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Application of Bacillus Subtilis Bacteria for Improving Properties and Healing of Cracks in Concrete

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Abstract: Concrete is a composite material composed of fine and coarse aggregate bonded together with a fluid cement (cement paste) that hardens over time. The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develop. Therefore, it is important to control the crack width and to heal the cracks as soon as possible. Since the costs involved for maintenance and repair of concrete structures are usually high, apart from conventional methods of repairing cracks with sealants or treating the concrete with adhesive chemicals to prevent the cracks from widening, a microbial crack healing approach has shown promising results and this research focuses on the development of self-healing concrete. Self-healing of cracks in concrete would contribute to a longer service life of concrete structures and would make the material not only more durable but also more sustainable.

Keywords: Healing of Cracks, Bacillus Subtilis, MICCP.

I. Introduction

Cracks in concrete are a common phenomenon due to the relatively low tensile strength. Durability of concrete is impaired by these cracks since they provide an easy path for the transportation of liquids and gasses that potentially contain harmful substances. If micro-cracks grow and reach the reinforcement, not only the concrete itself may be attacked, but also the reinforcement will be corroded. Bacillus Subtilis has the great potential to heal the cracks in concrete surface and thereby enhancing the strength and durability of a concrete structure or an element. Since, Bacillus Subtilis is a non-pathogenic and non-toxicogenic bacterium which does not produce any harm to humans or to an environment. Self healing property of a concrete is achieved by introducing the Bacillus Subtilis bacteria into a concrete matrix during mixing. When a crack formed in the concrete surface, the ingress water reacts with the bacteria and which in turn produce Calcium carbonate ($caco_3$) which is a main composition of lime. Since, the bacteria need a food to survive so we chose Calcium lactate as a chemical precursor to do the work.

II. LITERATURE REVIEW

H.m. Jonkers, a. Thijssen et al (2010) concluded that the addition of specific organic mineral precursor compounds plus spore-forming alkaliphilic bacteria as self-healing agents Produces up to 100-μm sized calcite particles which can potentially seal micro- to even larger-sized cracks. Further development of this bio-concrete with significantly increased self-healing capacities could represent a new type of durable and sustainable concrete with a wide range of potential applications.

Hamid kalhori, raheb bagherour et al (2017) in this study, the effect of bacillus subtilis on healing and mechanical properties of concrete was evaluated. For this purpose, bacteria were introduced into mix design and curing solution in order to examine the effect and approach on compressive strength, tensile strength, permeability, porosity and healing of concrete specimen.

Nafise hoseini balam, davood mostofinejad, et al (2017) presents the results of an experimental investigation carried out to evaluate the influence of two types of bacteria namely sporosarcina pasteurii and bacillus subtilis, with different cell concentration on the water absorption of four types of concrete aggregates. Surface deposition of calcium carbonate crystals was found to decrease water absorption by 20 – 30% depending on the type of bacteria and aggregate porosity.

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III. METHODOLOGY

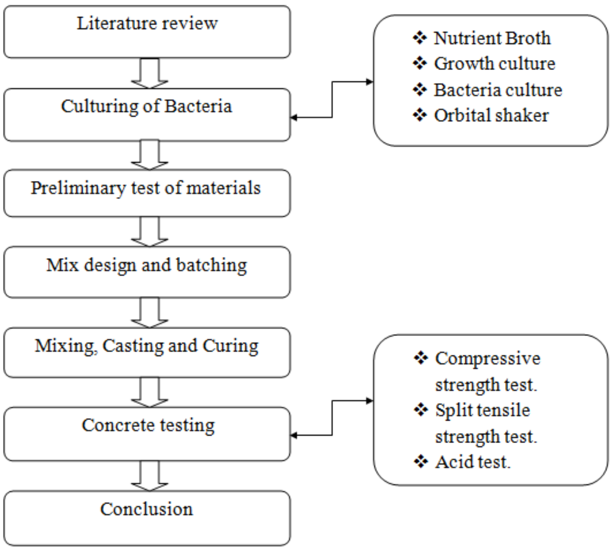

Fig.1 Methodology Flow chart

1. Culturing of Bacteria

The pure culture 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 nutrient both of 200ml in 500ml conical flask and the growth conditions are maintained at 37 degree temperature and placed in 125 rpm orbital shaker. The medium composition required for growth of culture is Peptone, NaCl, yeast extract.

Fig. 2 Culturing of Bacillus Subtilis

2. Preliminary Test on Materials

2.1 Cement

Ordinary Portland Cement(OPC) of 53 grade having specific gravity of 3.16 is used.

