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Strength And Durability Study On Fly Ash Modified Microbial Concrete

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Abstract: Concrete is an essential building material which is used in the construction of infrastructure and buildings. Its brittle nature with low tolerance for strain makes it vulnerable to cracking. These cracks expose the steel reinforcement to the elements, leading to corrosion which increases the maintenance costs and compromises the structural integrity. Microbial concrete is prepared by adding bacteria (Bacillus subtilis) which heals the damage sustained by the concrete structure. Fly ash continues the hydration after 28 days and also produces the secondary C-S-H gel very slowly. So the hydrated products from fly ash modify the microstructure and seal the crack. This project is an experimental investigation carried out to evaluate the influence of fly ash on the strength, sulphate resistance and rapid chloride permeability of microbial concrete made with Bacillus subtilis bacteria. Cement was replaced with 5%, 15% and 25% of fly ash by weight and the cell concentration of 105 cells/ml of bacteria was used in making the concrete mixes. Tests were performed for compressive strength, split tensile strength, flexural strength, sodium sulphate exposure and rapid chloride permeability. Test results indicated that inclusion of fly ash in microbial concrete enhanced the compressive strength and impermeability thereby increasing the durability of microbial concrete. The increase in strength of microbial concrete is mainly due to filling of the pores and voids with microbiologically induced calcium carbonate precipitation. The optimum percentage of fly ash is found to be 5% for cement replacement for the modification of microbial concrete. Combined effect of calcite deposition and C-S-H production improved the impermeability of microbial fly ash concrete resulted in very less reduction in strength of 0.3% after 90 days of sodium sulphate exposure and nearly 5% reduction in rapid chloride permeability than microbial concrete. The incorporation of fly ash significantly improves the strength and durability of microbial concrete through combined self-healing effect of fly ash and Bacillus subtilis bacteria.

KEYWORDS: Microbial Concrete, Fly ash, Bacillus subtilis, Durability studies.

I.INTRODUCTION

Self-healing concrete is a product that will biologically produce limestone to heal cracks that appear on the concrete structures . Specially selected types of the bacteria genus Bacillus, along with a calcium-based nutrient known as calcium lactate, are mixed with the ingredients of the concrete during the mixing process of concrete. These self-healing agents can lie passive within the concrete for up to 200 years. However, when a concrete structure cracks and water starts to seep through the cracks that appear in the concrete, the spores of the bacteria germinate on contact with the water and nutrients. When activated, the bacteria start to feed on the calcium lactate. As the bacteria feeds oxygen, the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface, thereby seals the crack. It is similar to the process in the human body by which bone fractures are naturally healed by osteoblast cells that mineralise to re-form the bone.

The consumption of oxygen during the conversion of calcium lactate to limestone increases the durability of steel reinforced concrete constructions as oxygen is essential for corrosion of steel.

1.1. Finding the Right Bacteria

The first step of the research was to find bacteria capable of surviving in an extreme alkaline condition. Cement and water when mixed together have a pH value of up to 13, usually a hostile environment for life: most organisms die in an environment with a pH value of 10 or above. The search concentrated on microbes that flourish in alkaline environments which can be found in natural environments, such as alkali lakes in Russia, carbonate-rich soils in desert areas of Spain and soda lakes in Egypt. Samples of endolithic bacteria (bacteria that can live inside stones) and bacteria found in sediments in the lakes were collected.

Strains of the bacteria genus Bacillus were found to survive in this high-alkaline environment. In a study conducted in Delft University, the bacteria from the samples were grown in a flask of water that would then be used as the part of the mixing water for the concrete. Various types of bacteria were incorporated into a small block of concrete.

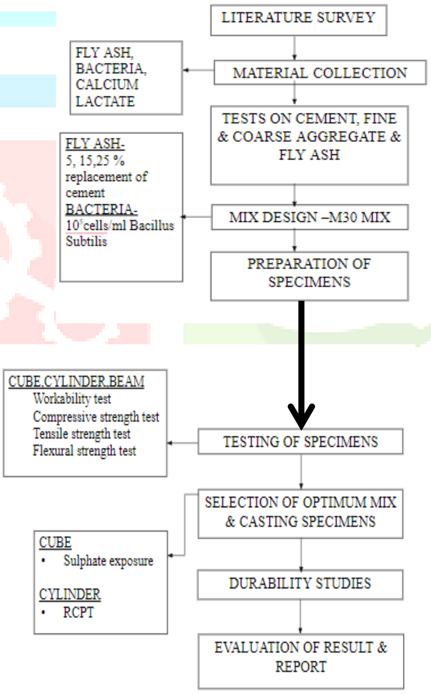
Each concrete block is left for two months to set hard. Then the block was powdered and the remains were tested to check whether the bacteria had survived. The only group of bacteria that were able to thrive were the ones that produced spores similar to plant seeds. The extreme thick cell walls of these spores help them to remain intact for up to 200 years while waiting for a better environment to germinate.

