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Effect of Partial Cement Replacement with GGBS in Self-Healing Concrete - Experimental Study

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ABSTRACT: Concrete is the most common material used for all types of construction. Due to its strength and durability, concrete became inevitable. The word concrete is originated from the Latin word concretus which means condensed and hardened. The only defect in the use of concrete is that it is weak in tension. Since the concrete is weak in tension the possibility of formation of cracks is more. Apart from this, freeze–thaw action and shrinkage also leads to cracking in concrete. Durability of concrete is highly affected due to these cracks and it leads to corrosion of reinforcing bars. So it is very essential to find the suitable repair mechanism for regaining the strength of concrete. In concrete structure, repair of cracks usually involves applying a cement slurry or mortar which is bonded to the damaged surface Repairs can particularly be time consuming and expensive. For crack repair, a variety of techniques are available like impregnation of cracks with epoxy based fillers. Self-healing materials are artificial or synthetically-created substances that have the built-in ability to automatically repair damage to themselves without any external diagnosis of the problem or human intervention. Generally, materials will degrade over time due to fatigue, environmental conditions, or damage incurred during operation. Cracks and other types of damage on a microscopic level have been shown to change thermal, electrical, and acoustical properties of materials, and the propagation of cracks can lead to eventual failure of the material. In general, cracks are hard to detect at an early stage, and manual intervention is required for periodic inspections and repairs. Tiny cracks in concrete do not necessarily affect structural integrity in short term, but they do allow water and other chemicals to seep into the structure, which may cause problems over time. Self-healing concrete has embedded clay particles that contain dormant bacteria and a food source. When a crack appears in the concrete, water seeps in and activates the bacteria. When they wake, the bacteria eat their packed lunch and then conveniently excrete chalk, which fills the crack. (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. Ground-granulated blast furnace slag is highly cementitious and high in calcium silicate hydrates (CSH) which is a strength enhancing compound which improves the strength, durability and appearance of the concrete.

I. INTRODUCTION

Ground Granulated Blast Furnace Slag (GGBS)

GGBS increases strength, durability and appearance of the concrete. It reduces the risk of damages caused by alkali-silica reaction and reduces corrosion. Ground-granulated blast furnace slag is highly cementitious and high in calcium silicate hydrates (CSH).GGBS is a by-product of steel industry.

Bacillus Subtilis

Bacillus subtilis also known as the hay bacillus or grass bacillus, is a Gram-positive bacterium, found in soil and the gastrointestinal tract of ruminants and humans. Bacillus subtilis is rod-shaped, and can form a tough, protective endospore, allowing it to tolerate extreme environmental conditions. It is historically classified as an obligate aerobe, though evidence exists that it is a facultative anaerobe. Bacillus subtilis is also considered the best studied Gram-positive bacterium and a model organism to study bacterial chromosome replication and cell differentiation. It is one of the bacterial champions in secreted enzyme production and used on an industrial scale by biotechnology companies.

Calcium Lactate

Calcium Lactate is a good nutrient for the bacteria, it is in powder form. And it is been added by the weight of cement. Activated bacteria feeds on calcium nutrient (Calcium Lactate) and forms Calcite or Limestone.

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Bacteria

Bacillus subtilis cells is a typically rod shaped and are about 4-10 mm long and 0.25- 1.0 micron in diameter with cell volume about 4.6 fl at stationary phase. Bacillus subtilis is also known as hay bacillus or grass bacillus found in soil and gastrointestinal tract of humans. A bacterium that is selected for the process should be stable and survive at a high alkaline environment that is usually in the pH of 10 or above. Bacteria of Bacillus strain are renowned to have a high stability at a high alkaline environment. Because they form viable endospores in harsh conditions and become activated once spores get in to contact with water and other nutrients. Once the Ca2+ in the process of demineralization negatively charged bacterial cell wall will draw captions from the environment. Ca2+ will eventually get deposited on their cell surface. These Ca2+ ions subsequently react with the CO3 2−ions, leading to the precipitation of CaCO3. Bacterial cell surface serves as a nucleation site. Carbonate is produced extra cellularly through autotrophic and heterotrophic metabolic pathways. In the Autotrophic pathway in the presence of carbon dioxide, microbes convert it to carbonate through non-methylotrophic, methanogenesis, oxygenic photosynthesis, and an oxygenic photosynthesis. Whereas in heterogenic pathway calcium carbonate crystals precipitate as a result of their growth in different natural habitats.

