestone. The deterioration of concrete structures before the end of service life can be prevented by means of using self-healing concrete. From the construction of foundation to bridge structures, concrete is the main component for construction. Traditional concrete when subjected to tensile load, it exhibits cracking. A healing agent that works when bacteria embedded in the concrete convert nutrients into limestone has been under development. This project is to study the self-healing potential of plastics, polymer composites, asphalt and metals as well as concrete. The first self-healing concrete products successful research results permitting are expected to hit the market in two years' time and are expected to increase the lifespan of many Civil Engineering structures. This research aims to discuss the effects of self-healing of concrete by adding any mineral admixtures like silica fume. The effects of self-healing on normal concrete incorporating the mineral admixtures when subjected to continuous water exposure will be studied.

2.METHODOLOGY

This research aims to discuss the effects of self-healing of concrete by adding any mineral admixtures like silica fume and bacteria . The effects of self-healing on normal concrete incorporating the admixtures when subjected to concrete will be studied. For this purpose, normal concrete with different mineral admixture replacement ratios will be prepared having a constant water-cementitious material ratio of 0.45. A uniaxial compression load was applied to generate micro cracks in concrete where cube specimens were pre-loaded up to 70% and 90% of the ultimate compressive load determined at 28 days. Later, the extent of damage will be determined as percentage of loss in mechanical properties as determined by compressive strength and sem analysis

3. MATERIALS USED:

3.1. Cement:

Figure 1 Cement

Cement is the most common binder which allows to make products and structures of the highest strength. Cement is the result of highly dispersed grinding of clinkering products of one of the clay type –marl or mixture of Limestone and clay. Cement ranks the leading place among building materials. In the modern construction techniques, the role of cement in producing the new advanced materials and products for prefabricated building construction has been constantly increasing. It is used for making cast-in-place and precast concrete, reinforced concrete, asbestos-cement products, mortars, and many other man-made materials, as well as for binding the individual structural elements (parts), heat insulation, etc. Cement is much used in the oil and gas industry. Cement and cement-based advanced building materials successfully substitute for scare timber, bricks, lime, and other conventional materials used in construction activities.

3.2. Aggregates

The properties of aggregates are decisive for the compressive strength anmodulus of elasticity of HSC. In normal strength concrete (NSC), the aggregate has a higher strength and stiffness than the cement paste. Failures in NSC are characterized by fractures in the cement paste and in the transition zone between paste and aggregate .Reduced watercement ratio, therefore, causes a great improvement in compressive strength of cement paste and hence of concrete.

3.3 Coarse aggregate

In HSC the capacity of the aggregate can be the limiting factor. This may be either the result of the aggregate being weaker than the low water-cement matrix, or alternatively it is not sufficiently strong and rigid to provide strengthening effect. This is mainly related to the coarse aggregate (CA). For optimum compressive strength with high cement content with low water-cement ratios the maximum size of the CA should be kept to a minimum, at ½ in or 3/8 in .The strength increases were caused by the reduction in average bond stress due to the increased surface area of the individual aggregate. Smaller aggregate sizes are also considered to produce higher concrete strength because less severe concentrations of stress around the particles, which are caused by differences between the elastic moduli of the paste and the aggregate .Many studies have shown that crushed stone produces higher strength than rounded gravel .The most likely reason for this is the greater mechanical bond, which can develop with angular particles. However , accentuated angularity is to be avoided because of attendant high water requirement and reduced workability. The ideal CA clean, cubical, angular , 100% crushed aggregate with minimum of flat and elongated particles(ACI 363R,1992). Among the different crushed aggregate that have been studied –trap rock, quartzite, limestone, greywacke, granite, and crushed gravel-trap rock tend to produce the highest concrete strength. Limestone, however, produces concrete strengths nearly as little difference in strength of HSC. Optimum strength and workability of HSC are attained with a ratio of CA to FA above that usually recommended for NSC. Also, due to the already high fines content of HSC mixes, use of ordinary amounts of CA results in a sticky mix.

Figure 2 Coarse Aggregate

3.4. Fine aggregate

Fine aggregates (FA) with a rounded particle shape and smooth texture have been found to require less mixing water in concrete and for this reason are preferable in HSC. HSC typically contain such high contents of fine cementitious materials that the grading of the FA used is relatively unimportant. However, it is sometimes helpful to increase the fineness modulus (FM) as the lower FM of FA can give the concrete a sticky consistency (i.e. making concrete difficult to compact) and less workable fresh concrete with a greater water demand. Therefore, sand with a FM of about 3.0 is usually preferred for HSC (ACI 363R, 1992).

