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A Study on Performance of Standard Grade Bacterial Concrete with Fly Ash

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***Abstract*:-Concrete is prone to micro crack formation which is undesirable because they provide an open pathway for the ingress of water and other deleterious substances. Main reason to prevent cracks or limit crack width is to enhance the durability of the structure. Concrete surface treatments with water proofing materials to prevent the access of aggressive substances are a common way to repair concrete structures. These cracks should be repaired to increase the strength and durability of the structure, using either epoxy injections or latex treatment. However, the most common surface treatments include using organic polymers (epoxy, acrylics and polyurethanes). The characteristics of pore structure of concrete have a direct influence on its durability. One way to avoid costly manual maintenance and repair is to incorporate an autonomous self-healing mechanism in concrete. One such alternative repair mechanism, i.e. a novel technique based on the application of bio mineralization of bacteria in concrete. The bacteria present in the concrete rapidly fill cracks through calcite production. The search for new environmental friendly construction materials like fly ash which can improve the strength and durability of concrete structures has developed interest in self healing bacterial concrete with Fly Ash. The present experimental investigation is carried out to study the mechanical and durability properties of M40 grade concrete using Sporosarcina Pasteurii which would make it, self-healing. The bacterial concentrations were varied by 10^5, 10^6 and 10^7cells/ml. The percentage replacement of fly ash used were 0%, 10%, 20% and 30% by mass of cement. The experiments were carried out to evaluate the effect of Sporosarcina Pasteurii on the compressive strength, split tensile strength, flexural strength, strength loss and weight loss at 7, 28, 56 and 90 days. The test results indicated that inclusion of Sporosarcina Pasteurii with mix 1x10^6 cells/ml bacteria and 20% fly ash gives optimum performance in terms of compressive strength, split tensile and the mix with 1x10^7 cells/ml bacteria and 30% fly ash gives optimum performance in terms of strength loss and weight loss and acid durability factor.**

Keywords: Concrete, Self healing concrete, Fly Ash, Bacteria, Mechanical properties, Durability.

1.0 INTRODUCTION

Rapid growth and development in the infrastructure can be seen over the past hundred years in the construction activities. In this development concrete plays an important role in the development of the infrastructure in the day-to-day life. Among all the building materials concrete is the artificially made building material which is got special characteristics.

The major drawback of concrete is its low tensile strength due to which microcracks occurs when the structure is subjected to sustained loading and exposed to aggressive environmental conditions results in to decreasing the life of the structure. Entry of harmful chemicals through these cracks may result in concrete deterioration through chemical attack and can also cause corrosion of steel reinforcement. This corrosion leads to increase in crack damage resulting in loss of strength and stiffness of concrete structures. Even though there are many crack repairing techniques to reduce the extent of cracking by available modern technology, There are large number of techniques to repair cracks in concrete such as Grouting,Guniting,Sealing with epoxy's and many more.However,the above mentioned techniques are costly and also in high maintenance cost. In order to overcome this a special type of concrete is developed with the introduction of bacteria in concrete which results in bacterial concrete. This is also called as Self Healing concrete.

In view of the global sustainable development, it is imperative that supplementary cementing materials be used to replace large proportions of cement in the concrete industry. The most available supplementary cementing material worldwide is fly ash, a by-product of thermal power stations. which indicates that there is a potential for the use of much larger amounts of fly ash in concrete, and therefore, for significant reductions in cement production resulting in considerable environmental benefits.' To considerably increase the utilization of fly ash that otherwise is being wasted, and to have a significant impact on the production of cement, it is necessary to advocate a use of concrete that will incorporate large amounts of fly ash as a replacement for cement.

An attempt is made to study the properties of bacterial concrete using Sporosarcina pasteurii (Bacillus Pasteuri) along with fly ash as partial replacement to cement.

Bacteria The "Bacterial Concrete" is a concrete which can be made by embedding bacteria in the concrete that are able to constantly precipitate calcite. This phenomenon is called microbiologically induced calcite precipitation. It has been shown that under favorable conditions for instance Sporosarcina pasteurii(Bacillus Pasteruii), a common soil bacterium, can continuously precipitate a new highly impermeable calcite layer over the surface of an already existing concrete layer.