The suitability of very specific extremophiles calcifying bacteria & their ability to repair cracks in building structure using sustainable and bio-based self- healing agent. Setting of the laboratory for Bio-concrete. Methodology to develop self healing material using alkaliphlic calcifying bacteria. Reduces the corrosion of steel and thus improves the durability of steel reinforced concrete. Since this method proved out to be Eco-friendly, It can bring a wide revolution in the future. The following objectives are made from this studies.

- To Develop high strength concrete and self-healing property with a characteristic compressive force of 40MPa with different combinations of additional cementitious materials such as GGBS.
- Select a suitable admixture throughout the flow test.
- To improve self-healing property in concrete.
- To enhance the workability of the mixed concrete.
- To gain the knowledge on efficiency of bacterial treatments.

II. LITERATURE REVIEW

V Srinivasa Reddy, M V SeshagiriRao and S Sushma, 2015 [3] In this paper variations on compressive strength of concrete with respect to various bacterial cell concentration of Bacillus Subtilis JC3 is studied. Cement mortar cubes of standard size were casted, with different variations, cured and tested for compressive strength. Test results showed an increase of compressive strength at cell concentration of 105 /ml. The initial cost of bacteria concrete is upto three times more than the conventional concrete, however there is a reduction in carbon.

his document is template. Ravindranatha, N. Kannan, M. Likhit, (2014) In this research comparison was done among mix variations (with and without the bacterium Bacillus pasteurii in calculated quantity of bacterial solution). Cube and beam samples were casted and tested at 7 & 28 days for compressive and flexural strength. The bacteria pro- duced calcium carbonate which filled the void volume, making the concrete withstand more load, i.e. increase in compressive and flexural strengths and decrease permeability. Kunamineni Vijay , Meena Murmu , Shirish V. Deo (2017) Bacillus subtilis species in healing of cracks in concrete . This study has identified that cteria has a positive effect on the compressive strength of Portland cement mortar cubes and concrete . The advantage of using bacteria decreases water penetration and chloride ion permeability . The present study results recommends that using the " microbial concrete " can be an alternative and high quality concrete sealant which is cost effective , environmental friendly , and eventually leads to improvement in the durability of building materials . Divya Bhavana (2017) The cement is replaced by the GGBS contain of bacteria of 106 bacillus subtilis in M40 mix . The GGBS used in the proportions of 10 % by weight of cement . From this research the results are much better as compare to that of the convention concrete. Thivya J et al (2016) The recent research has shown that specific species of bacteria can actually be useful as a tool to repair cracks in already existing concrete structures. This new concrete, that is equipped to repair itself, presents a potentially enormous lengthening in service-life of public buildings and also considerably reduces the maintenance costs. The objective of the present investigation is to study the potential application of bacterial species i.e. Bacillus subtilis to improve the strength of cement concrete. The aim of this research project is the development of a new type of concrete in which integrated bacteria promote self-healing of cracks. Various test such as compressive strength test, split tensile strength test and

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flexural strength test will be carried out. The strength properties will be compared with the conventional concrete after the curing period of 7, 14 and 28 days. The grade of concrete used in this project is M25. The bacteria Bacillus Subtilis in solution form is added to the concrete by 3 ml, 6 ml and 9 ml per litre of water. Salmabanu Luhar, Suthar Gourav(2014) Self-healing mechanism is introduced in the concrete which helps to repair the cracks by producing calcium carbonate which block the micro cracks and pores in the concrete. The bacteria was selected according to the alkali environment. Bacteria improves tensile strength water permeability, durability and compressive strength of normal concrete. Anas Mohd. Afaque Khan Mixture of cement, fine aggregate, coarse aggregate and water is known as concrete. Concrete plays a very important role in the development of infrastructure i.e., buildings, bridges and highways etc. Ordinary Portland cement The main ingredients used for the production of concrete is Ordinary Portland cement . Unfortunately, a large amounts of carbon-dioxide gas emit into the atmosphere during the production of cement, which has a major contributor for green house effect and global warming. Hence, it is required either to search any other material or partially alternative of it. Ground Granulated Blast Furnace Slag is a by product from the blast-furnace of iron and it is very beneficial in the concrete production. The present paper reviews the literature related to the utilization and efficiency of GGBFS which effect the properties of concrete. Number of properties of partially replaced GGBFS concrete were studied with the help of previous journals which include the properties like compressive strength, split tensile strength, flexural strength, workability, electrical conductivity, resistance against chloride and sulphate attack. The study revealed the performance and applications of GGBFS concrete in the construction world. Hence, GGBFS concrete can be used as a building material as well as reduce the dumping of GGBFS in environment. Shariq et al.(2008) studied the effect of curing procedure on the cement mortar and concrete incorporating ground granulated blast furnace slag compressive strength development. The compressive strength development of cement mortar is calculated by the 20 and 40 percent replacement of GGBFS for different types of sand. Similarly the strength development of concrete is investigated with 20 and 40 percent replacement of GGBFS on two grades of concrete. Tests results show that the incorporating 20% and 40% GGBFS is highly significant to increase the compressive strength of mortar after 28 days and 150 days, respectively. Where more than replacement level affects the concrete strength.