3.5 Water

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. In practice, very often great control on properties of cement and aggregate is exercised, but the control on the quality of water is often neglected. Since quality of water affects the strength, it is necessary for us to go into the purity and quality of water. If water is fit for drinking it is fit for making concrete. This does not appear to be a true statement for all conditions. Some waters containing a small amount of sugar would be suitable for drinking but not for mixing concrete and conversely water suitable for making concrete may not necessarily be fit for drinking. Some specifications require that if the water is not obtained from source that has proved satisfactory, the strength of concrete or mortar made with questionable water should be compared with similar concrete made with pure water. Some specifications also made accept water for making concrete if the pH of water lies between 6 and 8 and the water is free from organic matter.

3.6. Bacteria selection

These are the different approaches for the addition of bacteria in concrete. According to the pH, temperature and other properties of concrete these conditions are not suitable for the growth of bacteria. So, the bacterial spores are used instead of the nutrient broth or liquid form of bacteria in concrete. One more alternative method is the encapsulation of the microorganisms. But this method is economically not good. And the last method for introduction of bacteria in concrete is the use of vascular network to distribute the microbial broth in the cement matrix. This method is very complicated and current technology is not much developed to exhibit this method. Since 1980’s after a lot of researches it has been found that, Out of all these methods the direct addition and addition in form of spores mostly used by the researchers because these methods are economical and easy to proceed with the current available technology. calcium carbonate precipitation results from both passive and active nucleation. Passive carbonate nucleation occurs from metabolically driven changes in the bulk fluid environment surrounding the bacterial cells. This increases the mineral saturation and induces nucleation. In the Ammo acid degradation driven system, this occurs from an increase in pH due to ammonification. Active carbonate nucleation occurs when the bacterial cell surface is utilized as the nucleation site. The cell clusters exhibit a net electronegative charge which favors the adsorption of Ca^{2+} ions. The Ca^{2+} ions attract $CO_3{}^{2-}$ and $HCO_3{}^{-}$ ions, which will eventually form calcium carbonate precipitates. Although it is known that there are many different types of bacteria capable of calcium carbonate precipitation, it has been hypothesized that there are specific attributes of certain bacteria that promote and affect $CaCO_3$ precipitation more than others [10]. It has already been noted that cell walls have an inherent electronegative charge that affect the binding of certain ions, but the extracellular polymeric substance associated with biofilms may also be involved. Biofilm cells are contained in the extracellular polymeric substance matrix and may exhibit an overall negative charge. This negative charge is important in trapping metal ions. Strain *Bacillus subtilis* JC3, selected for the present study, was distinguished as aerobic alkaliphilic spore-forming soil bacteria. The medium used to grow *Bacillus subtilis* JC3 was based on peptone, NaCl , yeast extract. The pure culture was isolated from the soil sample of JNTU. Microbiologically induced calcium carbonate precipitation occurs via more complicated processes than chemically induced precipitation. In nutrients medium, it is possible that individual microorganisms produce ammonia as a result of amino acids degradation to create an alkaline micro-environment around the cell. The high pH of these localized areas, without an initial increase in pH in the entire medium, commences the growth of CaCO3 crystals around the cell. Specific proteins present in biological extracellular polymeric substances cause the formation of different calcium carbonate polymorphs. Some bacteria and fungi can induce precipitation of calcium carbonate extracellularly through a number of processes that include photosynthesis, ammonification, denitrification, sulfate reduction and anaerobic sulphide oxidation. Although all the Bacillus strains were capable of depositing calcium carbonate, differences occurred in the amount of precipitated calcium carbonate on agar plate colonies. Oxidative deamination of amino acids by *Bacillus subtilis* JC3 is temperature dependent and that the highest calcite precipitation rates occurred near the point of critical saturation. *B. Subtilis* JC3 member of the genus Bacillus is Gram-positive, rod-shaped, endospore forming bacteria commonly found in soil; precipitate calcium carbonate ($CaCO_3$) in its micro-environment by the ammonification of amino acids into ammonium ($NH_4{}^{+}$) and carbonate ($CO_3{}^{2-}$) ions. Microbiologically induced (also called ‘‘bacteriogenic’’) calcite carbonate precipitation by *Ammonification* (Ammo acid degradation**)** comprises of series of complex biochemical reactions. Amino acids released during proteolysis (the process of enzymatic breakdown of proteins by the microorganisms with the help of proteolysis enzymes) undergo deamination in which nitrogen containing amino ($-NH_2$) group is removed. Thus, process of deamination which leads to the production of ammonia is termed as "ammonification". The process of ammonification is mediated by *Bacillus subtilis* JC3. Ammonification usually occurs under aerobic conditions (known as oxidative deamination) with the liberation of ammonia (NH3) or ammonium ions (NH_4) when dissolved in water .The biochemical reactions of ammonification in peptone based medium is represented as follow