Microbiologically induced calcium carbonate precipitation (MICCP) is comprised of a series of biochemical reactions.In this process, an alkalophilic soil microorganism, Bacillus pasteurii, plays a key role by producing urease that hydrolyzes urea to ammonia and carbon dioxide.In aqueous environments, the overall chemical equilibrium reaction of calcite precipitation can be decribed as:

$[Ca^{2+}]+ [CO_3^{2-}]$ --------> $CaCO_3$

Possible biochemical reactions in Urea-$CaCl_2$ medium to precipitate $CaCO_3$ at the cell surface can be summarized as follows

$CO (NH_2)_2+H_2O$--------->$NH_2COOH+NH_3$

$NH_2COOH+H_2O$--------> $NH_3 + H_2CO_3$

$2OH+ H_2CO_3$ -------> $CO_3^{2-} + 2H_2O$

Cell - $Ca^{2+}+ CO_3^{2-}$ ------->Cell – $CaCO_3$

Bacterial spores are specialized cells which can endure extreme mechanical and chemical stresses and spores of this specific genus are known to remain viable for up to 200 years. Spores are dormant but viable bacterial spores immobilized in the concrete matrix will become metabolically active when revived by water entering freshly into the concrete.

2.0 RESEARCH SIGNIFICANCE

Cracks in a concrete structure reduces the life and cracks of dimension smaller than that of cement (micro cracks) cannot be filled with chemicals. Crack treatment processes involve harsh materials such as cement and chemicals adding to the pollution of environment. There have been instances of allergic reactions due to chemicals faced by the inhabitants and handlers. Bacteria secretes calcite which fills the cracks and compressive strength and durability of concrete is improved.The environmental impacts of poor disposal of mineral wastes like fly ash, GGBS need to be addressed. Use of fly ash in the manufacture of concrete reduces its interaction with the environment as well plays an important role in imparting strength and durability to the concrete. As there is limited literature available on the study of properties and characteristics of such combination, it is intended to investigate in this direction.

3.0 MATERIALS

3.1 Cement

Ordinary Portland cement of 53 grade available in local market conforming to specifications of IS: 12269-1987 having specific gravity of 3.06 is used.

3.2 Fine Aggregate

Locally available clean, well-graded, natural river sand conforming to specifications of IS 383-1970 having specific gravity of 2.50 is used.

3.3 Coarse Aggregate

Crushed granite angular aggregate of size 20 mm nominal size from local source with specific gravity of 2.65 is used.

3.4 Water

Locally available potable water conforming to IS 456 is used.

3.5 Fly Ash

Fly Ash of class ‘F’ with 2.32 specific gravity is used

3.6 Microorganisms

Sporosarcina Pasteurii, a soil bacterium which is cultured and grown at laboratory of Biotechnology Department, CBIT, is used in 10^5,10^6 and 10^7cells/ml concentrations.

Calcium lactate is added by 1% of mass of cement.

3.7 Grade designation: M40 grade concrete

3.8 Culture of Bacteria

The pure culture was isolated from the soil sample and is maintained constantly on nutrient agar slants. It forms irregular dry white colonies on nutrient agar. Whenever required a single colony of the culture is inoculated into glass bottles containing nutrient broth of 13 grams in 1000 ml of distilled water and the growth condition is maintained at 37°C temperature. The medium composition required for growth of culture is Peptone: 5 gm/lit., NaCl: 5 gm/lit., Yeast extract: 3 gm/lit.

3.9 Maintenance of Stock Cultures

Stock cultures of Sporosarcina Pasteurii were maintained on nutrient agar slants. The culture was streaked on agar slants with an inoculating loop and the slants were incubated at 37°C. After 2-3 days of growth, slant cultures were preserved under refrigeration (4°C) until further use. Contamination from other bacteria was checked periodically by streaking on nutrient agar plates.

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4. 0 EXPERIMENTAL PROGRAM

Table 1: Types of Mix

Mix	Fly Ash (%)	Bacteria (cells/ml)
NC	0	0
105BC	0	$1x10^5$
105BCF10	10	$1x10^5$
105BCF20	20	$1x10^5$
105BCF30	30	$1x10^5$
106BC	0	$1x10^6$
106BCF10	10	$1x10^6$
106BCF20	20	$1x10^6$
106BCF30	30	$1x10^6$
107BC	0	$1x10^7$
107BCF10	10	$1x10^7$
107BCF20	20	$1x10^7$
107BCF30	30	$1x10^7$

4.1 Compressive Strength Test

In the present investigation, compressive strength is determined as per the procedure given in IS 516:1959. Compressive strength is determined on 150 x 150 mm cubes using UTM at a loading rate of 140kg/cm ^{2}/min. Compressive strength = P /A

P - Maximum load applied on the specimen during the test in Newton

A - Cross-sectional area calculated from the mean dimensions of the section in mm^2

4.2 Split Tensile Strength Test

A diametric compressive load will be applied along the length of the sample at a continuous rate until failure occurs. This loading induces tensile stresses on the plane containing the applied load, causing tensile failure of the sample. IS 5816:1999 formed the basis for the development of this procedure. The measured splitting tensile strength of the specimen shall be calculated using the following formula F_{ct}=2P/Π dl

