PERMEABILTY PROPERTIES OF SELF HEALING CONCRETE PRODUCED WITH BACTERIA (BACILLUS SUBSTILIS) AND PUMICE AS A CARRIER

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Abstract -*Concrete is one of the most commonly used building materials in the construction industry. Many researchers have researched into methods of improving the properties of concrete to overcome the observed limitations of concrete especially in terms of durability and permeability. Microbiologically Induced Calcite Precipitation (MICP) is a technique that comes under a broader category of science called bio-mineralization with the ability to heal cracks in construction materials including concrete. This study investigated the effects of self-healing concrete produced with bacteria (Bacillus Subsilis) with pumice as micro-organism carrier material on the permeability properties of concrete in terms of porosity, water absorption and sorptivity. A Mix ratio of 1:2:3 (cement: fine aggregate: coarse aggregate) was adopted in this study. Pumice coarse aggregates were soaked in the bacteria solution until bubble formation stopped then drained and allowed to achieve a surface dry condition.150mm x 150mm x 150mm cubes of concrete samples were cast with the addition of bacteria in pumice as a carrier material partially replacing 20% of coarse aggregates. The results showed a 64.3% and 36% reduction in porosity with 41.07% and 33.0% reduction in water absorption for uncracked and cracked samples and 18.98% reduction in sorptivity. This indicates a substantial positive effect of the bio-based self-healing agent on the permeability properties of concrete. Hence to increase the resistance of concrete to ingress of fluids and harmful chemical, self-healing concrete can be produced with Bacillus Substilis bacteria with pumice as a carrier material.*

Key Words*: *Self-healing concrete, biomeneralization, Bacillus substilis, Sorptivity, Porosity, water absorption.

1. INTRODUCTION

Concrete is one of the most commonly used building materials in the construction industry and thus great interest has been invested by numerous researchers in effort to produce concrete with better properties that will overcome the limitations of concrete in terms of strength, durability, permeability and resistance to cracking [1]. Improving the lifespan of concrete structures will indirectly improve the sustainability of the environment [2]. The major shortcoming of concrete is that it cracks when subjected to tension.

Crack formation in concrete and mortar could be a development that may hardly be fully avoided. Tiny cracks formed on the surface of the concrete make the whole structure vulnerable due to seepage of water into the concrete, promoting corrosion of steel reinforcement thus reducing the life span of the structure [3]. Whereas larger cracks will doubtless hamper a structures' integrity requiring immediate repair actions to be taken, smaller cracks like crack with dimension between 0.1mm to 0.2mm do not have an effect on strength properties of concrete structures but they do contribute to material porousness allowing the penetration of harmful substance [4]. Ingress of aggressive chemicals like chlorides, sulfates and acids could result on the long run in concrete matrix degradation and premature corrosion of the embedded steel reinforcement and so hamper the structures' sturdiness in the future [5].

The concept of self- healing of cracks by biological means is an area of great interest to researchers due to its natural approach and environmental friendliness. Cracks in concretes are sealed due to stimulation of metabolic activity of bacteria by water leading to the precipitation of insoluble Calcium Carbonate on crack surfaces [6]. Self-healing concrete based on bacteria also has potential of improving the durability of concrete [7].

Autogenic and autonomic mechanisms are the two processes of self-healing in cementitious materials. Autogenic refers to the process where the cementitious material heals cracks using its own basic innate constituents. If cracking of the concrete occurs, unreacted cement grains may become exposed to moisture penetrating the crack causing the hydration process to start again and hydration products may fill up and heal the crack. This inherent self-healing mechanism is known since long as autogenous healing [3]. Autonomous self-healing is defined as a purposely designed self-healing mechanism where cementitious healing agent can be used in the presence of water as a prerequisite for the self-healing process to happen [3]. A cementitious healing agent requires water in order to become effective, else healing will not occur. The water may penetrate into a crack from external sources or alternatively water-saturated porous lightweight aggregate particles can be added to the concrete mixture. These porous particles may release water when a crack occurs and moisture gradients stimulate the flow of water there by activating the self-healing process [3].