$$Ca^{2+} + \textit{B.subtilis}\text{ Cell} \rightarrow \textit{B.subtilis}\text{ Cell- }Ca^{2+}$$

$$CH_3CH(NH_2)COOH\text{ (Peptone)} + ½O_2 \text{ --------->} C_2H_2 + H_2CO_3 + NH_3$$

$$H_2CO_3 \text{ ---------->} H^+ + HCO_3^-$$

$$NH_3 + H_2O \text{ -------->} NH_4^+ + OH^-\text{ (pH increase)}$$

$$HCO_3^- + H^+ + OH^- \text{ ---------->} CO_3^{2-} + H_2O$$

$$\textit{B.subtilis}\text{ Cell- }Ca^{2+} + CO_3{}^{2-} \rightarrow \textit{B.subtilis}\text{ Cell- }CaCO_3$$

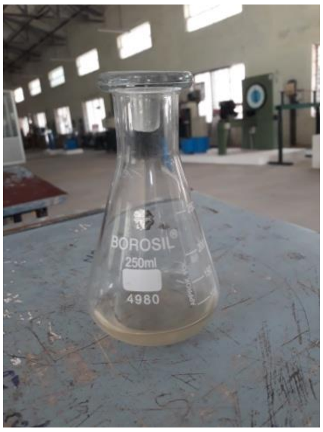

Figure 3 Bacteria Substillus Liquid

Upon examination, bacterial cells were shown encased in calcite crystals, which indicated that the bacteria acted as a nucleation site for the mineralization process, an example of active nucleation

3.7. Silica Fume

Silica fume (SF) is a by-product of the melting process used to produce silicon metal and ferrosilicon alloys. The main characteristics of SF are its high content of amorphousSiO2 ranging from 85 to 98%, mean particle size of 0.1 – 0.2 micron (approximately 100times smaller than the average cement particle) and its spherical shape. Because of its extreme fineness and high silica content, SF is a highly effective pozzolanic material. The SF reacts pozzolanically with the lime during the hydration of cement to form thes table cementitious compound calcium silicate hydrate (CSH). Normal SF content ranges from 5 to 15 percent of Portland cement (ACI 363R, 1992) . The use of SF as replacement of a part of the cement gives considerable strength gain. For most binder combinations, the use of SF is the only way of producing concrete of normal workability with a strength level exceeding 80 MPa. To ensure a proper dispersion of the ultrafine SF particles, plasticizers should be used in these mixtures Silica fume, also referred to as micro silica or condensed silica fume, is another material that is used as an artificial pozzolanic admixture. It is a product resulting from reduction of high purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume rises as an oxidised vapour. It cools, condenses and is collected in cloth bags. It is further processed to remove impurities and to control particle size. Condensed silica fume is essentially silicon dioxide (more than 90%) in non-crystalline form. Since it is an airborne material like fly ash, it has spherical shape. It is extremely fine with particle size less than 1 micron and with an average diameter of about 0.1 micron, about 100 times smaller than average cement particles. Silica fume has specific surface area of about 20,000 m2/kg, as against 230 to 300 m2/kg. Silica fume as an admixture in concrete has opened up one more chapter on the advancement in concrete technology. The use of silica fume in conjunction with super-plasticizer has been the backbone of modern High performance concrete. In one article published in 1998 issue of ‘Concrete International’by Michael Shydlowski, President, Master Builder, Inc states “Twenty five years ago no one in the concrete construction industry could even imagine creating and placing concrete mixes that would achieve in place compressive strengths as high as 120 MPa . . . . . The structures such as Key Tower in Cleave land with a design strength of 85 MPa, and
Wacker Tower in Chicago with specified concrete strength of 85 MPa, and two Union Square in Seattle with concrete that achieved 130 MPa strength – are testaments to the benefits of silica fume technology in concrete construction”.