P = Maximum load applied on the specimen during the test in Newton

l = length of the specimen in mm

d = cross sectional dimension of the specimen in mm

4.3. Durability (Acid test)

The chemical resistance of the concretes was studied through chemical attack by immersing concrete blocks in an acid solution. After 28 days period of curing, the specimens were removed from the curing tank and their surfaces were cleaned with a soft nylon brush to remove weak reaction products and loose materials from the specimen. The initial weights were measured and the specimens were identified with number. The specimens were immersed in 5% $H2SO_4$ and HCL and reading for weight and compressive strengths were recorded for all mix types at 7, 28, 56 and 90 days. The solution was replaced at regular intervals to maintain constant concentration throughout the test period.

Acid Durability Factor (ADF) can be designed as follows. [5]

Acid Durability Factor (ADF) = Sr N / M

where, Sr = relative strength at N days, (%)

N = number of days at which the durability factor is needed.

M = number of days at which the exposure is to be terminated.

Acid attack test was terminated at 90 days. So, M is 90 in this case.

5.0 TEST RESULTS

5.1 Compressive Strength

Table 1. Compressive strength values

Mix designation	**Cell concentration (cells / ml)**	**Average cube compressive strength in MPa**			
		7 days	**28 days**	**56 days**	**90 days**
NC	-	32.44	48.39	48.76	49.10
105BC	10^5	36.29	50.88	52.93	54.03
105BCF10		34.07	48.07	51.19	54.69
105BCF20		33.33	48.71	54.29	56.44
105BCF30		32.60	47.81	50.74	55.31
106BC		36.69	50.91	52.80	55.48
106BCF10		34.32	47.68	51.33	55.16

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106BCF20	10^6	34.69	48.58	53.81	57.83
106BCF30		32.46	47.39	51.27	55.56
107BC	10^7	36.28	50.18	53.24	54.21
107BCF10		34.21	47.22	51.73	55.03
107BCF20		33.25	48.39	52.31	56.47
107BCF30		32.06	47.19	50.38	55.55

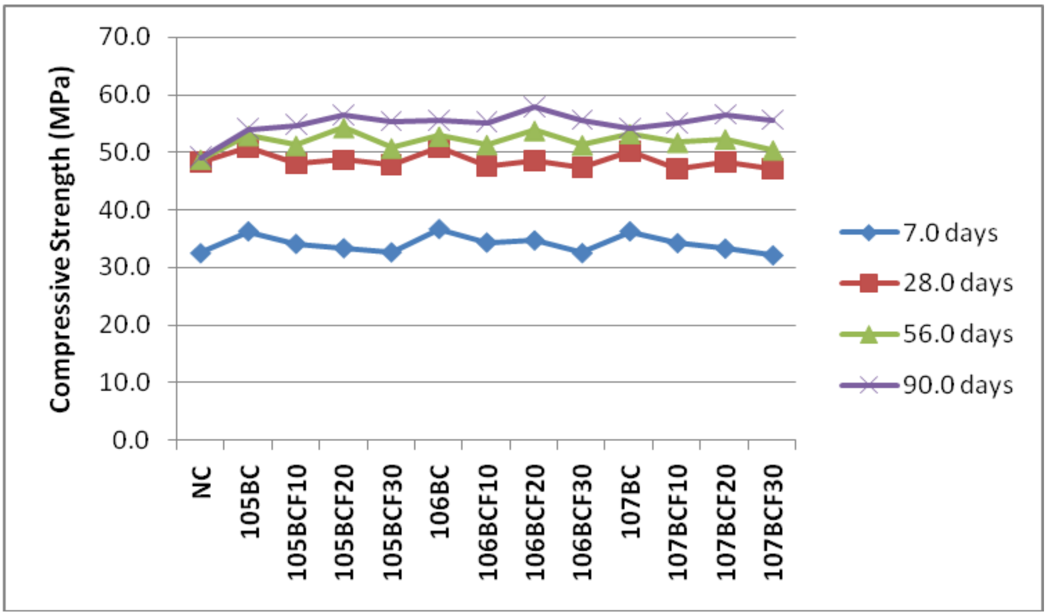

Figure1 Comparison of Compressive Strength development

5.2 Split tensile Strength

Table 2. Split Tensile strength values

Mix designation	Cell concentration(cells / ml)	Split Tensile strength (N/mm^2)	
		28 days	90 days
NC	-	3.76	4.22
105BC	10^5	3.86	4.47
105BCF10		3.72	4.49
105BCF20		3.76	4.52
105BCF30		3.92	4.47
106BC	10^6	3.89	4.45
106BCF10		3.78	4.51
106BCF20		3.94	4.62
106BCF30		3.75	4.49
107BC	10^7	3.90	4.41
107BCF10		3.69	4.49
107BCF20		3.81	4.49
107BCF30		3.79	4.46

