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Full Length Research Paper

Self-Healing Bacteria Concrete: An Approach for Sustainable Crack Repair for Ethiopian Construction Industry

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Abstract

Cracking is a natural phenomenon in concrete under ageing, exposure to severe climate conditions and under certain loading conditions in a structure. There are several methods which are available for crack repair that are mostly labor intensive and not cost-effective. Sporosarcina Pasteurii bacteria which is a common type of bacteria found in soil when exposed to air produces calcium carbonate around its body. This mechanism can certainly be helpful for auto healing the cracks in concrete when these bacteria are used in the concrete mixing process. Few research has shown that these bacteria have the ability to fill the cracks when used in concrete. In essence, this paper presents the mechanical and durability properties evaluation of concrete when mixed with bacteria. Compressive strength and tensile strength have been investigated from a mechanical properties perspective and resistance to acid attack, water desorption, carbonation and effect of high temperature have been studied as part of the durability investigation. The experimental results revealed that, there was no negative effect of bacteria on the compressive strength of concrete however the tensile strength showed an improvement by 10%. The durability test results revealed that the resistance of bacteria concrete to water desorption, acids attack, carbonation and high temperature enhanced compared to controlled concrete and the optimum percentage of bacteria was found to be 3%. So, bacteria concrete can certainly be used as a crack healing measure in concrete for a cost effective and sustainable approach for Ethiopian construction industry.

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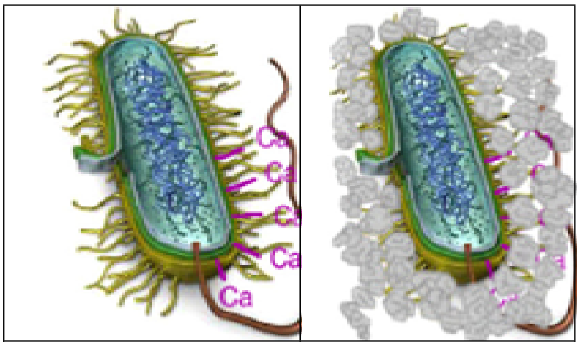
1. Introduction

A concrete structure is always subjected to different loading and harsh environmental condition. So cracks in concrete are not uncommon. The most traditional measure to repair the cracks is applying mortar and a round of finishing, which is certainly an expensive and time consuming affair. To deal with this frequent maintenance activities in concrete, use of bacteria which has a property of generating calcium carbonate under exposure as shown in Figure 1 to air can be considered as a suitable measure. However the inclusion of bacteria in concrete can alter the mechanical and durability properties of concrete there by impacting the intended purpose. So along with verifying the auto-healing capabilities of bacteria in concrete it is highly imperative to understand how the concrete behaves by inclusion of bacteria in it from the strength and durability perspective. Such verification is very important to win the confidence of the construction industry before they actually use this bacteria in concrete as a crack-healing measure in pace of traditional methods. Workability of concrete which is one of the most prominent features that alters the strength and durability of the hardened concrete has been evaluated in this research. The compressive strength and tensile strength are the important mechanical properties which have been evaluated by conducting experimental investigation in this research. Out of several durability properties of concrete the most important ones are its resistance to water desorption, carbonation, acids attack and elevated temperature which have been experimentally investigated in this research.



Bacteria at Inert state	Bacteria Creating Calcium Carbonate Under Exposure to Air

Figure 1: Calcium Carbonate formation by bacteria

2. Properties of Materials

Ordinary Portland cement of 42.5 grade has been as a binding material used for the concrete. The properties of cement have been presented in table 1 and table

Table 1: Physical Properties of Cement

Material	Density	Specific Gravity	Fineness (µm)	Specific Surface (m^2/kg)	Mean Grain Size
OPC	1.16	3.17	81	305	22

Table 2: Chemical Properties of Cement

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI
OPC	21.57	5.67	3.38	64.26	0.84	0.34	0.58	2.48	1.80

Locally available coarse aggregate of maximum size 20 mm was used having fineness modulus of 7.65 and sp.gr of 2.67, bulk density of 1470 kg/m^3 at compacted state and the water absorption of 1.3% respectively. River sand with sp.gr 2.57, fineness modulus 2.85, bulk density of 1720 kg/m^3 at compacted state and the water absorption of 2.06% respectively was used as fine aggregate. Clean, free from impurities i.e. potable water was used for concrete preparation and curing. Sporosarcina Pasteurii bacteria which is a common type of bacteria available in soil procured from Ethiopian Biological Institute have been used for this research. The nutrients used for bacteria culture was Broth. Bacteria in three different proportions (1%, 3% and 5%) by volume of entire concrete were used for preparing different concrete mixes.