2.2 Fine aggregate

River sand belongs to Zone II having specific gravity of 2.668 is used.

2.3 Coarse aggregate

Crushed angular aggregate of size 20mm having specific gravity of 2.686 is used.

2.4 Water

Locally available potable water is used.

2.5 Bacteria

Bacillus Subtilis bacteria of gene Bacillus, a laboratory cultured bacteria is used.

3. Mix Design and Batching

We designed a mix for M25 grade concrete for the following datas.

a. Grade designation : M25
b. Type of cement : OPC 53 grade
c. Maximum nominal size of aggregate: 20mm
d. Minimum cement content : 320 kg/m^3
e. Maximum water-cement ratio : 0.50
f. Workability : 100mm (Slump)
g. Exposure condition : Moderate
h. Method of placing : Manual
i. Degree of supervision : Good
j. Type of aggregate : Crushed angular aggregate
k. Maximum cement content : 450 kg/m^3

4. Mixing, Casting and Curing

4.1 Mixing

The mixing involves, mixing of bacteria in concrete in three different proportions like 10ml, 20ml and 30ml for both cubes and cylinders. The specimens without bacteria are also used for comparison purpose. To activate the growth of bacteria in a concrete specimen when it cracks, a chemical precursor called Calcium lactate is used. Depending on its molarity 1.09g/l of water is used for mixing in concrete.

4.2 Casting

The casting involves, casting of cube of size 150mmx150mm and Cylinder of diameter 150mm and length 300mm.

4.3 Curing

In curing process, we adopted two types of curing first one is curing of bacterial specimen and normal specimen in ordinary potable water and another type is curing of normal specimen (without bacteria) in bacterial solution (Bacillus Subtilis).

5. Concrete Testing

5.1 Compressive Strength Test

A total of 45 cubes were tested for Compressive Strength including both with and without bacteria concrete specimen. Compressive strength of 7 days, 14 days and 28 days curing were tested.

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5.1.1 Compressive strength of cubes at 7 days curing

S. No.	GRADE	NAME	PROPORTION	LOAD	COMPRESSIVE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm²	N/mm²
1.	25	Normal concrete	0	520	23.11	
2.	25		0	498	22.13	21.81
3.	25		0	454	20.18	
1.	25	Bacterial concrete	10	380	16.89	
2.	25		10	442	19.64	18.99
3.	25		10	460	20.44	
1.	25	Bacterial concrete	20	390	17.33	
2.	25		20	380	16.89	16.75
3.	25		20	360	16.00	
1.	25	Bacterial concrete	30	414	18.44	
2.	25		30	440	19.56	19.24
3.	25		30	444	19.73	

Table 1 Compressive strength of cubes at 7 days

5.1.2 Compressive strength of cubes at 14 days curing

S. No.	GRADE	NAME	PROPORTION	LOAD	COMPRESSIVE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm²	N/mm²
1.	25	Normal concrete	0	580	25.77	
2.	25		0	564	25.06	25.33
3.	25		0	574	25.18	
1.	25	Bacterial concrete	10	398	17.69	
2.	25		10	422	18.76	19.14
3.	25		10	472	20.98	
1.	25	Bacterial concrete	20	412	18.31	
2.	25		20	410	18.22	18.87
3.	25		20	452	20.09	
1.	25	Bacterial concrete	30	440	19.56	
2.	25		30	442	19.64	19.94
3.	25		30	456	20.27	

Table 2 Compressive strength of cubes at 14 days

5.1.3 Compressive strength of cubes at 28 days curing

S. No.	GRADE	NAME	PROPORTION	LOAD	COMPRESSIVE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm²	N/mm²
1.	25	Normal concrete	0	640	28.44	
2.	25		0	620	27.56	28.43
3.	25		0	660	29.33	
1.	25	Bacterial concrete	10	694	30.84	
2.	25		10	740	32.88	33.72
3.	25		10	842	37.42	
1.	25	Bacterial concrete	20	580	25.78	
2.	25		20	590	26.22	25.79
3.	25		20	570	25.38	
1.	25	Bacterial concrete	30	568	25.24	
2.	25		30	560	24.89	25.33
3.	25		30	582	25.87	

Table 3 Compressive strength of cubes at 28 days

5.1.4 Compressive strength of cubes at 7 days curing in Bacterial solution

S. No.	GRADE	NAME	PROPORTION	LOAD	COMPRESSIVE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm²	N/mm²
1.	25	Normal concrete	0	420	18.67	
2.	25		0	454	20.18	19.59
3.	25		0	448	19.91	