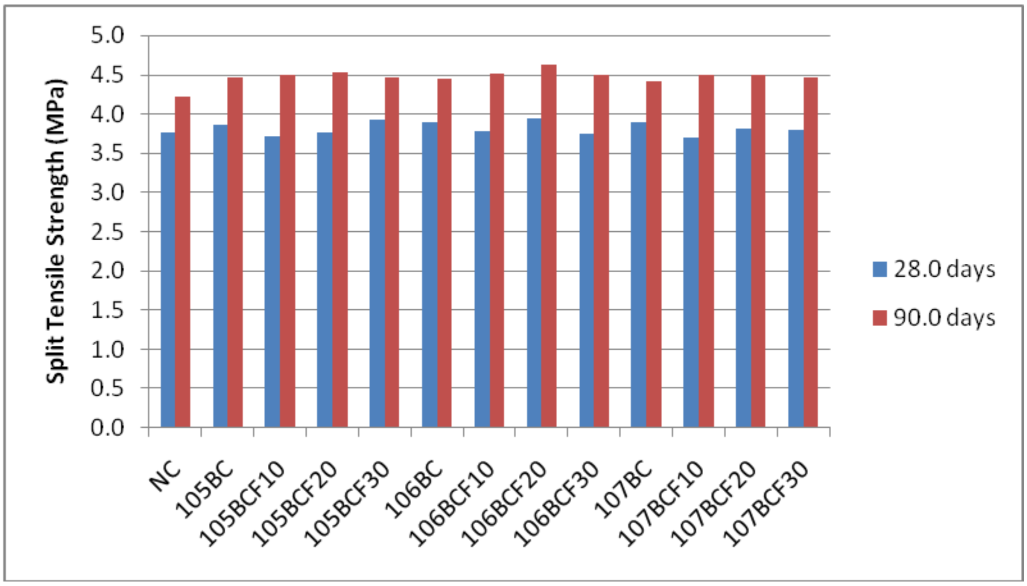

Figure 2: Split Tensile strength values at 28 and 90 days curing

5.3. Durability

5.3.1 Acid Test

Table 3. Percentage weight loss immersed in 5% H_2SO_4 acid

Mix designation	Cell concentration (cells / ml)	Percentage weight loss (H_2SO_4)			
		7 days	28 days	56 days	90 days
NC	-	0.53	1.67	5.55	6.91
105BC	10^5	0.49	1.78	4.52	5.83
105BCF10		0.50	1.71	3.82	5.80
105BCF20		0.93	1.83	4.58	5.89
105BCF30		1.02	1.79	5.02	6.00
106BC	10^6	0.60	1.69	4.46	5.60
106BCF10		1.12	1.78	5.30	5.80
106BCF20		1.17	1.77	5.00	5.55
106BCF30		1.09	1.79	4.92	5.89
107BC	10^7	0.55	1.71	4.34	5.61
107BCF10		0.72	1.94	4.24	5.64
107BCF20		0.98	1.95	4.85	5.57
107BCF30		0.49	1.61	4.80	5.61

