EXPERIMENTAL STUDY ON FLEXURAL BEHAVIOR OF BACTERIAL CONCRETE WITH INTERNAL CURING

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Abstract: *The present paper discusses the experimental studies of flexural behavior of concrete by adding bacteria and also the lighter weight aggregates like light expanded clay aggregate and vermiculite in the internal curing of the concrete. It is a process by which living organisms from inorganic solids. Bacillus subtilis, a common soil bacterium can make the precipitation of calcite. The purpose of the present investigation is to study the potential application of bacterial species, i.e. Bacillus subtilis to improve the strength of concrete. Water is an essential component for cement hydration which can be gained with proper curing. 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. Under practical situations, many structures do not allow curing with water after the construction. In such a case often curing compounds are used to avoid loss of water from the concrete. However, it is not sufficient for continuous hydration of cement. The properties studied reveal that incorporation of LWA does not have remarkable change in mechanical properties and also the strength of concrete can be analyzed by using bacteria. In this respect, the porosity of light weight aggregate provides a source of water for internal curing of concrete which can provide continued enhancement of concrete strength and durability. For this reason, fine aggregate is replaced by 5% and 10% of LWA in the mix to find its enhancement of internal curing in this study.*

***Keywords*- Internal curing; Bacillus Subtilis; Plastic Shrinkage; Workability; Vermiculite; LECA**

1. INTRODUCTION

In the 21st century, internal curing concrete has emerged as a new technology that holds promise for producing concrete with increased resistance to early-age cracking and enhanced durability. Since the concrete service life span is a key component of providing a sustainable infrastructure, internal curing concrete can provide a positive contribution to increasing the sustainability of our nation's infrastructure. Internal water curing has a significant effect on concrete.

In addition to affecting hydration and dampness distribution, it influences mainly concrete properties, such as shrinkage, cracking, vulnerability and durability. In 2010, the American Concrete Institute (ACI) defined internal curing of concrete in its ACI Terminology Guide as "supplying water throughout a freshly located cementitious mixture using reservoirs, via pre-wetted lightweight aggregates, that readily release water as needed for hydration or to restore moisture gone through evaporation". Internal curing refers to the process by which the hydration of cement occurs because of the ease of use of additional internal water that is not part of the mixing water.

The additional water being complete by using relatively small amounts of saturated light weight fine aggregates in concrete. Internal curing works by supplying water from the pre-wetted lightweight aggregate (LWA) to plug in the voids created by chemical shrinkage (O. Arioz, 2008). Internal curing has been shown in the laboratory to be fairly effective as a mitigation strategy for self-desiccation and autogenous shrinkage. More recent findings have also shown that in addition to reducing shrinkage, internal curing can decrease shrinkage cracking, trim down plastic shrinkage cracking and reduce water absorption. The aim of the paper is to locate the performance of lightweight aggregates (LECA and Vermiculite) as 5% and 10% replacement of fine aggregate as self curing agent and also the strength properties by adding bacteria (Henkensiefken R, 2006). The use of self curing aggregate is very important from the summit of view that water resources get valuable every day additional over requirement of water for concreting is also high. (i.e.,) $1m^3$ of concrete requires 3 m^3 of water designed for construction, most of which is required for curing. At present, the assistance of a self curing agent is realized in desert areas and dry seasons of dry areas and soon may be felt in all areas.

2. MATERIALS

- Ordinary Portland Cement (53 grade) conforming to IS: 12269 was used. The physical and chemical properties of cement are presented in Table 1 & 2.
- Locally available river sand was used as one of the constituent in the present work. The properties of the sand were studied in accordance with IS 2386-1963 and the results are given in Table 3.
- Light Expanded Clay Aggregate (LECA) and Vermiculite were used to provide internal curing agent in this study. The LECA is produced by baking pure natural clay in a rotary kiln at about 1200 degree centigrade. Vermiculite is a natural mineral to facilitate expands with the application of heat. Vermiculite is formed by hydration of certain basaltic minerals. The properties of LECA and vermiculite are given in Table 4.
- Locally available coarse aggregate having maximum size 20 mm was used in the present work. The physical properties of coarse aggregates were measured in accordance with IS 2386-1963 and the results are presented in Table 3.