3. Mix Design and Concrete Mixes

According to ACI 211 code book, the mix design was performed for the C30 grade concrete and the ratios of the constituent materials were obtained. Four different type of concrete mix were prepared shown in the table 3. The mix proportions are presented in table 4.

Table 3: Concrete Mixes

Sr. No	ID	Percentage of Bacteria by volume of water
1	SP-1	1
2	SP-3	3
3	SP-5	5
4	CC	N/A

Table 4: Mix Proportion of C30 grade Concrete

Grade	Cement	Fine Aggregate	Coarse Aggregate	Water
C-30	1	2.01	3.32	0.50

4. Testing Procedure

The concrete was mixed as per the proportion derived from the design mix by a batch mixer. Concrete cube of size 150 mm x 150 mm x 150 mm, 100 mm x 100 mm x 100 mm and a cylinder of size 150 mm (D) x 300 mm (L) were cast as part of this investigation. After the casting the concrete was cured for 28 days post which the cubes were taken out of the curing tank and surface dried followed by testing. Workability was measured by slump testing. Compressive Testing machine was used for measuring the compressive and tensile strength of concrete. Oven and muffle furnace was used for Water Desorption and High Temperature testing. 10% diluted HCl was used for the acids resistance test. Each test result was averaged out from three test specimen test results. Crack was applied to the cube and the auto healing was verified by manual observation.

Figure 2: Concrete Preparation

Figure 3: Workability Testing

Figure 4: Curing of Concrete Speciments

Figure 5: Compressive Strength Testing

Figure 6: Acids Attack Testing

Figure 7: Water Desorption Testing

5. Discussion of Results

5.1 Concrete Workability

The impact of the use of bacteria on concrete has been presented in table 5. It can be clearly seen that with inclusion of the bacteria, the workability is increasing from 44 mm to 55 mm for the controlled concrete to 5% bacteria concrete. The reason for increased workability is due to decreased friction in the constituent materials of concrete after inclusion of bacteria in concrete.

Table 5: Concrete Slump

Sr. No.	% of Bacteria	Concrete slump (mm), to nearest 5mm
1	0%	44
2	1%	50
3	3%	52
4	5%	55

5.2 Auto-Healing Ability of Concrete Cracks

For visualizing the auto-healing ability of cracks in concrete, cracks was intentionally developed and verified by magnifying glass for its healing which is shown in the figure 8 below. It was clearly visualized that the bacteria fills the crack on the concrete by producing calcium carbonate when exposed to air.

Figure 8: Self-Healing of Cracks in Concrete

5.3 Concrete Compressive Strength

The table 6 shows the results from the compressive strength testing of controlled and bacteria concrete. It can be clearly seen that, the compressive strength doesn't change significantly and is within the limits of expected strength. This is a clear indication that inclusion of bacteria in concrete doesn't alter the compressive strength of concrete.

Table 6: Concrete Compressive Strength

Grade	% Bacteria	Density (kg/m^3)	Compressive strength at different age		
			7 days	28 days	90 days
C30	0%	2358	24.30	35.8	38.2
	1%	2361	25.22	36.2	39.1
	3%	2352	25.82	36.9	39.8
	5%	2464	22.12	33.2	36.5

5.4 Concrete Tensile Strength

The table 7 shows the results from the tensile strength testing of controlled and bacteria concrete. It can be clearly seen that, the tensile strength slightly increases with the inclusion of bacteria in concrete. The possible reason for the tensile strength enhancement is that, the bacteria helps in increasing the bonding in the concrete. This is a clear indication that inclusion of bacteria in concrete helps in enhancing the tensile strength of the concrete.