III. METHODOLOGY OF PROPOSED SURVEY

Compressive Strength Test

The cube mould should be of 100 mm size conforming to IS 10086-1982. In assembling the mould for use, the joints between the sections of mould shall be thinly coated with mould oil. A similar coating of mould oil shall be applied between the contact surfaces of the bottom of the mould in order to ensure that no water escapes during filling. The interior surfaces of the assembled mould shall be thinly coated with mould oil to prevent adhesion of the concrete. The cylinder mould should be of 150 mm diameter and 300 mm height conforming to IS10086-1982. In assembly the mould for use, the joints between the sections of the mould shall be thinly coated with mould oil and a similar coating of mould oil shall be applied to the contact surfaces of the bottom of the mould and the base plate in order to ensure that no water escapes during filling. The interior surface of the mould shall be thinly coated with mould oil to prevent the adhesion of concrete. The prism mould should be of 10 mm x 100 mm x 100 mm conforming to IS100861982. In assembly the mould for use, the joints between the sections of the mould shall be thinly coated with mould oil and a similar coating of mould oil shall be applied to the contact surfaces of the bottom of the mould and the base plate in order to ensure that no water escapes during filling. The interior surface of the mould shall be thinly coated with mould oil to prevent the adhesion of concrete. Casting is a manufacturing process in which a liquid material is usually poured into a mold, which contain a hollow cavity of desired shape, and then allowed to solidify. The solidified part is known as casting, which is ejected or broken out of the mold to complete the process. The concrete should normally be cast in one continuous operation so as to discontinuity of more than one hour. Mixed concrete should not be allowed to stay on the platform for more than 45 minutes and must be placed in the forms and compacted. Fig.1 shows the casting of specimen which was used for this study.

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Fig 1: Casting Of Specimen

Compressive strength is the ability of material or structure to carry the loads on its surface without any crack or deflection. A material under compression tends to reduce the size, while in tension, size elongates. Remove the specimen from water after specified curing time and wipe out excess water from the surface. Take the dimension of the specimen to the nearest 0.2m Clean the bearing surface of the testing machine Place the specimen in the machine in such a manner that the load shall be applied to the opposite sides of the cube cast. Align the specimen centrally on the base plate of the machine. Apply the load gradually without shock and continuously at the rate of 140 kg/cm2/minute till the specimen fails. Record the maximum load and note any unusual features in the type of failure. Fig .2 shows the compressive strength test machine which was used for this study.

Compressive Strength = Load / Cross-sectional Area.

Fig-2 Compressive Strength Test

3.1 Rebound Hammer Test

As per the Indian code IS: 13311(2)-1992, the rebound hammer test have the following objectives;

- To determine the compressive strength of the concrete by relating the rebound index and the compressive strength.
- To assess the uniformity of the concrete
- To assess the quality of the concrete based on the standard specifications
- To relate one concrete element with other in terms of quality

Rebound hammer test method can be used to differentiate the acceptable and questionable parts of the structure or to compare two different structures based on strength.The casted concrete cube were cured for 28 days. Then the samples were tested using rebound hammer and its compressive strength were measured.