Table-1 Physical Properties of Cement

S.No	Properties	Observed values
1.	Standard Consistency	33%
2	Initial setting time	30 minutes
3	Final setting time	600 minutes
4.	Compressive Strength	54.08 N/mm^2
5.	Fineness by sieving	6%
6.	Specific Gravity	3.1

Table-2 Chemical Properties of Cement

S.No	Properties	Observed Values (%)
1.	CaO	63.8
2.	SiO_2	21.4
3.	Al_2O_3	5.1
4.	Fe_2O_3	2.6
5.	MgO	0.36
6.	SO_3	3.38
7.	Insoluble Residue	0.8
8.	Loss On Ignition	1.6
9.	K_2O	1.88
10.	Na_2O	0.14

Table-3 Properties of River Sand and Coarse Aggregate

S.No	Properties	River Sand	Coarse Aggregate
1.	Specific Gravity	2.7	2.8
2.	Bulk density	1510 kg/m^3	1540 kg/m^3
3.	Water absorption test	0.51%	0.302%
4.	Fineness Modulus	3.28(Zone III)	8.27

Table-4 Properties of Leca and Vermiculite

S.No	Properties	LECA	Vermiculite
1.	Specific gravity	1.78	1.826
2.	Fineness Modulus	4.60(zone I)	4.736(zone I)
3.	Water absorption test (24 hrs soaking)	29.4%	18.4%
4.	Water absorption test (24 hrs soaking & 5 hrs heating)	86.2%	71.7%
5.	Porosity test	85.38%	26%

Various Bacteria Used in the Concrete

The bacteria are,

i) Bacillus pasteurii

ii) Bacillue sphaericus

iii) Escherichia coli

iv) Bacillus subtilis (used in the present study)

Bacterial Concrete

Bacterial concrete refers to a new generation of concrete in which discriminating cementation by microbiologically-induced $CaCO_3$ precipitation has been introduced for remediation of micro cracks. Considerable research on carbonate precipitation is complete by selecting ureolytic bacteria, but very limited work has been reported on the application part of it. Bacterial ureas enzymes disgrace urea into ammonia and carbon dioxide, which guide to increase in pH of the media and carbonate precipitation. Various researchers have confirmed the determination of organic $CaCO_3$ precipitate in the environment for an unlimited period of time using Bacillus subtilis. (RamakrishnanV.2001)

Microbiologically induced calcite precipitation utilizes a biological by-product, $CaCO_3$. In aqueous environments, the overall chemical equilibrium response of calcite precipitation can be Ca_2+ +cell. Prepared chemicals are shown in figure 1.

Chemicals used

- Potassium permanganate
- Nutrient Broth
- Urea
- Sodium bicarbonate ($NaHCO_3$)
- Calcium carbonate ($CaCl_2$)
- Ammonium chloride (NH_4Cl)

Figure 1 Preparation of chemicals used

3. MIX PROPORTION

The concrete mix design was done as per IS: 10262-2009. Control Mix M30 grade concrete without light weight aggregate was used. The proportions for the concrete, as determined were, 1:1.2:2.4 with water cement ratio of 0.4 by weight. The other concrete mixtures were made by replacing fine aggregate with 5% & 10% LECA and 5% & 10% vermiculate (Bentz.D.P 2005). The quantities of each mix proportion are listed in Table 5.

Table 5 Mix Proportions of Internal Curing Concrete

S. No	Material	Quantity kg/m^3		
		Control mix 0%	5% LECA/ Vermiculite	10% LECA/ Vermiculite
1.	Cement	492.5	492.5	492.5
2.	Fine aggregate (Sand)	594	564.3	534.6
3.	LECA/ Vermiculite	-	29.7	59.4
4.	Coarse aggregate	1195	1195	1195
5.	Water	197	197	197

4. PREPARATION AND TESTING OF SPECIMENS

- Fresh concrete and dry concrete density was measured at the fresh state as well as at hardened state.
- The workability of concrete was measured with a slump cone and with compaction factor apparatus.
- Cube moulds of 150 mm were used for compression testing of concrete. The Cubes were tested at the age of 7 days curing using compression testing machine as per IS: 516- 1959.
- The beam specimens of size 500 mm length, 100 mm breadth, 100 mm height were used to determine the flexural strength of concrete at the age of 28 days as per IS: 516 -1959.
- Splitting tensile strength tests were carried out on cylinder specimens of dimension 150 mm diameter and 300 mm, length at the age of 7 days as per IS: 5816 - 1970.
- The cylinder specimens of size 150 mm diameter and 300 mm height were used to determine the modulus of elasticity of concrete in compression at the age.
- Specimens demoulded after 24 hours were kept in an open atmosphere in order to study the effect of internal curing except for control concrete.