Pumice is one of the lightweight aggregates that can be used as carrier in self-healing concrete. The porous structure of pumice resulted from the outflow of gases from cooling magma during volcanic activation producing small hollow voids [8].Because of the gases small hollow voids renders the resulting solids to have a very porous structure, and this is why pumice has high porosity and absorption [9].

Bacterial spores along with organic mineral precursor compounds are immobilized and protected in capsules/porous medium and incorporated into the concrete. The encapsulation increases the lifespan of the biological healing agents and controls its release into the concrete matrix [10]. Once a crack is initiated, the bacterial spores become active and start to metabolize the inorganic compounds, resulting in the production of calcium carbonate crystals. The crystals formed are able to fill any open crack in the cementitious materials [11].

Biological self-healing of concrete is highly desirable in complex underground structures, hazardous liquid containers and concrete water tanks. The use of bacteria is a potent method for structural repair and different types of bacteria have been used to produce self-healing concrete materials [6].

Suitability of bacteria in concrete depends on factors such as the ability of the bacteria to live in little to no oxygen environment and environment which is high in alkaline. Some researchers have device methods to seal the bacteria and calcium nutrient source in capsules of light weight aggregate (LWA) to protect the bacteria from the roughness of concrete fabrication and protect the bacteria from high alkaline environment of bacteria. The bacteria and calcium source within the capsules or LWA are released once a crack is formed through external pressure or loading [5].

The aim of this study therefore is to investigate the permeability properties of self-healing concrete produced with bacillus substilis (bacteria) and pumice as a carrier medium in cracked and uncracked states.

2. LITERATURE REVIEW

Permeability is defined as the property that governs the rate of flow of a fluid into a porous solid. It is also a material ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. The performance of concrete subjected to many aggressive environments is a function, to a large extent, of the penetrability of the pore system. The measurements of the permeability of concrete are used as an indicator of durability. The more quickly a fluid moves through the material, the higher the permeability and the lower the anticipated durability. It was concluded by Mehta and Malhotra [12] that permeability is the key to all durability problems.

De Muynck, Debrouwer, De Belie and Verstraete [13] studied the effects of bacterial carbonate precipitation on the durability of mortar specimens. The result showed a decrease in porosity of the mortar specimen with decrease in the water absorption rate from 65% to 90% due to the deposition of calcium carbonate on surface.

Tittelboom, De Belie, De Muynck and Verstraete [14] studied the use of bacteria to repair cracks in concrete and reported that pure bacterial cultures alone were not able to bridge the cracks but when they were present in silica gel as a carrier material, the cracks become fully cured with resultant decrease in the permeability. The decrease in permeability after the incorporation of bacteria in silica gel was due to the filling of unavoidable air bubbles present in the specimen.

Wiktor and Jonkers [10] studied the potential of crack-healing in concrete using a novel self-healing agent that comprised of bacteria and nutrient encapsulated in porous clay particle with size ranging between 1-4mm used to replace a portion of fine aggregate in the concrete mix. The result indicated that calcium carbonate precipitated by the micro-organism helped in sealing of the micro cracks up to 0.46 mm wide reducing permeability. They concluded that the novel biochemical self-healing agent has a true potential towards increasing the durability of concrete structures existing in the wet environment.

Wang, De-Belie and Verstraete [5] studied the use of diatomaceous earth (DE) as a protective vehicle for bacteria in self-healing concrete and from their result, the precipitation in cracks profoundly decreased the water absorption of the cracked specimens within the first 24 hours. It was noted that the rate of water absorption in the specimens without bacteria was much faster than in the ones with bacteria. Cracks of the specimens with DE-immobilized bacteria immersed in were completely filled by the precipitation and showed the lowest water absorption. The ones with partly filled cracks showed more water absorption, but less water absorption than those without bacteria. Mohamed, Trupti, Andrew, Richard and Kevin [15] studied the application of expanded perlite to encapsulate bacteria for self-healing concrete and their result showed a much lower surface absorption values than control sample at 10 and 120 minutes. The values were less than 0.25 and 0.15 $ml/m^2/s$, respectively, suggesting that these mortars had excellent resistance to water absorption. Clearly, the precipitate had reduced the width of the cracks which in turn reduced the water flow through it.