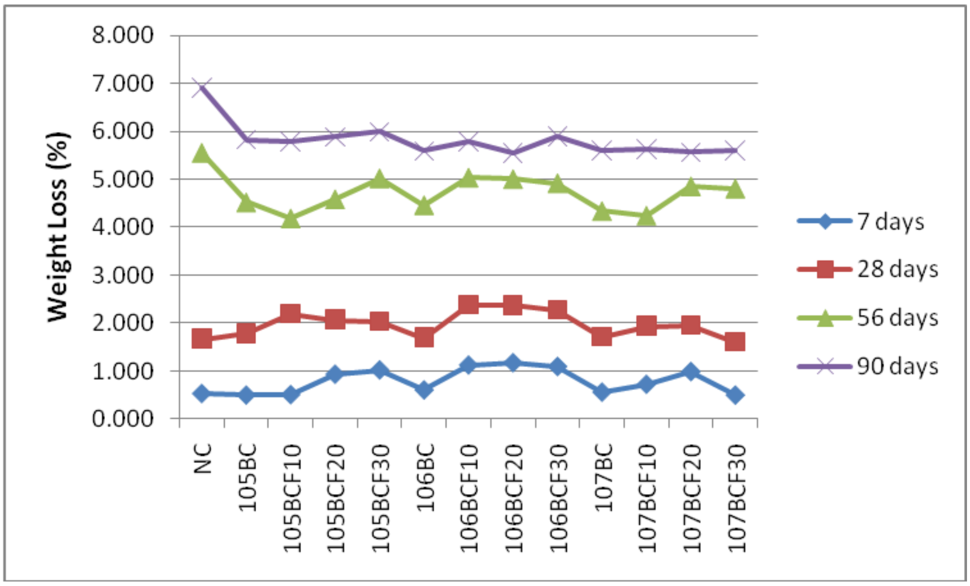

Figure 3. Percentage weight loss after immersion in 5% H_2SO_4

Table 4.Percentage strength loss after immersion in 5%H_2SO_4

Mix designation	**Cell concentration(cells / ml)**	**Percentage strength loss (H_2SO_4)**			
		7 days	**28 days**	**56 days**	**90 days**
NC	-	4.34	7.65	11.19	13.66
105BC	10^5	3.83	7.24	10.71	12.48
105BCF10		4.04	7.83	9.11	11.03
105BCF20		3.28	7.45	9.51	11.17
105BCF30		3.34	6.79	8.19	10.15
106BC	10^6	5.81	8.35	8.89	10.91
106BCF10		4.31	7.46	8.63	11.18
106BCF20		3.39	7.68	9.09	10.76
106BCF30		5.47	7.73	8.83	10.58
107BC	10^7	5.81	7.74	8.89	11.11
107BCF10		3.25	8.15	9.51	10.32
107BCF20		3.41	7.12	6.43	11.37
107BCF30		5.53	7.43	8.83	10.21

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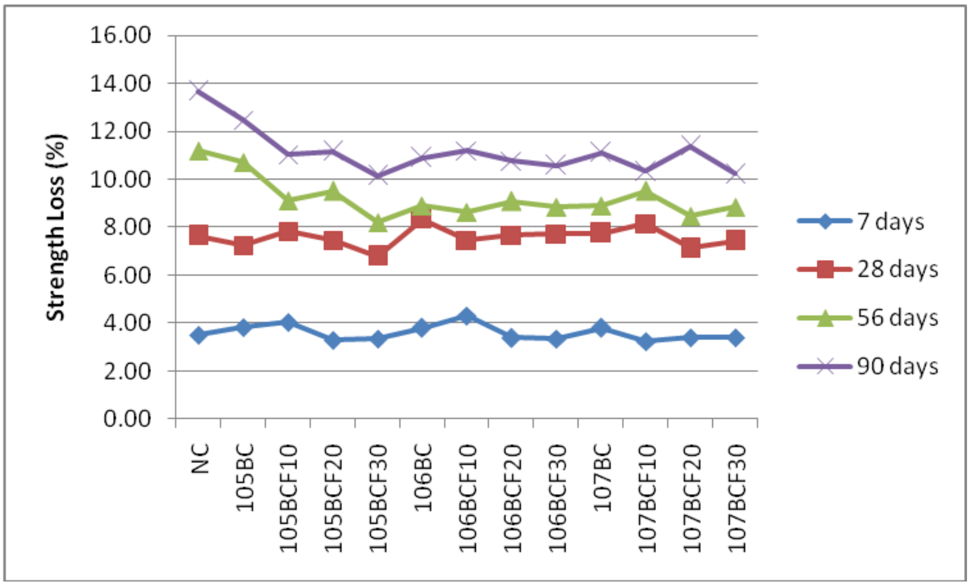

Figure 4.Percentage strength loss after immersion in 5%H_2SO_4

Table 5 Acid Durability Factor after immersion in 5%H_2SO_4

Mix designation	Cell concentration(cells / ml)	Acid Durability Factor(H_2SO_4)			
		7 days	28 days	56 days	90 days
NC	-	7.44	28.73	55.26	86.34
105BC	10^5	7.48	28.86	55.56	87.52
105BCF10		7.46	28.68	56.56	88.97
105BCF20		7.52	28.79	56.31	88.83
105BCF30		7.52	29.00	57.12	89.85
106BC	10^6	7.33	28.51	56.69	89.09
106BCF10		7.44	28.79	56.86	88.82
106BCF20		7.51	28.72	56.56	89.24
106BCF30		7.35	28.71	56.73	89.42
107BC	10^7	7.33	28.70	56.69	88.89
107BCF10		7.53	28.57	56.30	89.68
107BCF20		7.51	28.89	58.22	90.68
107BCF30		7.35	28.80	56.73	90.21