Table 7: Concrete Tensile Strength

Grade	% Bacteria	Density (kg/m^3)	Tensile strength at different age		
			7 days	28 days	90 days
C30	0%	2358	2.85	3.38	3.54
	1%	2361	2.91	3.81	3.95
	3%	2352	2.98	3.92	4.1
	5%	2464	3.1	4.05	4.22

5.5 Resistance to Concrete Water Desorption

The table 8 shows the results from the water desorption test of controlled and bacteria concrete. It can be clearly seen that, the water desorption decreases by the inclusion of bacteria in concrete. The possible reason for resistance to water desorption is that, bacteria acts as a sealing agent in the concrete. This is a clear indication that bacteria in concrete can also be used for water retaining structures without impacting the water desorption of controlled concrete.

Table 8: Concrete Water Desorption

Grade	% of Bacteria	Weight of Saturated Sample (kg)	Weight of Oven-Dried Sample (kg)	Water Desorption at 56 Days (%)
C30	0%	8.3	8.24	0.81
	1%	8.67	8.61	0.74
	3%	8.68	8.62	0.69
	5%	8.59	8.54	0.61

5.6 Resistance to Acid Attack in Concrete

The table 9 and table 10 shows the results from the acids attack test (HCl) on controlled and bacteria concrete. It can be clearly seen that, the weight reduction and compressive strength reduction for the bacteria concrete is lower compared to the controlled concrete. The possible reason for higher resistance to acids attack is that, bacteria acts as an inhibitor to the acidic reaction that reduces the chance of weight reduction in the concrete. This is a clear indication that bacteria concrete performs better compared to controlled concrete in an acidic environment.

Table 9: Weight Loss due to Acids Attack

% of Bacteria	Initial weight (kg)	Weight after 28 Days of immersion (kg)	% Loss of weight at 28 Days	Weight after 56 Days of immersion (kg)	% Wt. Loss at 56 Days
0%	2.56	2.46	3.75	2.39	6.64
1%	2.709	2.61	3.58	2.6	4.02
3%	2.683	2.58	3.54	2.581	3.8
5%	2.641	2.55	3.45	2.55	3.45

Table 10: Loss in Compressive Strength due to Acid Attack (10% HCl)

% of Bacteria	% Comp. Strength Loss at 28 Days	% Comp. Strength Loss at 56 Days
0%	32.6	41.2
1%	23.5	27.6
3%	16.3	19.7
5%	8.3	13.4

5.7 Resistance to Elevated Temperature

The table 11 show the results from the high temperature (400° and in 2 hours exposure) resistance test of controlled and bacteria concrete. It can be clearly seen that, with inclusion of bacteria in concrete the resistance to high temperature increases along with the weight loss and strength is less compared to the controlled concrete. The possible reason for resistance to high temperature the action of bacteria as an obstructing agent for crack propagation and less spalling under exposure to high temperature. This indicates the bacteria concrete can be used as a construction material subjected to high temperature.

Table 11: Weight Loss due to Elevated Temperature

% of Bacteria	Initial Weight (kg)	Final Weight (kg)	% of we
0%	2.72	2.63	3
1%	2.57	2.5	2
3%	2.5	2.4	2
5%	2.49	2.44	2

5.8 Resistance to Carbonation

The figure 9 below show the results from the carbonation test on concrete by applying Phenolphthalein solution. The entire area of concrete sprayed with the solution became pink indicating the carbonation depth is zero. This indicates that bacteria concrete is unaffected by the effect of carbonation in the atmosphere.

Figure 9: Concrete Exposed to Phenolphthalein Solution

6. Conclusions and Recommendations

Based on the experimental investigation carried out, the conclusions have been made as follows.

- Sporosarcina Pasteurii bacteria 3% by volume of concrete can be used as an agent for the crack healing measure in the concrete.
- Broth can be considered as a right nutrient for culturing the bacteria.
- Inclusion of bacteria enhances the workability of concrete.
- Mechanical properties such as compressive strength and tensile strength are not altered by the inclusion of bacteria in concrete. Enhanced tensile strength can be found in concrete by the inclusion of bacteria.
- Inclusion of bacteria enhances the durability to a great extent. The resistance to water desorption, acids attack, elevated temperature and carbonation in concrete enhances which is a good indication that bacteria can be used as a measure for crack healing measure for structures subjected to harsh environmental conditions.

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