3. EXPERIMENTAL DETAILS

The Pumice used in this study was obtained from Kerang, Mangu Local Government Area of Plateau state, Nigeria. The dry density test on pumice was carried out in accordance with the requirements of [16]. The result of the dry density of the Pumice was 663.5kg/m^3. The result show that the pumice used in this study satisfies the requirements of [17] for lightweight coarse aggregate for structural concrete which is in the range of 560 to 1120kg/m^3. The specific gravity of the pumice aggregate was determined as 1.59. This value is low when compared to the specific gravity value of normal weight aggregates which is 2.0-2.6 [18]. The result of the chemical composition revealed that the pumice used contained 68.56% Silica Oxide and 21.93% Alumina.

The coarse aggregate used was machine crushed rock obtained from JOLEX Construction Company, Jos, Plateau State, Nigeria. The gravel corresponds to the requirement of the nominal size of graded aggregate of size 5mm to 20mm, with a fineness modulus of 3.5, specific gravity of 2.6 which is within the required standard for coarse aggregate (2.0-2.6), un-compacted bulk density of 1,354 Kg/m^3 and compacted bulk density of 1,506 Kg/m^3.

The fine aggregate used was naturally occurring clean river sand. The sand has a fineness modulus of 4.04 and falls within the grading limits of zone 1 as specified by [16]. The specific gravity of the sand was 2.6. The un-compacted bulk density was 1,558 Kg/m^{3}while the compacted bulk density was 1,693 Kg/m^3. This implies that the ratio of compacted to un-compacted bulk density is 0.9 which falls within the range of 0.87-0.96 stipulated by Neville and Brooks [18].

"BUA" brand of ordinary Portland cement (OPC) of grade of 42.5R was used in this study. The cement satisfies the requirement of [19]. The results of the sieve analysis showed that the cement has a fineness modulus of 1.55 which is within the specified range for OPC [19]. Water used for this research was clean water and free from impurities satisfying the requirements of [20]. The water was obtained from the tap in the concrete laboratory of Department of Building, University of Jos.

In the preparation of material used in this research, the pure culture of *Bacillus* bacteria was isolated from the soil sample in National Veterinary Research Institute (NVRI), Vom and cultured in the Microbiology Laboratory of the department of Microbiology University of Jos as vegetative cell in a nutrient broth using Peptone water (15g/L). The medium used to grow B. substilis was Peptone water which was first autoclaved for 20 min at 120ºC and then a loop of pure culture was added after cooling. The cultures were incubated at 28ºC for 24 hours. Pumice coarse aggregates were soaked in the bacteria solution until bubble formation stopped then drained and allowed to achieve a surface dry condition. Nutrients consisting of Calcium Chloride, Urea and yeast extract for the micro-organism was dissolved in the mixing water of the self-healing concrete in proportions of 2%, 2% and 0.2% of cement weight respectively.

A Mix ratio of 1:2:3 (cement: fine aggregate: coarse aggregate) was adopted in this study. 150mm x 150mm x 150mm cubes of concrete samples were cast with the addition of bacteria in pumice as a carrier material partially replacing 20% of coarse aggregates. Samples were demolded after 24 hours and cured in water for a hydration period 28 days.After 3 days of curing, selected samples were induced with cracks by subjecting them to compressive force using the compressive test machine until visible cracks appeared. The cracked samples were then immersed in water for 28 days. The permeability properties consisting porosity, water absorption and sorptivity were conducted on the cracked and uncracked specimens after 28 days of curing. The porosity was measured by total water saturated method. After 3 days of oven drying to remove moisture, the samples were weighed suspended in air and water and the porosity obtained using the equation,

$(W_w - W_d)/(W_w - W_h)) \times 100$

Where:

W_d = weight in air.

W_h = weight in water.

W_w = saturated weight after 24 hours' immersion in water.

The water absorption of concrete was determined as per BS 1881 [21] by oven drying cubes (150 x 150 x 150mm) for 24 hours and immersed in water for another 24 hours with the respective dry and wet weight (W_w and W_d) taken and computations made using the equation $\frac{Ww-Wd}{Wd} \times 100$ to obtain the water absorption for each mix.