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Fig 3: Rebound Hammer Test

Ultra Sonic Pulse Velocity Test (UPV)

This test is done to assess the quality of concrete by ultrasonic pulse velocity method as per IS: 13311 (Part 1) – 1992. The underlying principle of this test is to calculate cracks. The method consists of measuring the time of travel of an ultrasonic pulse passing through the concrete being tested. Comparatively higher velocity is obtained when concrete quality is good in terms of density, uniformity, homogeneity etc.First UPV test is conducted for before crack formation cubes in all three bacterial percentages. Then same test is repeated for after crack formation cubes in all three bacterial percentages. After crack formation the cubes were tested on day 3. The UPV test set up is shown in the Fig.4.

Fig 4: Ultra Sonic Pulse Velocity Test (UPV)

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IV. RESULTS AND DISCUSSIONS

Table -1: Test Results on Conventional Concrete

S.NO	Compressive strength of concrete at 7 days (N/mm^2)	Compressive strength of concrete at 28 days (N/mm^2)
1	34.99	51.46
2	37.14	54.58

Table 2: Rebound Hammer Test Results

Bacteria solution	GGBS in %	Rebound hammer strength at 28 days(N/mm^2)
1%	0%	35.41
	10%	33.34
	20%	33.55
	30%	33.69
	40%	33.97
2%	0%	34.86
	10%	34.15
	20%	34.55
	30%	34.85
	40%	34.76
3%	0%	32.96
	10%	32.55
	20%	33.37
	30%	34.66
	40%	33.30

Table 3: Ultra Sonic Pulse Velocity Test (UPV) Results

Bacteria solution	GGBS in Percentage	Ultra Sonic Pulse Velocity (UPV)	
		Velocity	Time
1%	0%	4.424	33.90
	10%	4.379	34.27
	20%	4.299	34.89
	30%	4.412	34.03
	40%	4.404	34.05
2%	0%	4.496	33.36
	10%	4.470	33.57
	20%	4.379	34.21
	30%	4.424	33.90
	40%	4.482	33.52
3%	0%	4.492	33.92
	10%	4.441	33.80
	20%	4.403	34.08
	30%	4.361	34.41
	40%	4.390	34.17

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Table 4: Average result of UPV Test of Concrete with GGBS and all Bacteria percentages Before crack formation

Bacteria solution	GGBS in Percentage	Ultra Sonic Pulse Velocity (UPV)	
		Velocity	Time
1%	0%	2.254	66.82
	10%	2.309	65.16
	20%	2.312	65.22
	30%	2.342	64.64
	40%	2.469	65.94
2%	0%	2.343	64.06
	10%	2.312	65.52
	20%	2.217	67.85
	30%	2.146	70.15
	40%	2.441	61.63
3%	0%	2.338	64.17
	10%	2.482	60.91
	20%	2.175	69.26
	30%	2.225	67.15
	40%	2.305	65.24

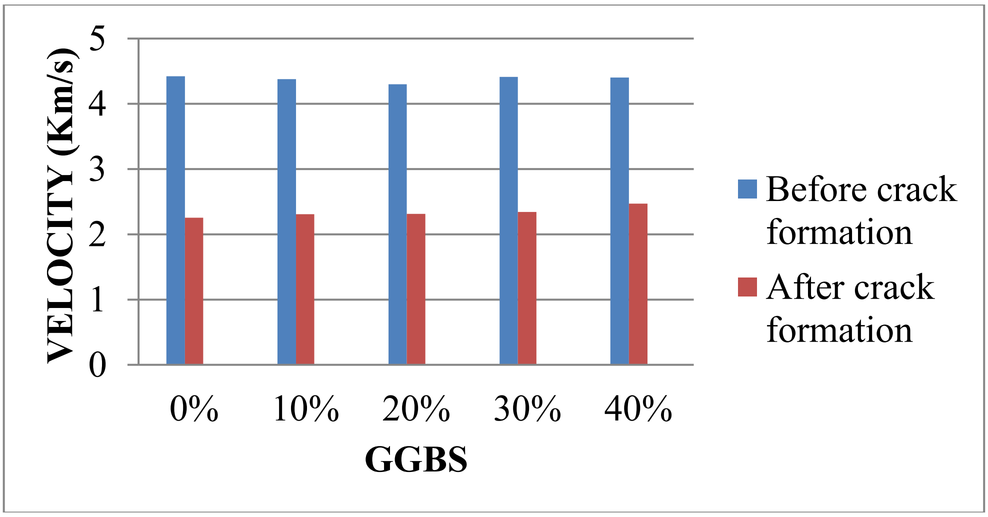

Fig 5: Graph on UPV test results for before crack formation and after crack formation with 1% of bacteria solution.