Figure 4 Silica Fume

4.THE PHYSICAL PROPERTIES OF MATERIALS USED

4.1. Silica fume.

Particle size (typical) < 1 μ m
Bulk density (as-produced) :130 to 430 kg/m^3
Bulk density (slurry):1320 to 1440 kg/m^3
Bulk density (densified):480 to 720 kg/m^3
Specific gravity: 2.2
Surface area (BET): 13,000 to 30,000 m^2/kg

The presence of any type of very small particles will improve concrete properties. This effect is termed either “particle packing” or “micro filling”.Silica fume is simply a very effective pozzolanic material which plays a vital role in producing calcium hydroxide which helps in healing the cracks.

The physical properties of the cement, fine aggregate and coarse aggregate used in concrete mix were determined by means of conducting standard tests like consistency, setting time, water absorption, specific gravity and density .

4.2 Cement

Specific gravity 3.45
Fineness of cement by dry sieving 1%

4.3 Fine Aggregate

Fineness modulus 3.720
D10 0.30 mm
D30 0.45 mm
Uniformity coefficient 3.30
Coefficient of curvature 0.85
Percentage of coarse sand 48.2%
Percentage of medium sand 47.8%
Percentage of fine sand 1.0%
Specific gravity 2.875
Bulk density in loose state 1750 kg/m3
Bulk density in rodded state 1774.2 kg/m3

4.6 Coarse Aggregate

Fineness modulus 3.169
Bulk density in loose state 1650.22 kg/m3
Bulk density in rodded state 1723.20 kg/m3
Specific gravity 2.733
Water absorption 0.45%

In order to determine the mechanical properties of conventional concrete and the concrete made with silica Fume and bacteria, compressive strength, and sem analysis tests were conducted and the results are given below.

4.7 Bacteria

Pores 2x10^9

5 MIX PROPORTION

Use of well graded particles in concrete mix conceptually produces a dense matrix which is in turn affected by the use of mineral additives such as silica fume, or by the use of low water-to-cement ratios. In order to produce a highly durable self-healing concrete, cubes have been prepared by adding Silica Fume (SF) in percentage of 0%, 5%, 10%, and 15%. And the concrete mix prepared to produce self healing concrete, cubes have been prepared by adding Bacteria Liquid (BL) 10ml,20ml and 30ml. A conventional mixture without any admixture is cast for comparing the strength and durability properties of silica fume concrete and bacterial concrete. Microcracks are produced in the concrete specimens by applying 70% and 90% of ultimate compressive strength after 28 days curing. The preloaded concrete specimens are tested for compressive strength at 7 ,14 and 28 days. The physical properties of the cement, fine aggregates and coarse aggregates are determined by means of conducting standard tests. M25 grade concrete was used for testing.

Figure 5 mixing of concrete

Figure 6 Demoulding of Concrete

6 RESULTS AND DISCUSSION

Table – 1: Compressive Strength of Silica Fume Concrete Results In N/mm^2

Sample	Days	0%(SF)	5%(SF)	10%(SF)	15%(SF)
1	7	15.20	19.30	20.30	22.10
2		16.45	18.80	19.70	22.50
1	14	22.30	24.00	26.25	29.17
2		22.80	23.85	25.60	28.20
1	28	26.75	28.45	31.35	34.40
2		27.15	27.75	30.45	33.20