Sorptivity tests were carried out following the procedure described by [22]. A uni-directional water absorption test was conducted on the samples after 28 days of curing in water. The adjacent surfaces were covered with sealing adhesive (silicon sealant), leaving only the bottom face exposed to capillary suction being allowed to be in contact with water; the specimens were placed on a wire mesh in a box containing water in such a way that the lower 5 ± 1 mm of the specimens were immersed in water. At regular time intervals for 1.5 hours, the specimens were weighed to determine the weight gain with time. The cumulative absorbed volume defined as the change in mass divided by the cross sectional area of the test specimen and the density of water at the recorded temperature were plotted against square root of time. The slope of the obtained line defines the sorptivity index (S) of the specimen during the testing time.

4. RESULTS AND DISCUSSION

4.1 Porosity of the samples

The results of the porosity tests are presented in Figure 1. The results show that for the uncracked samples, porosity of the bacteria based mix is 5.04% while that of the control mix is 8.28%. This implies that the porosity of the bacteria based mix is 64.3% lower than that of control mix samples. For cracked samples, the porosities were 6.45% and 8.77% for the bacteria based mix and control respectively. This implies a reduction in porosity of 36.0%. This was due to micro pores within the concrete filled with calcium carbonate precipitated by the bacteria carried by pumice and hence more durable than the control mix sample in term of porosity.

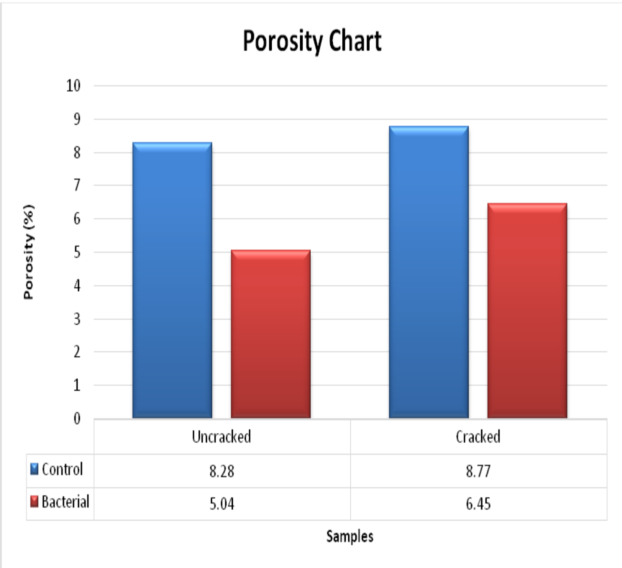

Figure 1. Porosity of cracked and Uncracked concrete cube at 28 days of curing age

4.2 Water Absorption Tests

The results of the water absorption tests are presented in Figure 2.The results of water absorption test showed that there was a 41.07% reduction in the percentage of water absorbed by the bacteria based concrete with water absorption value of 2.41% compared with the control with absorption value of 3.40% for the uncracked sample. In the cracked sample, the result showed 33.0% reduction in percentage water absorption with the bacterial based self-healing concrete having 3.21% and the control having 4.27%.This is attributed to a reduced interconnected pore spaces within the concrete matrix as a result of micro-filing of pores by precipitated Calcium Carbonate.

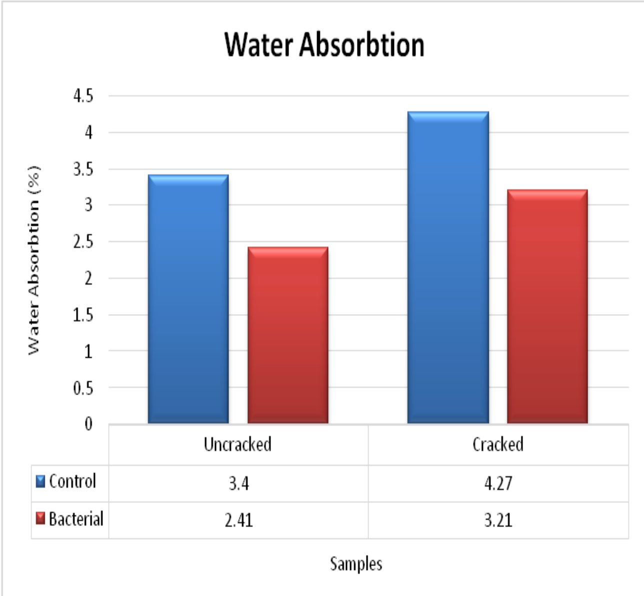

Figure 2. Water Absorption of cracked and Uncracked concrete cube at 28 days of curing age