Table 4 Compressive strength of cubes in BS at 7 days

5.1.5 Compressive strength of cubes at 14 days curing in Bacterial solution

S. No.	GRADE	NAME	PROPORTION	LOAD	COMPRESSIVE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm²	N/mm²
1.	25	Normal concrete	0	620	27.56	
2.	25		0	616	27.38	27.26
3.	25		0	604	26.84	

Table 5 Compressive strength of cubes in BS at 14 days

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5.1.6 Compressive strength of cubes at 28 days curing in Bacterial solution

S. No.	GRADE	NAME	PROPORTION	LOAD	COMPRESSIVE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm^2	N/mm^2
1.	25	Normal concrete	0	720	32.00	
2.	25		0	726	32.27	32.42
3.	25		0	742	32.98	

Table 6 Compressive strength of cubes in BS at 28 days

5.2 Split Tensile Strength Test

A total of 45 Cylinders were tested for split tensile strength including both the specimens of with and without bacteria. In this test, concrete cylinder is subjected to compression load along two axial lines which are diametrically opposite. The test was carried out by placing cylindrical specimen horizontally (using plates) along the loading surface of compression testing machine.

5.2.1 Split Tensile strength of cylinders at 7 days curing

S. No.	GRADE	NAME	PROPORTION	LOAD	TENSILE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm^2	N/mm^2
1.	25	Normal concrete	0	180	2.54	
2.	25		0	182	2.57	2.52
3.	25		0	174	2.46	
1.	25	Bacterial concrete	10	170	2.40	
2.	25		10	178	2.52	2.51
3.	25		10	184	2.60	
1.	25	Bacterial concrete	20	160	2.26	
2.	25		20	158	2.23	2.26
3.	25		20	162	2.29	
1.	25	Bacterial concrete	30	174	2.46	
2.	25		30	172	2.43	2.41
3.	25		30	166	2.35	

Table 7 Split tensile strength of cylinders at 7 days

5.2.2 Split Tensile Strength of cylinders at 14 days curing

S. No.	GRADE	NAME	PROPORTION	LOAD	TENSILE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm^2	N/mm^2
1.	25	Normal concrete	0	240	3.39	
2.	25		0	218	3.08	3.25
3.	25		0	232	3.28	
1.	25	Bacterial concrete	10	266	3.76	
2.	25		10	254	3.59	3.66
3.	25		10	258	3.28	
1.	25	Bacterial concrete	20	212	3.00	
2.	25		20	210	2.97	3,04
3.	25		20	222	3.14	
1.	25	Bacterial concrete	30	234	3.31	
2.	25		30	246	3.48	3.48
3.	25		30	258	3.65	

Table 8 Split tensile strength of cylinders at 14 days

5.2.3 Split Tensile strength of cylinders at 28 days curing

S. No.	GRADE	NAME	PROPORTION	LOAD	TENSILE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm^2	N/mm^2
1.	25	Normal concrete	0	356	5.03	
2.	25		0	390	5.51	5.31
3.	25		0	382	5.40	
1.	25	Bacterial concrete	10	370	5.23	
2.	25		10	398	5.63	5.51
3.	25		10	402	5.68	
1.	25	Bacterial concrete	20	315	4.45	
2.	25		20	324	4.58	4.47
3.	25		20	310	4.38	
1.	25	Bacterial concrete	30	358	5.06	
2.	25		30	372	5.26	5.28
3.	25		30	390	5.52	

Table 9 Split tensile strength of cylinders at 28 days

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5.2.4 Split Tensile strength of cylinders at 7 days curing in Bacterial solution

S. No.	GRADE	NAME	PROPORTION	LOAD	TENSILE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm^2	N/mm^2
1.	25	Normal concrete	0	188	2.66	
2.	25		0	192	2.71	2.65
3.	25		0	182	2.57	

Table 10 Split tensile strength of cylinders in BS at 7 days

5.2.5 Split Tensile strength of cylinders at 14 days curing in Bacterial solution

S. No.	GRADE	NAME	PROPORTION	LOAD	TENSILE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm^2	N/mm^2
1.	25	Normal concrete	0	244	3.45	
2.	25		0	232	3.28	3.37
3.	25		0	240	3.39	

Table 11 Split tensile strength of cylinders in BS at 14 days

5.2.6 Split Tensile strength of cylinders at 28 days curing in Bacterial solution

S. No.	GRADE	NAME	PROPORTION	LOAD	TENSILE STRENGTH	AVERAGE STRENGTH
	M		ml	KN	N/mm^2	N/mm^2
1.	25	Normal concrete	0	370	5.23	
2.	25		0	398	5.62	5.47
3.	25		0	394	5.57	