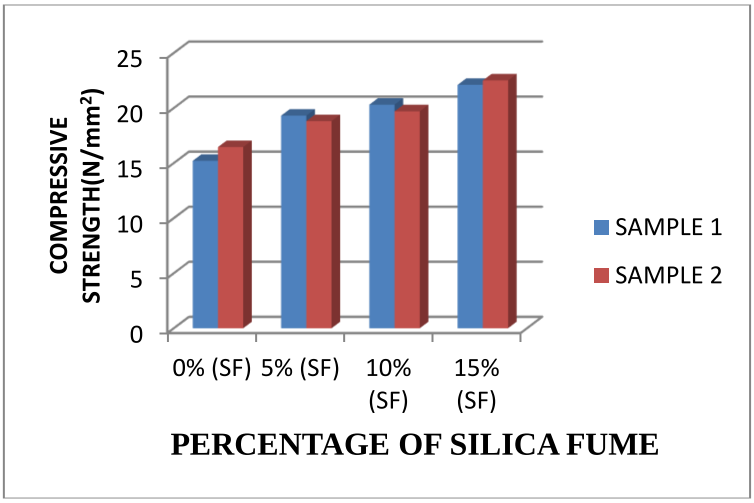

Chart 1 - 7 Days of compressive strength

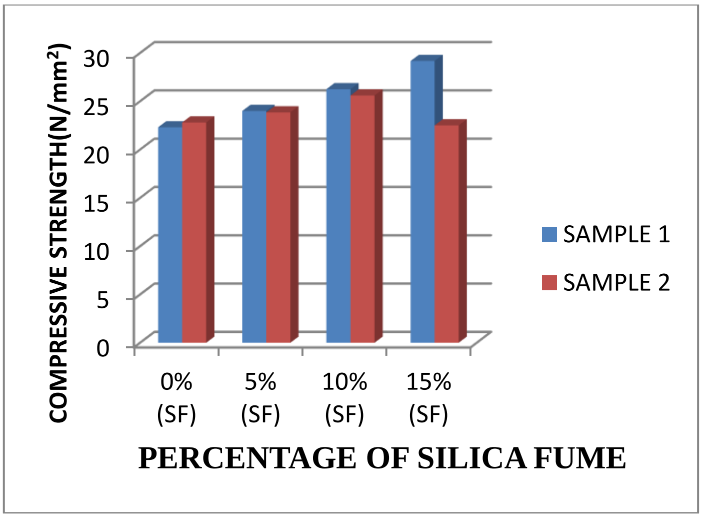

Chart 2 - 14 Days of compressive strength

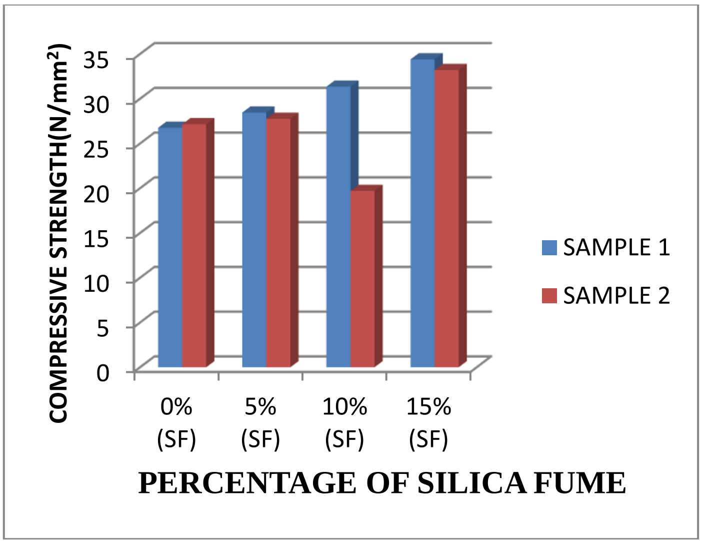

Chart 3 - 28 Days of compressive strength

Table - 2 :Compressive Strength Of Bacterial Concrete Results In N/mm^2

Sample	Days	0ml(BL)	10ml(BL)	20ml(BL)	30ml(BL)
1	7	15.20	15.90	16.18	18.50
2		16.45	16.75	16.90	17.45
1	14	22.30	23.45	24.00	24.65
2		22.80	24.20	23.45	24.35
1	28	26.75	27.76	28.65	28.90
2		27.15	27.85	29.05	29.50