5. RESULTS AND DISCUSSIONS

A. Fresh Concrete Properties of Internal Curing of Concrete

The slump value and compaction factor for the mixes with LECA and Vermiculite are given in Table 6. The s values remain almost same for the mixes studied. Incorporation of LECA and Vermiculite as internal curing agent does not have any effect on slump value and compaction factor. The fresh concrete and hardened concrete density are put into a Table 7. Addition of LECA and Vermiculite plays a role in reducing the density at fresh as well as in the hardened state of concrete. As anticipated, the density is reduced to increase in quantity of LECA and Vermiculite due its low density.

Table 6 Internal Curing Concrete Fresh Properties

S.No	Mix	Slump Value (mm)	Compaction Factor
1.	0%	28	0.89
2.	5% LECA	29	0.89
3.	10% LECA	29	0.9
4.	5% Vermiculite	29	0.9
5.	10% Vermiculite	28.5	0.9

Table 7 Density of Internal Curing of Concrete

S.No	Mix	Fresh Concrete Density (kg/m^3)	Hardened Concrete Density (kg/m^3)
1.	0%	3080	1600
2.	5% LECA	2480	1300
3.	10% LECA	2780	1000
4.	5% Vermiculite	2480	1300
5.	10% Vermiculite	2780	1000

B. Hardened Concrete Properties of Internal Curing of Concrete

The hardened concrete properties such as compressive strength, split tensile strength, flexural strength and E-value of internal curing of concrete are presented in Table 8 & 9. The compressive strength and split tensile strength of mixes containing LECA and Vermiculite is found to be less than that of control mix. However, it was higher than design strength. Further, similar observations were not made in flexural strength and E-value of internal curing of concrete while comparing with control mix. No variation in compressive strength and split tensile strength was observed among two LWAs and control mix. In general, no variation in strength properties was observed between LECA and Vermiculite.

Table 8 7 Days Compressive Strength of Internal Curing and Bacterial Concrete

Mix	Compressive Strength of Internal Curing Concrete (N/mm^2)	Compressive Strength of Bacterial Concrete (N/mm^2)
0% Conventional	41.52	41.52
5% LECA	32.5	35.64
10% LECA	33.5	37.42
5% Vermiculite	33	34.66
10% Vermiculite	33.6	35.46

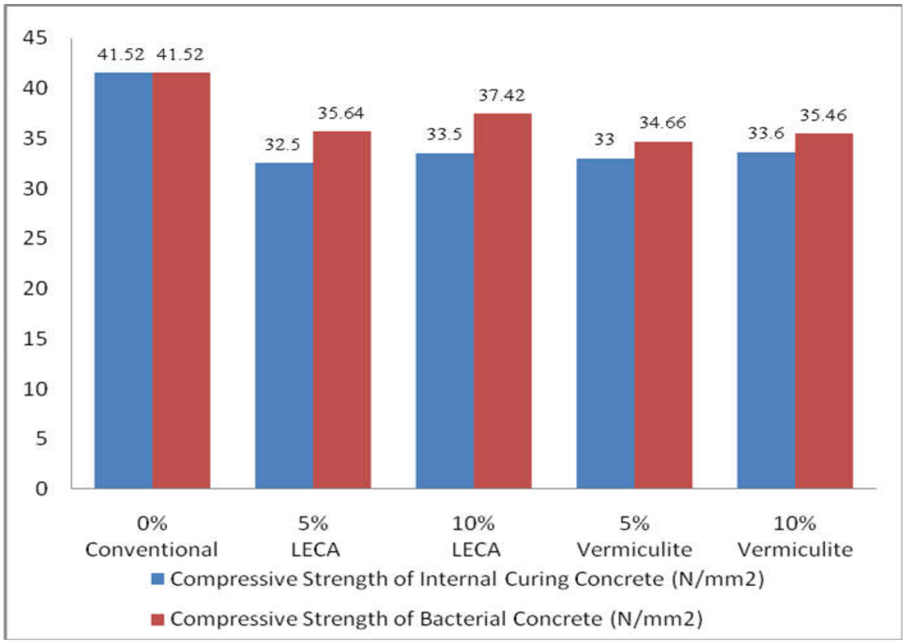

Figure 2 7 Days Compressive Strength of Internal Curing and Bacterial Concrete

Table 9 7 Days Split Tensile Strength of Internal Curing and Bacterial Concrete

Mix	Split Tensile Strength of Internal Curing Concrete (N/mm^2)	Split Tensile Strength of Bacterial Concrete (N/mm^2)
0% Conventional	5.76	5.76
5% LECA	2.6	2.58
10% LECA	2.62	2.64
5% Vermiculite	2.75	2.78
10% Vermiculite	2.78	2.81