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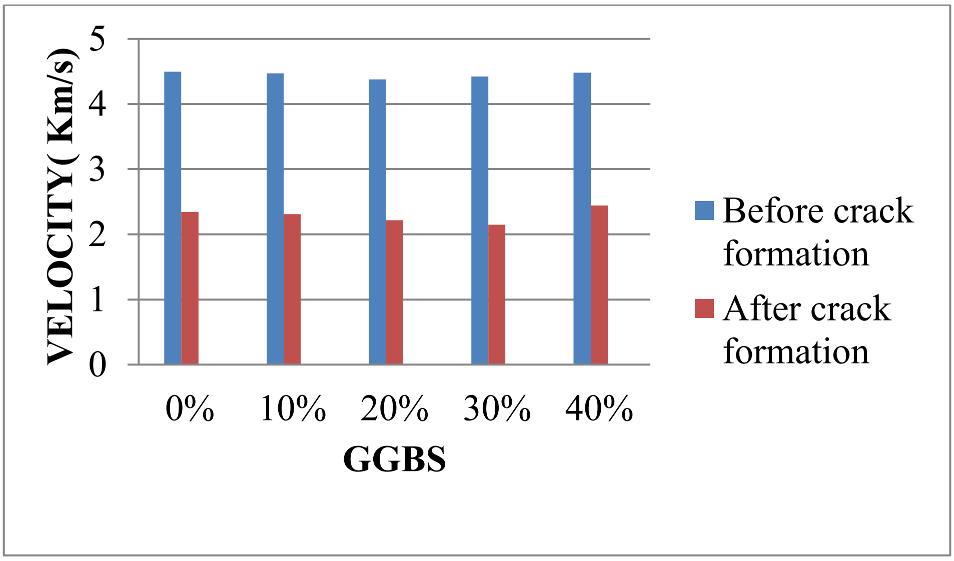

Fig 6: Graph on UPV test results for before crack formation and after crack formation with 2% of bacteria solution.

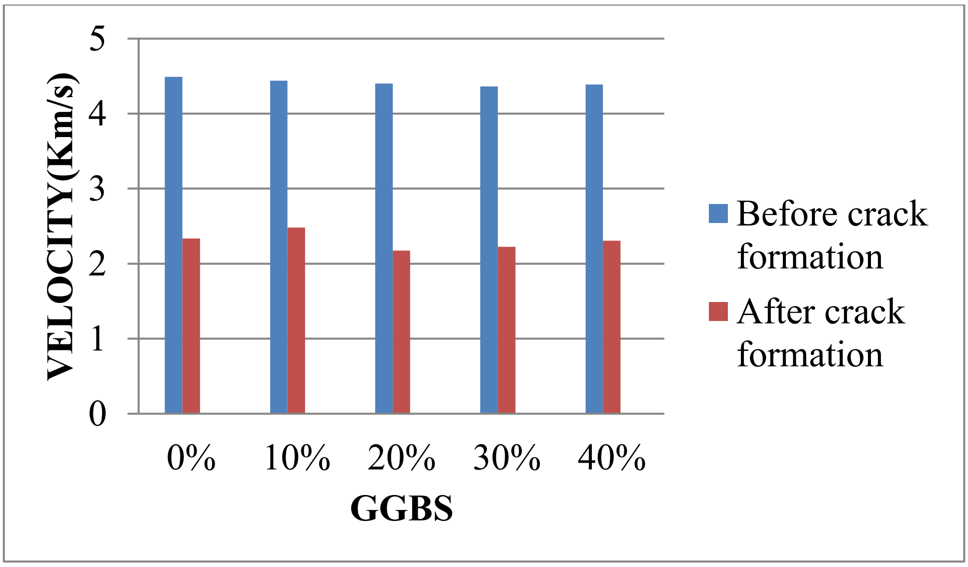

Fig 7: Graph on UPV test results for before crack formation and after crack formation with 3% of bacteria solution.