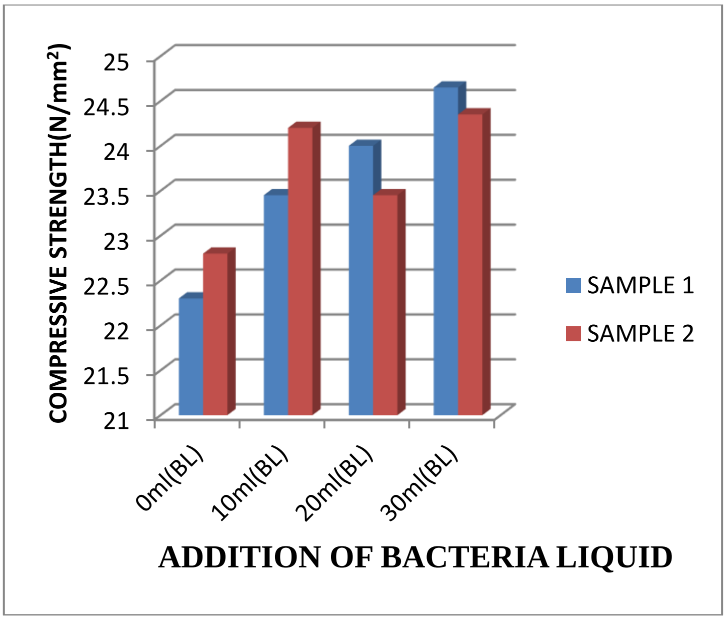

Chart 4 - 7 Days of compressive strength

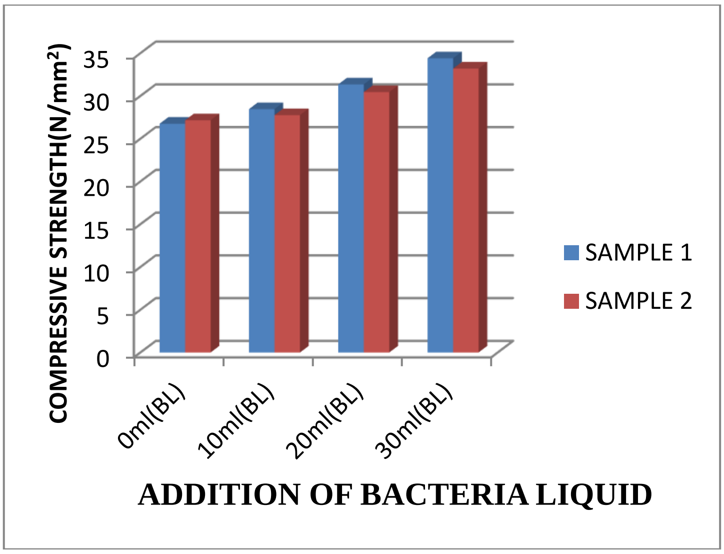

Chart 5 - 14 Days of compressive strength

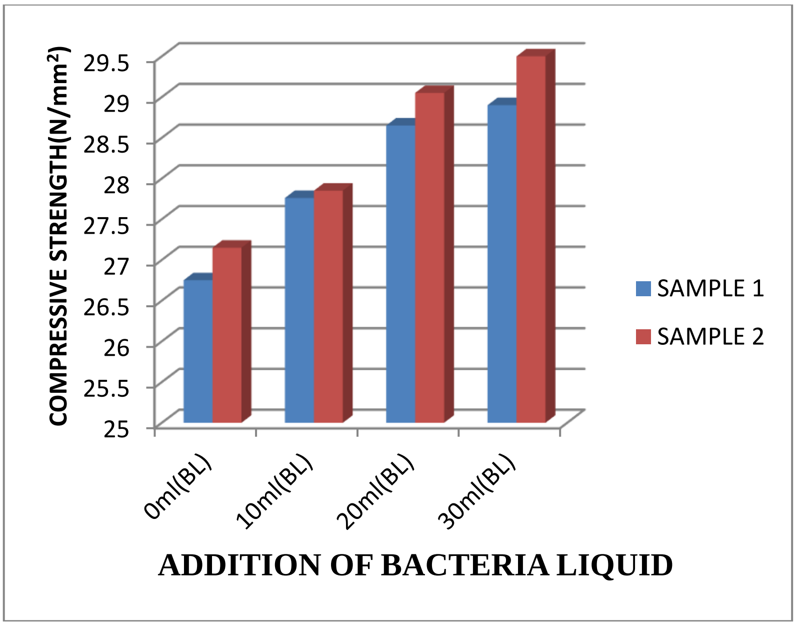

Chart 6. 28 Days of compressive strength

Comparision Chart

The high compressive strength has been observed by adding 15% of silica fume concrete and adding 30 ml of bacteria liquid in concrete so, the comparison chart of self healing concrete has given below.