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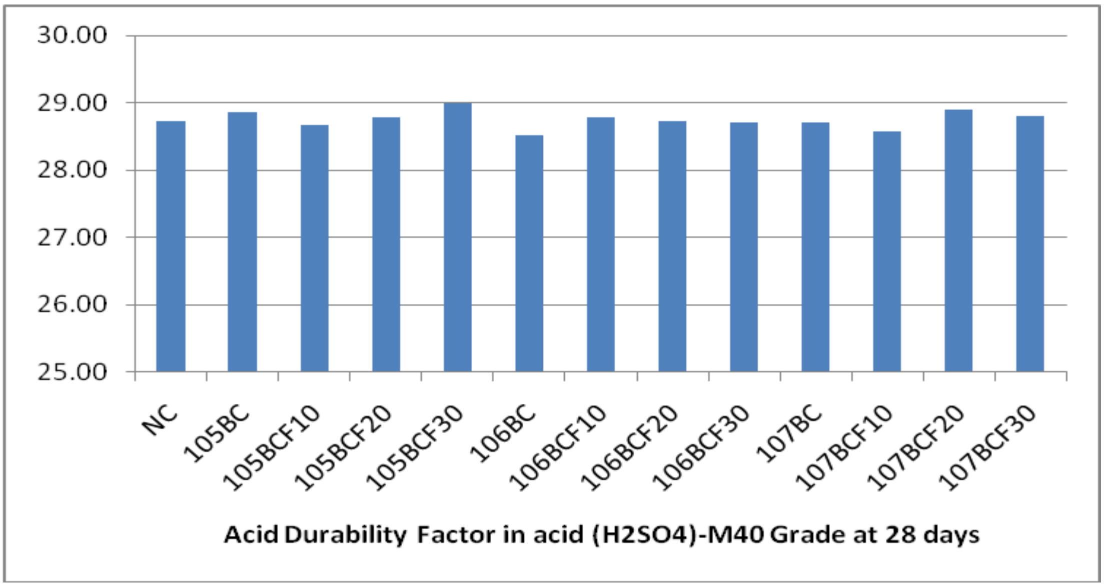

Figure 5. Acid Durability Factors after immersion in 5%H_2SO_4 at 28 days

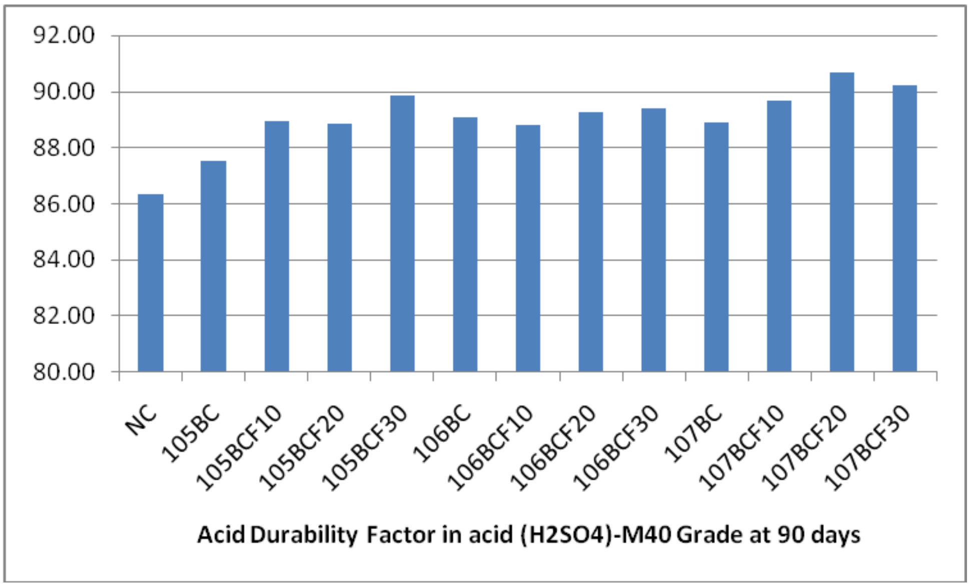

Figure 6. Acid Durability Factors after immersion in 5%H_2SO_4 at 90 days

6.0 MICROSTRUCTURE

Scanning Electron Microscope (SEM): The microstructure of the fly ash-based bacterial concrete with different calcium contents was observed by SEM. It was notable that the Figure 7 of normal concrete matrix was not homogeneous and contained small pores and cracks. Figure 8, indicates normal concrete sample which had no depositions of calcium carbonate whereas Figure 9 shows good amount of calcium carbonate deposition on the surface and less number of pores are seen in comparison to the samples of normal concrete. Figure 10, shows a reasonable amount of calcium carbonate content along with fairly good amount of silica and this is due to addition of fly ash in the concrete. And it is consistent with the values of higher compressive strength for bacterial concrete and bacterial concrete with fly ash compared to normal concrete. From the micrographs of figure 9 and figure 10, it can be seen that increase in calcite content in white colour formed on the surface and fly ash particles resulted in a more compact and denser matrix filling the voids and cracks in the concrete improving the pore structure of the concrete. Due to reaction of silica with free lime at later age forms calcium silicate hydrate compound. Because of this hydrated compound the values of compressive strength for bacterial concrete with addition of fly ash are higher at 90 days compared to normal concrete.