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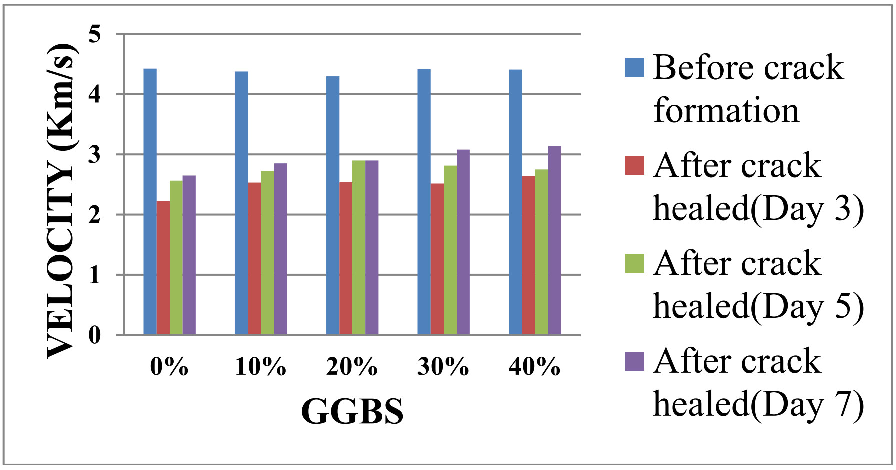

Fig 8: Graph on UPV test results for 3 days, 5 days and 7 days with 1% of bacteria solution.

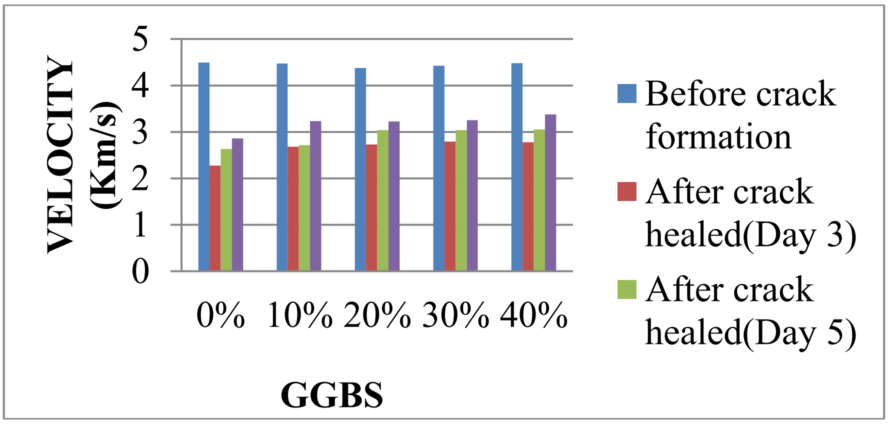

Fig 9: Graph on UPV test results for 3 days, 5 days and 7 days with 2% of bacteria solution.

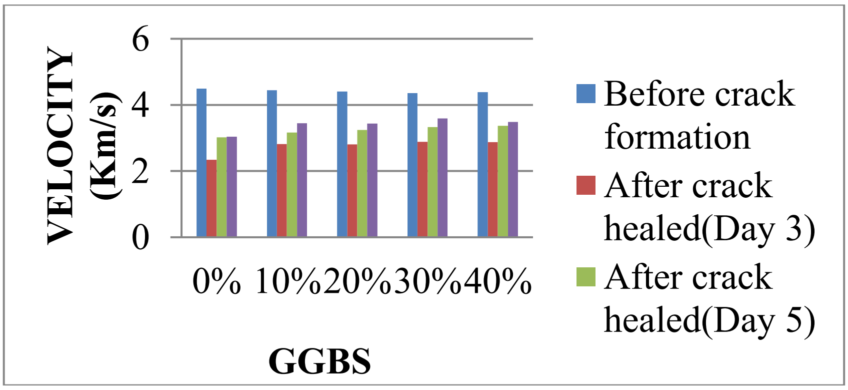

Fig 10 Graph on UPV test results for 3 days, 5 days and 7 days with 3% of bacteria solution.