They would become activated when the concrete damaged and cracked, food is available, and water seeps into the structure. This operation decreases the pH of the highly alkaline concrete to values in the range (pH 10 to 11.5) where the bacterial spores become activated. Finding a suitable nutrient for the bacteria that could survive in the concrete was the next problem faced and many different nutrients were tried. Finally it was discovered that calcium lactate was a carbon source that provides biomass. If it starts to dissolve during the mixing process, calcium lactate does not change the setting time of the concrete.

Various bacteria used in concrete are

- Bacillus pasteurii
- Bacillus sphaericus
- Escherichia colli
- Bacillus subtilis

II. METHODOLOGY



III. LITERATURE REVIEW

Jonkers and Schlangen (2019) studied about two component bacteria-based self-healing concrete. The aim of the work was the development of a new type of concrete which promote self-healing of cracks by incorporating bacteria in the concrete. The development of a new type of bacteria-based self-healing concrete appears as new achievement in concrete research 11 history. In this project they have shown the proof-of-principle, i.e. concrete-incorporated bacteria can produce good quantity of minerals which can potentially seal freshly formed cracks.

Achal et al. (2017) have highlighted that natural processes, such as weathering, faults, land subsidence, earthquakes, and human activities, create fractures and fissures in concrete structures that will reduce the service life of the structures. A novel strategy to restore or remediate such structures is MICP using microbes, such as those included in the genus of the Bacillus species. The present study investigated the effects of Bacillus sp. CT-5, isolated from cement, on compressive strength and water-absorption tests. The results with a 36% hike in compressive strength of cement mortar with the addition of bacterial cells were observed. Water absorption of treated cubes was six times less than control cubes as a result of microbial calcite deposition. This 13 work demonstrated that production of “microbi concrete” by B ci us sp. on constructed facilities could enhance the durability of building materials.

Jonkers (2016) investigated the crack healing capacity of a specific bio-chemical additive, consists of a mixture of viable but dormant bacteria and organic compounds packed in porous expanded clay particles. Microscopic techniques and permeability tests revealed that complete healing of cracks occurred in bacterial concrete and partly in control concrete. The mechanism of crack healing in bacterial concrete occurs through chemical conversion of calcium lactate to calcium carbonate by the bacteria. This biochemical process resulted in efficient sealing of concrete cracks with a width of 0.15 mm.

Soundari et al. (2014) discussed a new technique in remediating cracks and fissures in concrete by utilizing microbiologically induced calcite (CaCO3) precipitation. The objective of the study was to study the potential application of bacterial species i.e. Bacillus subtilis to improve the strength of cement concrete. Here we have made an attempt to incorporate dormant but viable bacteria in the concrete matrix which will contribute to the strength of the concrete. In this project, bacterial concrete of grade M25 is prepared. The design mix proportioning is also carried out using IS code. Testing of specimens is carried out at 7 days ,14 days and 28 days of curing by Compression Testing Machine and Universal Testing Machine for corresponding specimens. The Compressive Strength, Split Tensile Strength and Flexural Strength of Bacterial Concrete are found to be more than conventional Concrete.

V. EXPERIMENTAL STUDY

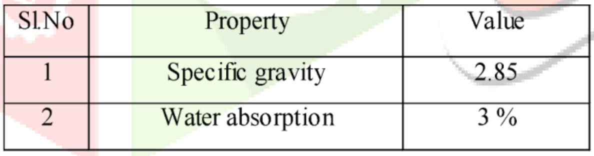
CEMENT

The cement used in the study was OPC 53 grade conforming to IS 4031:1988 (reaffirmed in 2009).

Properties	**Values**
Specific Gravity	3.15
Standard Consistency	38 %
Initial Setting Time	42 min
Fineness	4 %

FINE AGGREGATE

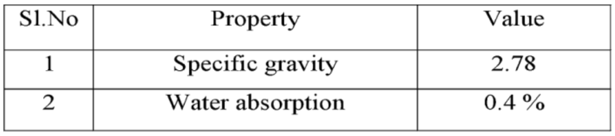
M-sand confirming to Zone II of IS 383:1970 was used as the fine aggregate



Sl.No	Property	Value
1	Specific gravity	2.85
2	Water absorption	3 %

COARSE AGGREGATE

Crushed angular aggregate of maximum nominal size 20 mm used were used as coarse aggregate



Sl.No	Property	Value
1	Specific gravity	2.78
2	Water absorption	0.4 %

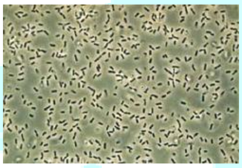
FLY ASH

Chemical composition of Fly ash

Compound	Content (% wt)
SiO_2	53.60
Al_2O_3	24.53
Fe_2O_3	5.47

BACTERIAL SOLUTION:

The bacteria Bacillus Subtilis strain no. JC3 is used in this study. The pure culture of Bacillus Subtilis was collected from the department of Agricultural Microbiology, College of Horticulture, Vellanikkara, Thrissur. It is a laboratory cultured soil bacterium



Optimum dosage- 10^5 cells/ ml bacterial solution

Calcium Lactate ($C_6h_{10}cao_6$. $5H_2O$)

PROPERTIES OF CALCIUM LACTATE

Description	Content (%)
Chloride (Cl)	0.02 % max
Sulphate (SO_4)	0.04 % max
Iron (Fe)	0.005 % max
Heavy metal (As, Pb)	0.002 % max
Acidity	3ml N/1 % max
Alkalinity	1 ml N/1 % max

SUPERPLASTICISER- Conplast 430

Property	Description
Specific gravity	1.20 to 1.22 at 30^0C
Chloride content	Nil (as per IS: 9103- 1999 & BS: 5075)
Air entrainment	Approx. 1% additional air over control
Compatibility	Used with all types of cements except high alumina cement
Toxicity	Non-toxic
Flammability	Non- flammable

MIX PROPORTION

M30 MIX

IS: 10262:2009
MIX PROPORTION- **w/c ratio-0.38**

Cement(kg)	**Fine Aggregate(kg)**	**Coarse Aggregate(kg)**
447.8	689.57	1295.79
1	1.54	2.89

Mixing and Casting

Mix Design for Fly Ash Modified Concrete (M30)

Mix design of fly ash concrete equivalent to M30 was done by incorporating the addition of fly ash as 5%, 15% and 25% of cement weight replacement. The mix proportioning for fly ash modified concrete is given

Mix proportion for 1 m^3 fly ash concrete

Material in Kg/m³	Percentage of Fly ash			
	0% (CM)	5% (F5)	15% (F15)	25% (F25)
Cement	447.8	393.39	349.68	306
Fly ash	-	43.71	87.42	131.1
Fine aggregate	689.57	679.53	679.53	679.53
Coarse aggregate	1295.79	1275.74	1275.74	1275.74
Super plasticizer	2.62	2.62	2.62	2.62
Water (litres/ m³)	153	153	153	153

Mix Design for Fly Ash Modified Microbial Concrete (M30)

Mix design of fly ash modified microbial concrete equivalent to M30 was done by incorporating bacteria and fly ash of 5%, 15% and 25% cement weight replacement. The mix proportioning for fly ash modified microbial concrete is given in Table 3.8.

Mix proportion for 1 m^3 microbial fly ash concrete

Material in Kg/m³	Percentage of Fly ash			
	0% (M)	5% (MF5)	15% (MF15)	25% (MF25)
Cement	447.8	393.39	349.68	306
Fly ash	-	43.71	87.42	131.1
Fine aggregate	689.57	689.57	689.57	689.57
Coarse aggregate	1295.79	1295.79	1295.79	1295.79
Super plasticizer	2.62	2.62	2.62	2.62
Water (litres/ m³)	153	153	153	153
Bacillus subtilis (litres/ m³)	0.153	0.153	0.153	0.153
Calcium lactate (Kg/m³)	18	18	18	18

Concrete mixing procedure for microbial concrete is same as that of conventional concrete. But instead of adding pure water, bacterial solution mixed water is added. The bacteria were diluted to the required concentration by the dilution equation given below. Available Concentration of bacterial solution = 10^8cells/ml of water

Dilution Equation

V1xC1 =V2xC2

Where,
V1 = Volume of Bacterial Solution Taken, C1 = original Bacterial concentration
V2 = final volume required, C2 = final concentration required
The nutrient for bacteria, Calcium lactate is added in the mixing procedure at a rate of 18Kg/$m^3$of concrete.

VI TEST RESULTS

WORKABILITY TEST RESULTS

Sl. No	Specimen	Notation	Slump Values(mm)
1	CONVENTIONAL MIX	C	72
2	MICROBIAL CONCRETE	M	72
3	FLY ASH-5	F-5	74
4	FLY ASH-15	F-15	75
5	FLY ASH- 25	F-25	77
6	MICROBIAL FLY ASH-5	MF-5	74
7	MICROBIAL FLY ASH-15	MF-15	75
8	MICROBIAL FLY ASH-25	MF-25	77

- The bacterial addition has no significant role on the workability of the control mix. Fly ash inclusion increases the workability of the concrete due to the lubricating effect of fly ash.

