TO EVALUATE THE MECHANICAL PROPERTIES OF SELF-HEALING CONCRETE STRENGTHENED WITH STEEL FIBERS

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Abstract

In this research the steel fibers replaced with 1% of coarse aggregate and 20% of fine aggregate with bacillus subtilis and calcium lactate. Compressive tests on three sets of specimen, control with no replacement, specimens with bacillus subtilis and specimens with bacillus and steel fibers. Experimental results show that the compressive strength loss of bacterial specimens compared to control specimens was up to 40 % which was regain in the third sets of cylinders containing steel fibers up to 35% showing that the compressive strength of the steel fiber specimens is 90% of the control specimens.

Keywords : Bacillus subtilis, steel fibers, calcium lactate, concrete mix, expanded clay particles, control specimen.

I. Introduction

Concrete is a mainly use for compressive load but when this applied load increase from a certain limit it reduce the load resisting capacity of concrete and induce cracks in its structure which leads to strength reduction of concrete. Cracks are
two type major and minor cracks, major cracks in a structure are considered either collapse or required some retrofitting action to maintain its serviceability while minor cracks have no direct impact on the structure but have some indirect action like durability, permeability and steel corrosion. Apart from direct strength reduction of concrete the indirect loss of durability of concrete in terms of steel and reinforcement corrosion is due to cracks and the associated permeability of water through these cracks as a result decrease the serviceability of. So for maintaining the serviceability and safety, the structure needs some repair and maintenance action at a specified period of time. These repair and maintenance will increase the total cost of the structure and also a time-consuming process. So it will be necessary to repair these cracks which lead to the concept of self-healing of concrete. The self-healing concrete uses some external self-healing agent to act as filler for these cracks when cracks occurs. By introduce the bacteria in concrete it producing calcium carbonate crystals which block the micro cracks and pores in the concrete. In concrete micro cracks are always avoided but to some extent they are responsible to their failure in strength. The selection of the bacteria is depend on the survive capability of bacteria in the alkaline environment. Most of the microorganisms die in an environment with pH value of 10 or above [V].

So it is necessary to identify the bacteria fit for intended purpose and resist the harsh environment. Strains of such bacteria genus are Bacillus that are found to resist high alkaline environment by forming spores around itself like plant seeds. These spores are thick wall and get activated with water when cracks occur in concrete. The pH of concrete is in the range of 10-11.5 which are fit for the bacillus spores. Apart from bacillus there are many bacteria that can survive in harsh alkaline environment. Van Tittleboom used light weight porous water saturated aggregate particles in concrete which release water when concrete cracks and the gradients start flow of water. In a research Van Tittelboom also investigated small tubes of glass which is filled in with some self-healing agent likely to breaks almost 100. But the problem is their vulnerability while mixing in concrete [III]. Due to the heterogeneous nature of concrete by definition the added capsules have no significant change on concrete nature but their stiffness and strength is different. The probability of passing the cracks from capsule largely depend of the number and size of the. This mean capsules with larger aspect ratio and with cylindrical shape for tubes are more effective compare to spherical shape capsules.[Breugel, 2012][II].

In a research by Kishi et al investigated self-healing of cracks by some cementations materials and recrystallization of some expansive agents. A polymer type healing agent is affective in filling the cracks but in long term it may possible to detached from the surface of crack and is likely susceptible to aging that eventually jeopardize the long-term performance in healing the cracks [I].

One of the researcher use silica fume and ground granulated blast furnace slag as a self-healing agent in concrete. Silica fume were added to concrete as 2.5%, 5%, 7.5% and 10% and GGBFS were replaced with cement as 35%. The compressive test and sorptivity test as a durability check were performed after two times 28 days of curing.
after cracking and before cracking showing very satisfactory results in term of compressive strength and healing like low water absorption of the specimens with silica fume and GGBFS [IV].

Tae-Ho Ahn used geo material in concrete and investigated for self-healing behavior. The tests results show that the cracks were healed after 28 days curing of the concrete specimens post cracking. Quantitative results show that 0.22mm cracks were healing after curing of cracked samples [I].

[V] in an another research in delft university of technology studied the effect of expanded clay particles embedded with bacterial spores with 50% replacement of 2-4mm size of aggregate. Before addition in concrete these expanded clay particles were oven dried. Control specimens have similar composition but not added with this bio chemical agent in clay particles. Despite self-healing capacity of specimens with expanded clay particles loaded with bio chemical agents the compressive strength was reduced to 50% of normal concrete specimens.

![Figure 1](image.png)

**Figure 1:** Expanded clay particles loaded with bacterial spores showing self-healing of concrete

[V] studied the effect of bacterial and organics addition on paste strength Sets of 6 replicate test specimens with dimensions of $4 \times 4 \times 4$ cm were tested for compressive strength after 3, 7 and 28 days curing. Splitting-tensile strength tests were performed on cement stone cylinders ($2.2$ cm diameter, $3$ cm height) containing different organics representing potential bio-mineral precursor compounds (see Figure 3). Concentration of added organics amounted to $0.5\%$ of cement weight, and triplicate cylinders for each compound were tested after 28 days curing. Incorporation of a high number of bacterial spores in the paste ($6 \times 108$ cm$^{-3}$) resulted in about 10% decrease in compressive strength as values amounted (compared to controls) to 91, 92 and 93% after 3, 7 and 28 days curing respectively.
II. Experimental Study

Selection of material

In this research work the methodology is identified from the literature study and experimentation/testing procedure based on codes and provisions. A standard of concrete ratio of 1:2:4 was selected based on target strength of 3000psi using sieve analysis of fine and coarse aggregate for ACI mix design having the following properties.