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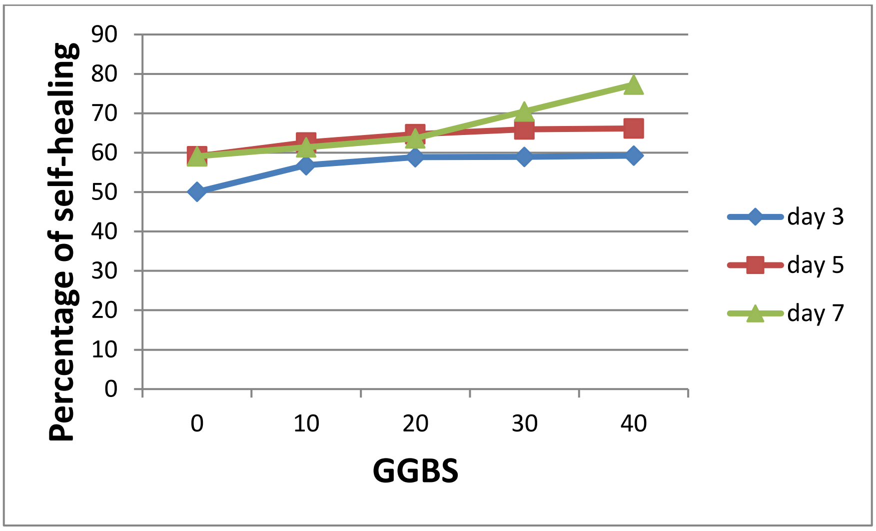

Fig 11: Line graph on self-healing with 1% bacteria and all GGBS percentages for day 3, day 5 and day 7.

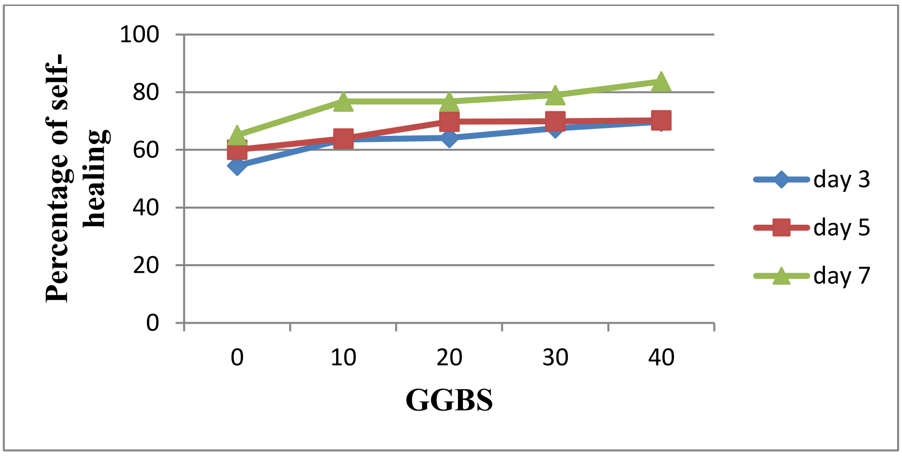

Fig 12: Line graph on self-healing with 2% bacteria all GGBS percentages for day 3, day 5 and day 7

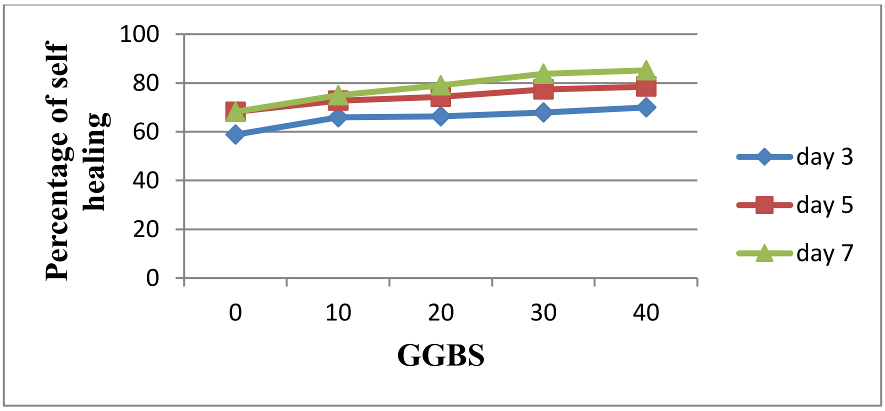

Fig 13: Line graph on self-healing with 3% bacteria all GGBS percentages for day 3, day 5 and day 7