4.3 Sorptivity Test Results

The results of sorptivity tests are presented in Figures 3 and 4. The results showed that the slope of the Sorptivity of the bacterial based concrete was 0.0527mm/sec and the slope of the control sample was 0.0627mm/√sec. From the two slopes (bacteria based sample and the control sample), there is 18.98% reduction in the rate at which the bacteria based concrete sample absorbs water. It can be inferred that the control sample absorbs more water than the bacteria sample. This is attributed to the interconnected micro pores in the bacterial sample filled with Calcium Carbonate precipitate, thereby reducing the micro-pore structure of the concrete.

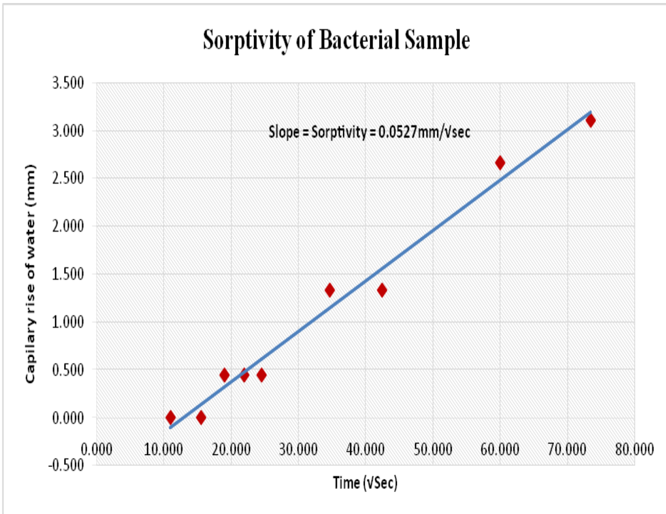

Figure 3.Sorptivity of Bacterial Samples

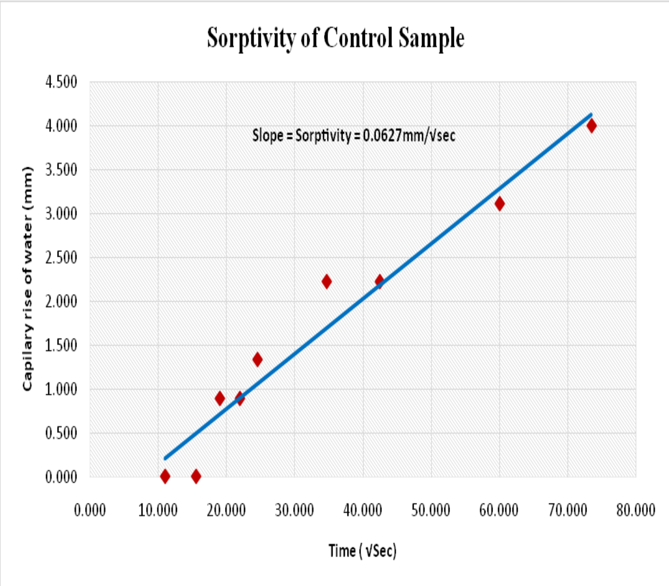

Figure 4.Sorptivity of Control Samples

5. CONCLUSSION

The result of this study revealed that the permeability properties of self-healing concrete produced with bacteria (*Bacillus Substilis*) with Pumice as carrier material decreased substantially indicating a positive effect of bio-based self-healing agent thereby increasing the resistance of the concrete to the penetration of fluids. This was due to micro pores and cracks being partially filled with Calcium Carbonate precipitate by the bacterial activity.

6. RECOMMENDATION

Based on the results of the findings, self-healing concrete can be produced with bacteria (Bacillus Substilis) and locally available pumice as carrier material to enhance the water tightness of structural concrete members.

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