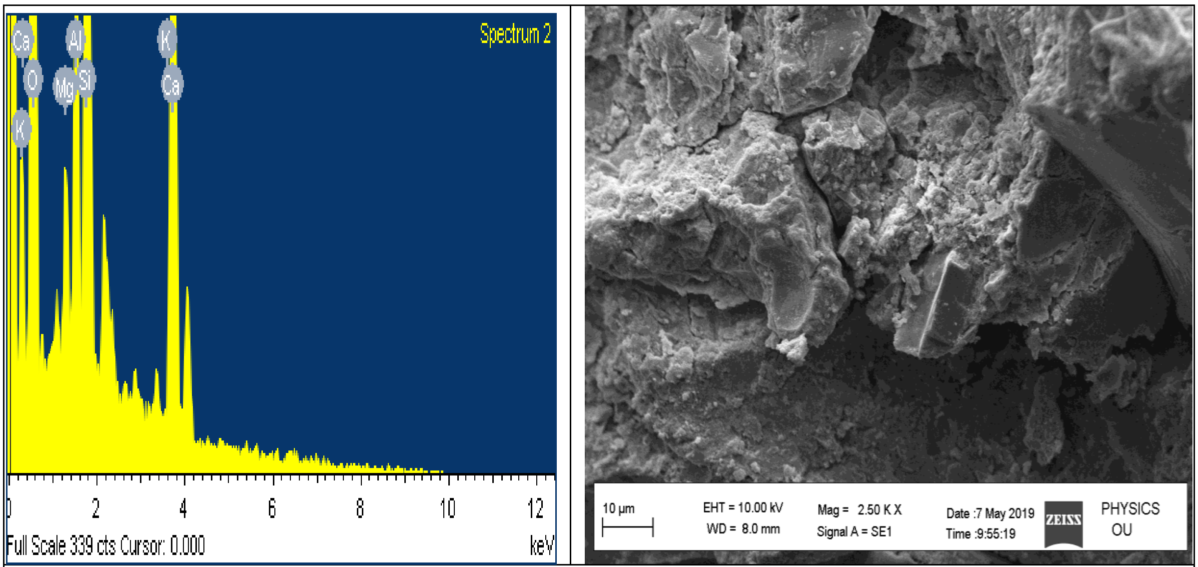

Fig.7: SEM Image of Normal Concrete @ 90 Days

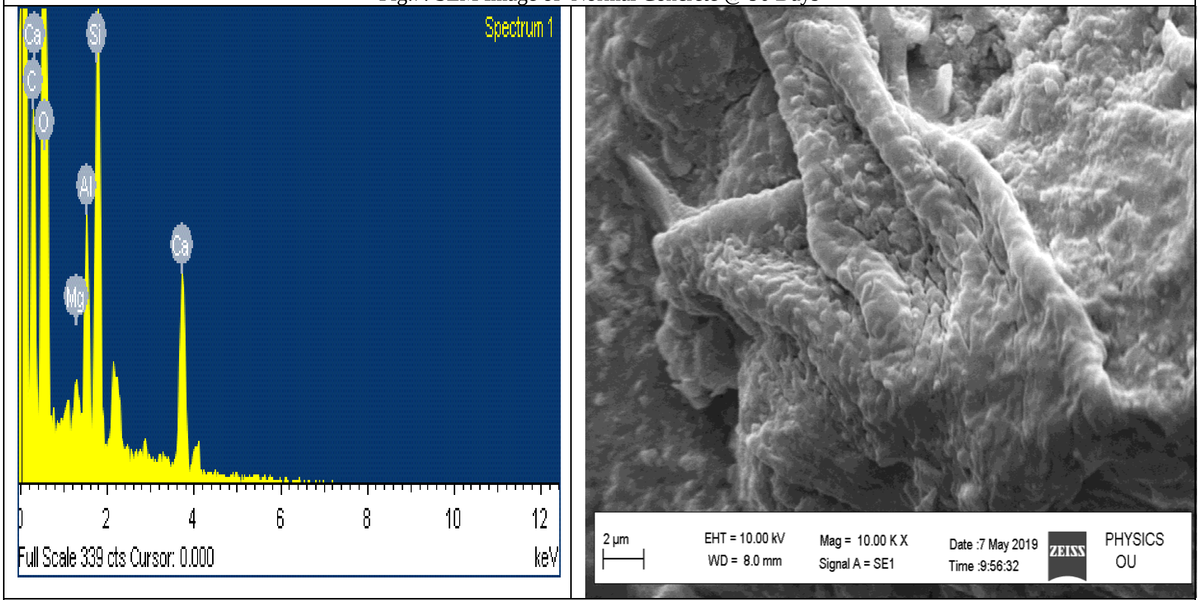

Fig.8: SEM Image of Bacterial concrete @ 90 Days

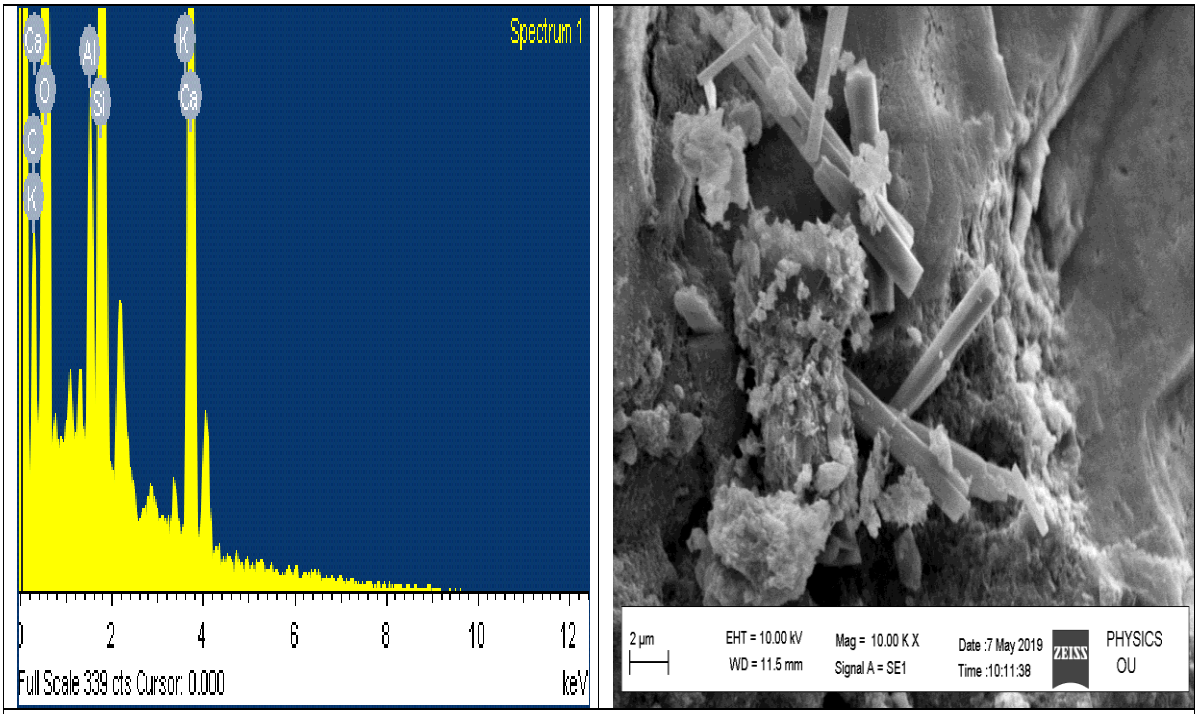

Fig.9: SEM Image of Bacterial concrete with Fly Ash @ 90 Days with Bacteria & Fly Ash

7.0 DISCUSSIONS

In M40 grade concrete the compressive strength is increased by maximum of 17.80% at 90 day for 106BCF20 when compared to conventional concrete as fly ash has the property of gaining strength over longer period and it is observed that compressive strength is decreasing with increase in fly ash content.

The maximum splitting tensile strengths obtained as 4.6 Mpa at the age 90 days for 106BCF20. Increase in compressive strength and split tensile strength values is due to the reason that the density of the concrete has been increased due to filling of cracks with calcium carbonate crystals secreted by the bacteria induced in concrete and fly ash gaining strength at later age.

It is observed that weight loss percentage for 107BCF30 is 5.61% compared to normal concrete of 6.91% at 90 days of immersion in H_2SO_4 It is observed that strength loss percentage for 107BCF30 is 10.21% compared to normal concrete of 13.66% at 90 days of immersion in H_2SO_4 . Acid durability factor is found to be high for bacterial concrete 107BCF20 as 90.68 compared to 86.34 of normal concrete.

8.0 CONCLUSIONS

Concrete mix 106BCF20 with $1x10^6$ cells/ml bacteria and 20% Fly Ash has given maximum compressive strength and split tensile strength compared to other mixes.

Concrete mix 107BCF30 with $1x10^7$ cells/ml bacteria and 30% Fly Ash has shown better performance in durability properties like resistance to acid attack compared to other mixes.

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