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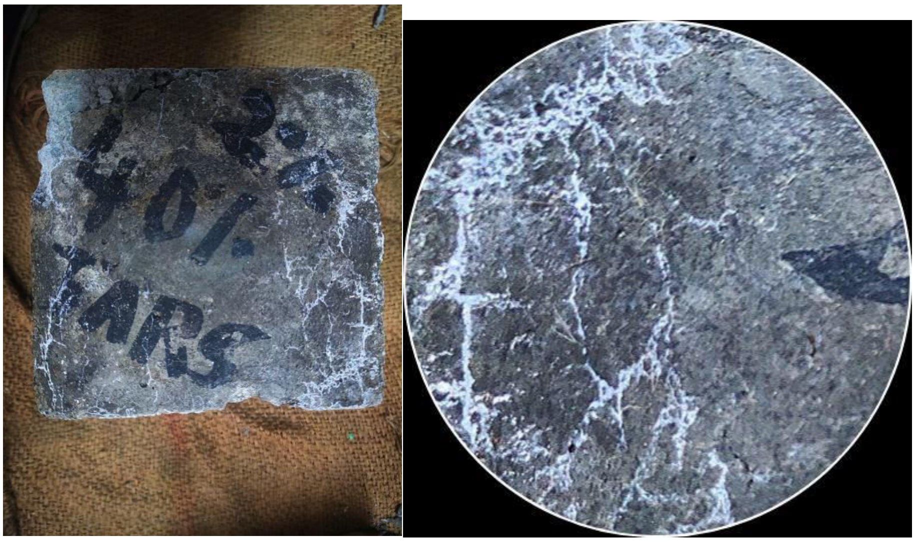

Fig 14: Crack healed after the compressive test at day 3

From Fig 5 It is observed the UPV reading from hardened concrete cubes are having the greater value than that of reading observed after the crack state. It is clearly indicated that the ultrasonic waves are highly distracted due to internal cracks developed in the concrete samples and hence UPV readings are shown lesser value in the cracked value samples. The same kind of effect is observed in the concrete samples of 1%, 2%and 3% of bacterial solution and added samples.These variations are also shown in Fig 6 and 7.

From Fig 8 It is observed that in normal concrete is self healed up to 59.09% where as concrete with GGBS is healed up to 77.27% for 1% bacterial solution added concrete.

From Fig 7.1.2.9 It is observed that in normal concrete is self healed up to 65.11% where as concrete with GGBS is healed up to 83.72% for 2% bacterial solution added concrete.

From Fig 10 It is observed that in normal concrete is self healed up to 68.18% where as concrete with GGBS is healed up to 85.16% for 3% bacterial solution added concrete.

From fig 12 and 13 It is clearly shown that a addition of GGBS to the self-healing concrete improves the performance of self-healing concrete. However in the previous research (**Shariq et al. 2008**). The addition of GGBS to the cement beyond 40% is affecting the strength of concrete. Therefore in this study the replacement of cement by GGBS is done only up to 40%.

V.CONCLUSION AND FUTURE WORK

The following points are concluded based on the investigation

- In the present study, an attempt was made to study the effect of partial cement replacement with GGBS in self-healing concrete. M40 was selected as a high-performance compound based on compressive strength.
- High level increase of GGBS content in concrete decreases the quality and strength of concrete but partial replacement up to 40% of GGBS gives more strength to the concrete.
- Bacillus subtilis can be produced in the laboratory and it is safe and cost effective.
- Based on the study, It clearly shows the UPV readings is highly distracted for the cracked samples compared with the hardened un cracked samples.

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- It is observed that the normal concrete are self-healed up to 59.09%, 65.11% and 68.18% whereas GGBS replaced samples is healed up to 77.27%, 83.72% and 85.16% for 1%, 2% and 3% bacterial solution added respectively.
- The self-healing of concrete is more effective, when the addition of bacillus subtilis bacteria is 3%.
- Bacterial concrete technology and it's repair to cracks have proved to be better than many conventional technologies, because of its eco-friendly nature and very convenient for usage.
- This innovative concrete technology will soon prove the basis for an alternative and high quality structures that will be cost effective and environmentally safe.
- The application of microbial concrete to construction may also simplify some of the existing construction processes and revolutionize the ways of new construction process.

In future Self-healing concrete is used in tunnel lining and constructed from steel and concrete in many forms. Walls of the building, highway bridges and in concrete floor . And used in structural basement and Marine structures.

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