Table 1: Specific gravity and water absorption of aggregate

<table>
<thead>
<tr>
<th>Material type</th>
<th>Specific gravity</th>
<th>Water absorption%</th>
<th>Fineness Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine aggregate</td>
<td>2.59</td>
<td>3</td>
<td>2.39</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>2.7</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

For particles size distribution ASTM C136 and ASTM C33 is used to find the gradation curve of fine and coarse aggregate respectively. Cement, sand and aggregate were locally available materials while bacillus subtilis and steel fiber were imported from china.

Bacillus subtilis

Spore forming bacteria and can survive in harsh concrete environmental condition like high PH of concrete when stressed. B. subtilis transforms itself into a spore and enters a dormant state, allowing it to tolerate extreme environmental conditions. B. subtilis mostly found in soil.
Calcium lactate
Calcium lactate is a source of calcium carbonate precipitation, it is a white crystalline material with a formula $\text{C}_6\text{H}_{10}\text{CaO}_6$. Primarily it is used in medicine and food industry, it can be prepared by reaction of lactic acid with calcium carbonate and is easily available in market.

Steel fibers
It is of size 75 mm in length and 1 mm diameter with bended ends. A certain amount of steel fibers in concrete can cause qualitative changes in concrete’s physical property, greatly increasing resistance to cracking, impact fatigue, and bending.
Specimens Preparation and Testing

Standard cylinders according to ASTM C39 of diameter 6 inches and height 12 inches were constructed. The fresh concrete were poured in layers according to ASTM method and were cured in water for 28 days before testing. The 3 controlled cylinders were cast from normal concrete having water cement ratio of 0.5 and cement sand aggregate ratio given in table 3.5 By 20% replacement by volume of fine aggregate with bacterial specimens the arrangement is given in table below The casting of 3 bacterial steel fibers cylinder specimens is the same as bacterial cylinders with only replacement of 1.5% of coarse aggregate by weight with steel fibers.

| Table 2: Three Types of Specimen Preparation |

Figure 5: Steel fibers

Figure 6: Controlled, Bacterial and Bacterial+Steel fibers Cylinders
### Compressive Testing of Concrete Cylinder

The purpose of this test is to check the effect of steel fibers and self-healing agent on compressive strength of bacterial concrete. The cylinder size is (height =12in diameter = 6in) according to ASTM C39 All cylinder specimens were tested under single cycle of axial loading in compression in Material Testing Laboratory in University of Engineering and Technology Peshawar using one dial gauge of 20mm having frame and two plat at the top and bottom The dial gauges are connected to UCAM-70 A data logger. UTM is connected to UCAM-70 Three active channels of data logger collect load and displacements from sensors.

<table>
<thead>
<tr>
<th>NO</th>
<th>Concrete Type</th>
<th>Concrete Ratio</th>
<th>Replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Controlled Specimens (CS)</td>
<td>1:2.2:2.6</td>
<td>Nil</td>
</tr>
<tr>
<td>3</td>
<td>Specimens Bacterial(BS-1)</td>
<td>1:2.2:2.6</td>
<td>20% EP with fine aggregate</td>
</tr>
<tr>
<td>3</td>
<td>Specimens with EP and steel fibres (BSS-1)</td>
<td>1:2.2:2.6</td>
<td>1.5% steel fibres with coarse aggregate</td>
</tr>
</tbody>
</table>

Figure 7: Compressive Testing of Specimens

### III. Results and Discussions

All type of concrete cylinders were tested obtaining the following results

**Table 3:** Compressive Test results of normal concrete
V. Results Comparison

3 sets of concrete cylinders of control specimens (CS), bacterial specimens (BS) and bacterial-steel fibers specimens (BSS) were tested, evaluating the average strength of each set and plotting on a single load vs. deformation curve. All type of concrete cylinders are represented by distinct lines.

![Figure 8: Comparison of the Compressive strength of three types of specimen](image)

Table 4: Compressive test results of bacterial concrete

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Load in Ton</th>
<th>Deformation in mm</th>
<th>stress in psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38</td>
<td>0.5</td>
<td>2962.5</td>
</tr>
<tr>
<td>2</td>
<td>39</td>
<td>0.6</td>
<td>3040.5</td>
</tr>
<tr>
<td>3</td>
<td>35</td>
<td>0.45</td>
<td>2728.6</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>2910.6</td>
</tr>
</tbody>
</table>

Table 5: Compressive Test Results of bacterial and steel fibers concrete

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Load in Ton</th>
<th>Deformation in mm</th>
<th>stress in psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>3.2</td>
<td>1949</td>
</tr>
<tr>
<td>2</td>
<td>27.3</td>
<td>0.6</td>
<td>2128.3</td>
</tr>
<tr>
<td>3</td>
<td>23</td>
<td>0.45</td>
<td>1793.1</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0.8</td>
<td>1956.9</td>
</tr>
</tbody>
</table>
VI. Conclusion

A number of research was done in the field of self-healing of concrete and proven to be very effective for micro cracks sealing but self-healing concrete reduce its compressive strength due to addition and replacement of bacillus subtilis and calcium lactate with some quantity of sand and aggregate. The current research aims to enhance the compressive strength of self-healing concrete by addition of steel fibers with partial replacement of coarse aggregate. The self-healing concrete reduce 35-40% of its strength compare to normal concrete with same concrete ratio as for self-healing concrete. The addition of steel fibers enhanced and retained its compressive strength up to 30 % compared to self-healing concrete. This research determined the effect of bacillus subtilis on compressive strength of self-healing concrete. Effect of steel fibers on self-healing concrete. It is recommended to study the effect of bacillus subtilis in a structure member for flexural capacity of concrete and to study the effect of steel fiber with a different ratio.

References