STRENGTH TEST RESULTS

Specimen	7th day Compressive strength(N/mm^2)	28th day Compressive strength(N/mm^2)	56th day Compressive strength(N/mm^2)
C	28.04	44.6	49.33
M	22.74	40.32	50.6
F-5	16.04	37.3	43.2
F-15	15.81	34.6	39.87
F-25	31.38	55.95	57.79
MF-5	30.6	53.87	59.41
MF-15	24.13	47.46	54.39
MF-25	21.45	40.59	51.47

From the results it is observed that on addition of fly ash, 28 day strength decreases with addition of fly ash. The decrease in strength may be due to the slow hydration process since fly ash is a slow reactive pozzolans which delays the hydration process. It is evident that beyond 28 day, the strength increased with the addition of fly ash. The 56 day strength of fly ash concrete with 15% and 25% replacement level is lower than 5% replacement level. Therefore the fly ash percentage is optimized to 5%, for making microbial concrete which is in line with the results obtained by Chahal et al. and Bai al. It is observed that the 28 and 56 day compressive strength of microbial fly ash concrete are higher compared to normal concrete and fly ash concrete.

FLEXURAL STRENGTH AND SPLIT TENSILE RESULTS

Specimen	**28th day Split tensile strength(N/mm^2)**	28 day Flexural strength(N/mm^2)
C	6.47	8.12
M	5.98	7.76
F-5	5.67	7.52
F-15	5.48	7.35
F-25	8.23	9.85
MF-5	7.86	9.51
MF-15	7.09	8.65
MF-25	6.21	7.88

- The increase in compressive strength of microbial concrete is mainly due to filling of the pores and voids with microbiologically induced calcium carbonate precipitation. The deposition of bacterial cells and calcium lactate within the pores makes the texture denser and compact.
- The increase in tensile strength of microbial concrete is mainly due to filling of the pores and voids with microbiologically induced calcium carbonate precipitation.

DURABILITY TEST RESULTS

Percentage decrease of Compressive Strength (Sulphate Resistance)

Type of concrete	28 day strength (N/mm^2)			56 day strength (N/mm^2)			90 day strength (N/mm^2)		
	water cured	Na_2SO_4 cured	% decrease	water cured	Na_2SO_4 cured	% decrease	water cured	Na_2SO_4 cured	% decrease
CM	44.6	42.61	6.66	49.33	45.64	9.8	50.33	45.14	12.74
F5	40.32	38.98	5.5	50.6	48.22	6.9	51.2	47.81	8.9
M	55.95	54.28	5.09	57.79	55.22	6.6	59.95	56.3	8.3
MF5	53.87	52.7	4.25	59.41	57.6	5.15	60.65	57.61	7.18

Percentage decrease of Weight (Sulphate Resistance)

Type of concrete	28 day strength (N/mm^2)			56 day strength (N/mm^2)			90 day strength (N/mm^2)		
	water cured	Na_2SO_4 cured	% decrease	water cured	Na_2SO_4 cured	% decrease	water cured	Na_2SO_4 cured	% decrease
CM	10.404	10.385	2.23	10.384	10.35	2.6	10.405	10.338	2.8
F5	10.41	10.396	2.17	10.386	10.368	2.25	10.402	10.37	2.38
M	10.89	10.876	2.16	10.91	10.89	2.23	10.895	10.866	2.33
MF5	10.884	10.872	2.13	10.915	10.897	2.2	10.909	10.882	2.3

Rapid Chloride Permeability Test (RCPT)

RCPT ratings of concrete (Source: ASTM C 1202:2005)

Charge passed (C)	Chloride ion penetrability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible

Chloride permeability of various concrete mixes

Type of concrete	Charge passed (C)	Chloride ion penetrability
CM	2387.8	Moderate
F5	2197.3	Moderate
M	1216.6	Low
MF5	1155.1	Low

VII CONCLUSION

Strength properties like compressive strength, split tensile strength and flexural strength properties were evaluated. The increase in strength of microbial concrete is mainly due to the filling of pores and voids with microbiologically induced calcium carbonate precipitation. The deposition of bacterial cells and calcium lactate within the pores makes the texture denser and compact. The addition of 5% fly ash increased the split tensile strength of MF5 by 31% compared to ordinary M30 mix.

The durability of microbial concrete is mainly due to filling of the pores and voids with microbiologically induced calcium carbonate precipitation. Thus the dense and compact structure will reduce the permeability and thus increase durability of concrete structures. The fly ash and calcium hydroxide combine in cementitious compounds trapping the calcium hydroxide so that it is no longer available for reaction with sulphates. This prevents the formation of gypsum.

From durability studies of rapid chloride permeability, with the inclusion of fly ash, chloride ingress capacity of microbial concrete is decreased. Pore refinement and grain refinement due to reaction between fly ash and liberated lime improves impermeability. The reduction in permeability of microbial concrete is mainly due to filling of the pores and voids with microbiologically induced calcium carbonate precipitation.

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