Table 12 Split tensile strength of cylinders in BS at 28 days

Fig. 3 Compression and Split Tensile strength test of specimen

6. Graphical Representation

6.1 Mean Compressive Strength

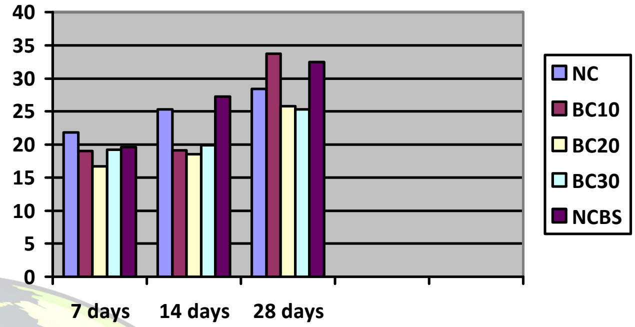

Fig. 4 Compressive strength of different specimens

6.2 Mean Split Tensile Strength

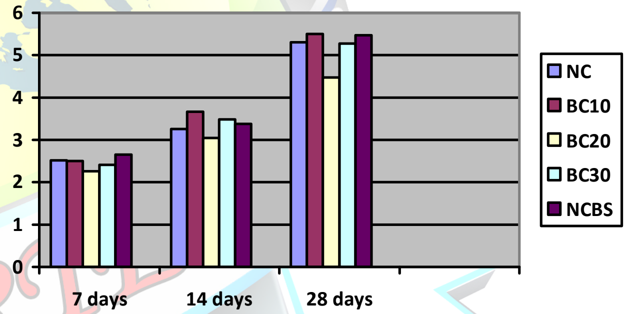

Fig. 5 Split Tensile strength of different specimens

6.3 Comparison of M25 Bacterial concrete to M30 Normal concrete

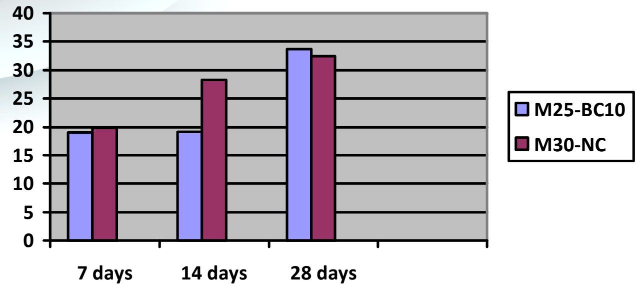

Fig. 6 Comparison of bacterial and normal concrete

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7. Self Healing of Cracks

The self healing process starts when the water enters into the cracks and reacts with the bacteria. This reaction produces $CaCO_3$ due to hydrolysis of urea in concrete. From this compound one molecule of CO_2 releases due to leaching effect and left CaO (lime) which is a main component of cement and thereby fills the crack.

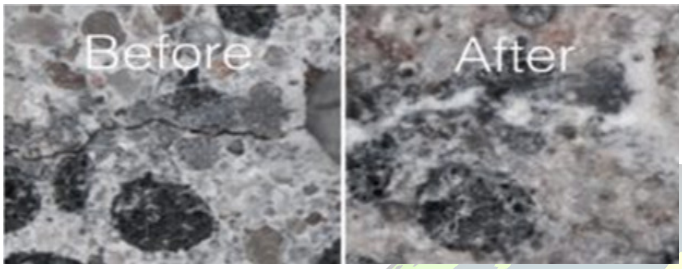

Fig. 7 Self Healing of cracks in concrete

IV. Conclusion

Based on the experimental investigation, we concluded the following results.

- The Compression and Tensile strength of 10ml specimen of M25 grade is 5.29 N/mm^2 and 0.20 N/mm^2 higher than the normal specimen of M25 grade.
- The Compression and Tensile strength of M25 normal specimen cured in Bacterial solution is 4.00 N/mm^2 and 0.16 N/mm^2 higher than the M25 normal specimen cured in water.
- The Compressive strength of 10ml specimen of M25 grade is 1.26 N/mm^2 higher than the M30 grade of normal specimen
- Therefore, it is advisable to use both the method such as 10ml bacterial concrete and normal specimen cured in bacterial solution.
- It is also advisable to use M25 grade of bacterial concrete instead of M30 normal concrete.
- Healing property of concrete is also achieved, hence it is used in repair techniques also.

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