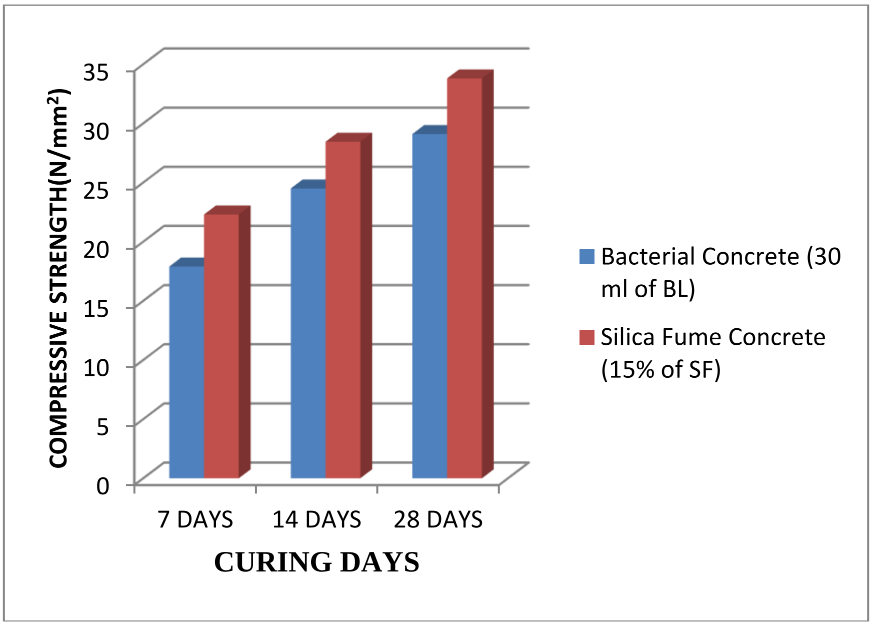

Chart 7 Comparison chart between silica fume concrete and bacterial concrete

7. TEST OF SEM RESULTS

Microcracks are produced in the concrete specimens which yield high strength among the ratios were taken. And applying 70% and 90% of ultimate compressive strength after 28 days curing. The preloaded concrete specimens are tested for compressive strength at 7, 14 and 28. The sample was tested in SEM analysis after applying load. The increases of voids will be observed.