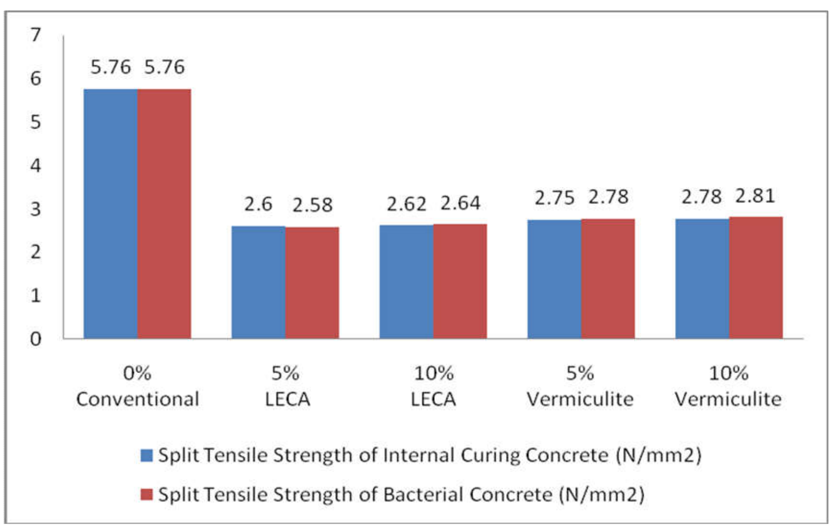

Figure 3 7 Days Compressive Strength of Internal Curing and Bacterial Concrete

Table 10 7 Days Flexural Strength of Internal Curing and Bacterial Concrete

S.No	Mix	Flexural Strength of Internal Curing Concrete (N/mm^2)	Flexural Strength of Bacterial Concrete (N/mm^2)
1.	0%	6.62	6.62
2.	5% LECA	6.8	7.1
3.	10% LECA	7	7.32
4.	5% Vermiculite	6.7	6.96
5.	10% Vermiculite	6.64	6.82

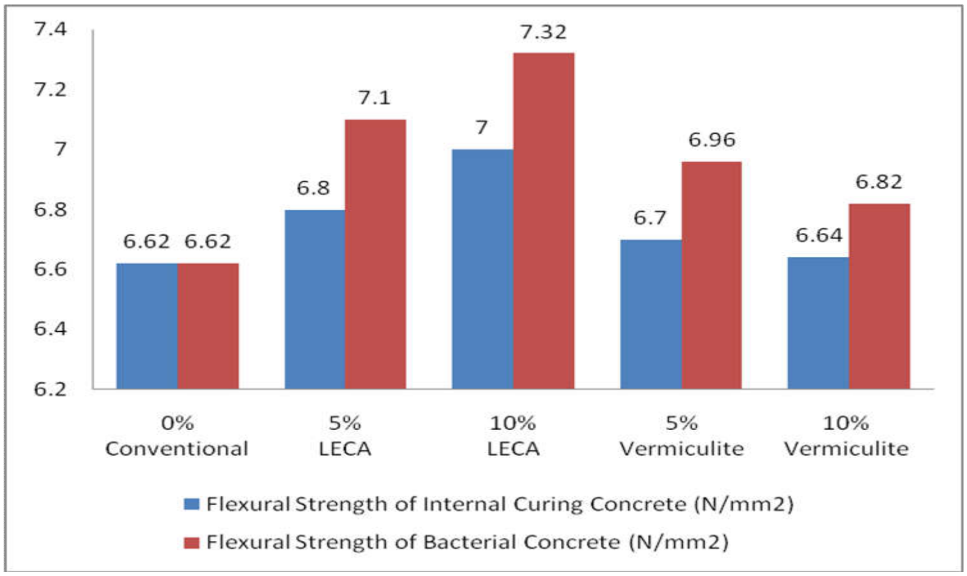

Figure 4 7 Days Flexural Strength of Internal Curing and Bacterial Concrete

6. CONCLUSION

The following conclusions are drawn from the study

- Partial replacement of fine aggregate, by saturating lightweight aggregate, LECA and Vermiculite had no effect on the workability of concrete
- Density of LWA concrete had a significant effect in comparison with control mix without LWA
- No remarkable variation was obtained in flexural strength of internal curing of concrete.
- The bacterial concrete is proving to be better than internal cured concrete by all means.
- The cost of the bacterial concrete is 12% increased to that of internal curing concrete. But compare to other type of special concrete it should be very economical.

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