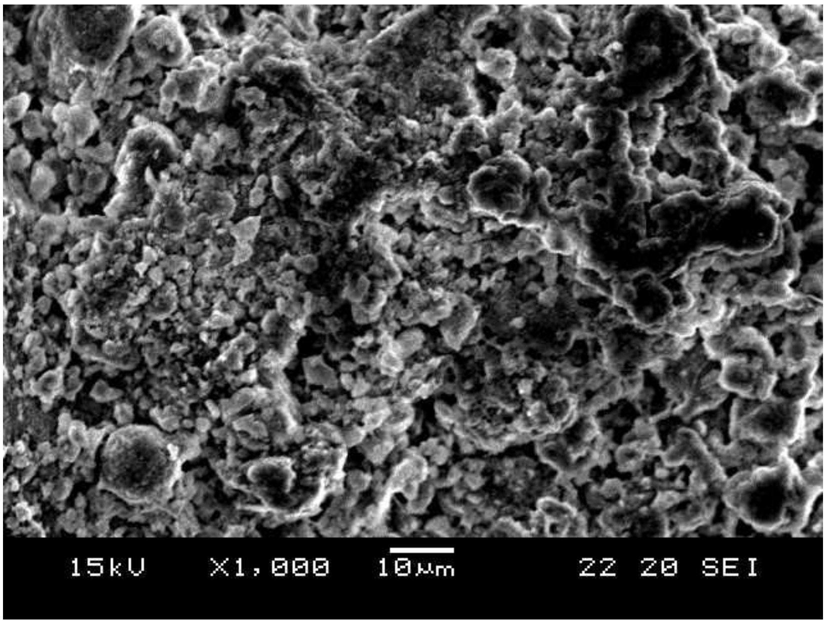

Figure 7 Silica Fume Concrete

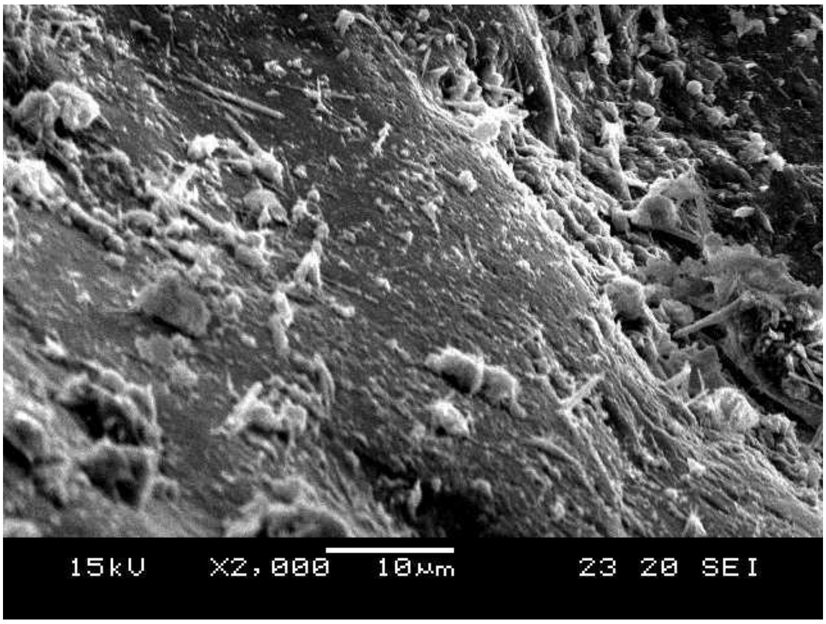

Figure 8 Bacterial Concrete

CONCLUSION:

Silica fume concrete was tested for compressive strength for ultimate loading. It was found that the mix has given maximum strength at 15% addition of silica fume The concrete had good workability and the hardened concrete had good durability. As the study describes the presence of very minute silica particles available in the microstructure of concrete, these observations are attributed to the self healing of the pre-existing cracks, mainly by hydration of anhydrous particles (Silica fume) on the crack surfaces. When 15% of silica fume is added to total weight of cement, the compression increases and hence there is increase in tensile strength thereby ductility increases and the cracks are reduced.

Durability characteristics improved with the addition 30ml of bacteria. The presence of bacteria had reduced the mean expansion by 55.30%, when compared to the control specimens without bacteria, when subjected to freezing and thawing.

I concluded that, High strength can be achieved by adding silica fume concrete than bacteria concrete. The repairing ability has good in bacterial concrete than the silica fume concrete. Bacteria concrete easily fill the voids and cracks are quickly healed.

REFERENCES:

[1] Fujii .T Ayano.T and Sakata .K, Strength and durability of steelslag hydrated matrix without cement, Proc.on29th conference of our world Concrete & Structures., pp.253-258, Jan 2004.

[2] Fujii .T, Tayano.T and Sakata .K, Freezing and thawing Resistance of Steel making slag concrete, Journal of

Environmental Sciences for sustainable society ., Vol1 , pp.1-10, Dec 2007.

[3] Garg.M and Singh.M, Strength and durability of cementious binder produced from fly ash lime sludge-portland cement, Indian Journal of Engineering & Materials Sciences., Vol 13, pp.75-79, Dec 2006.

[4] Hisham .Q, Faissal .S and Ibrahim .A, Use of low CaO unprocessed steel slag in concrete as fine aggregate, Construction and Building Materials., Vol 23 ,1118-1125, Sep 2009.

[5] Khidhair .J, Falak .O and Mohammed .O, Using of Steel Slag in Modification of Concrete properties, Engineering & Technology journal., Vol 27(9), 1711-1721, Dec 2009.

[6] Stocks-Fischer S, Galinat JK, Bang SS. Microbiological precipitation of CaCO3. Soil Biol Biochem 1999; 31(11):1563–71.

[7] Dick J, De Windt W, Graef BD, Saveyn H, Meeran PV, Belie N, et al. Biodeposition of a calcium carbonate layer on degraded limestone by Bacillus species. Biodegradation 2006;17(4):357–67.

[8] Ramachandran SK, Ramakrishnan V, Bang SS. Remediation of concrete using micro-organisms. ACI Mater J 2001;98:3–9.

[9] De Muynck W, Debrouwer D, De Belie N, Verstraete W. Bacterial carbonate precipitation improves the durability of cementitious materials. Cem Concr Res 2008;38:1005–14.