

EVALUATION OF EFFECT OF SODIUM SILICATE AND BACILLUS PASTEURII IN SELF-HEALING ABILITY OF CONCRETE

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Abstract

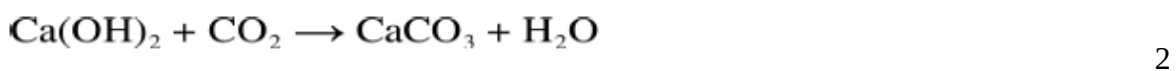
One of the major defects of hardened concrete is crack. Cracks allow water to permeate into concrete and it could corrode the reinforcing steel fibres. Concrete liquid retaining structures do not function properly if cracks are not controlled. This study examines the effectiveness of sodium silicate and bacillus pasteurii mixed in concrete to control its cracks. The objectives are to determine the healing ability of sodium silicate gel, spore bacillus pasteurii, and solution of bacillus pasteurii when mixed with concrete. Laboratory experimental methods were adopted for the research. The index properties of the materials were determined. Mix ratio of 1:2:4 was adopted for the concrete mixes. Results indicate that over 92 % of the concrete specimens tested show a reduction in water absorption. The cube specimens containing sodium silicate gel has an average density of 2440 kg/m^3 before healing and decreased to 2437 kg/m^3 after healing with an average compressive strength of 25.56 N/mm^2 . This strength approximately equals the value of control cube specimens of 25.18 N/mm^2 . Specimens that contained bacillus pasteurii have average 10.0% gain in compressive strength compared to the control specimens. The concrete specimens that contained bacillus pasteurii showed physical evidence of crack sealing. Specimens containing sodium silicate showed no physical signs of healing of the induced cracks. Specimens containing bacillus pasteurii manifested autogenous as well as autonomous healing in both spore and solution state. This is evident by the decrease in water absorption of the concrete. Bacillus pasteurii is compatible in incorporation into fresh concrete through media such as glass wares, glass tubes and light weight expanded clay aggregates (LECA), for later healing processes. It is also capable of surviving extreme alkaline environment and forming spore without contamination. Bacillus pasteurii in spore state is therefore recommended for addition in concrete to achieve self-healing.

Keywords: Concrete, Self-healing, Crack, sodium silicate gel, and bacillus pasteurii

Introduction

When cracks begin to appear in a structure, it is an important indicator of the overall failure condition of the structure. Although not all cracks in concrete are detrimental to its functionality, the emergence of cracks, micro or macro, in concrete or reinforced concrete, is a phenomenon that cannot be done away with (Neville, 1996). The size, location and severity can dictate the importance of repairs. Large cracks could indicate failure or deterioration of structure. Small cracks could also be evidence of damage, including those related to poor subgrade preparation, poor curing, and deterioration from a number of causes. A cost-effective alternative to concrete maintenance has been developed. It has ability for cracks to self-heal. Bacteria-based self-healing concrete has been found to successfully heal cracks up to 0.775 mm (Jonkers, 2011). Healing can occur through several mechanisms, including hydration of non-hydrated or partially hydrated cement particles (Zwaag, et al, 2009).

Ishraq et al (2019) and Talaiekhazan et al (2014), classified self-healing in concrete as 'Natural Self-healing or sealing of cracks in concrete. We have Chemical self-healing concrete and Biological self-healing Concrete. Natural self-healing concrete also known as Autogenous healing, is caused by un-hydrated cement present in the matrix. When water comes in contact with un-hydrated cement, further hydration occurs. Furthermore, dissolved CO₂ reacts with Ca²⁺ to form CaCO₃ crystals. This process is called carbonation. Carbon dioxide in water will react with non-hydrated cement particles resulting in secondary hydration. The portlandite (calcium hydroxide) particles react with the carbon dioxide to produce calcium carbonate-based mineral precipitates (Jonkers, 2011). As self-healing takes place within cracks the permeability of concrete reduces, and as a result the risk of water or chemicals reacting with steel reinforcements is limited. These two mechanisms, however, may only heal small cracks. Water that penetrates cracks would not only dissolve calcite (CaCO₃) particles present in mortar matrix, but would also react together with atmospheric carbon dioxide and lime constituents that is not fully hydrated, such as calcium oxide and calcium hydroxide as shown in equations 1 and 2 (Jonkers and Schlangen, 2008):



The freshly produced minerals (Ca(OH)₂ and CaCO₃) and dissolved/recrystallized calcite minerals, precipitate on the surfaces of cracks, which would result in crack-sealing and concomitant reduction in permeability of the concrete (Jonkers and Schlangen, 2008). Sealing of cracks could also result from accumulation of impurities in water which might block cracks and further expansion of the hydrated cementitious matrix in crack flanks. Chemical self-healing is another process. This is a method of injecting chemical matter into concrete cracks. It is also referred to as artificial healing (Talaiekhazan, 2014). To design chemical self-healing materials, liquid such as glue is needed to mix with fresh concrete in small containers like hollow pipettes (Van, 2013). Self-healing concrete was invented by Henk Jonkers, a microbiologist and professor at Delft University of Technology in the Netherlands. Jonkers began developing self-healing concrete in 2006. After three years of experimenting, he found the perfect healing agent - Bacillus. "You need bacteria that can survive the harsh environment of concrete", Jonkers said in an interview with CNN (Cables News Network). "It's a rock-like, stone-like material, very dry". When microorganisms are

used during the production of concrete, it is classified as biological self-healing (Wu, Johannesson and Geiker, 2012).

Far back as 1999, studies particularly on high strength concrete with a low water-cement ratio has shown a substantial self-healing capacity (Edvardsen, 1999 and Neville, 1999). A high percentage of non-hydrated or partially hydrated cement particles present in concrete mix was responsible because the non-hydrated cement particles in the presence of water or process of curing will undergo secondary hydration when water permeates through developed cracks. Research carried out by Reinhardt and Jooss (2003), indicated that concrete structures have a certain capacity for autonomous healing of micro cracks. The ability of self-healing in concrete appears to be limited to micro-cracks within widths up to 0.1–0.2 mm (Li and Yang, 2007).

Research by Jonkers and Schlangen (2008) showed 10% compressive strength loss with incorporation of bacteria (*B. pseudofirmus*). Furthermore, when bacterial spores were mixed directly with concrete constituents, their lifetime appeared to be limited to one to two months. Results gleaned from visual observation of the successful sealing of cracks due to early applications of bacteria-based mixtures to surface cracks led to further studies which centered on the use of an Alkali-Resistant bacterium of the genus *Bacillus* within a concrete mixture. The results showed that the bacteria spores grew when they came in contact with water, with a by-product of crack-filling calcium carbonate (Jonkers, et al, 2010). Certain organic bio-cement precursor compounds (food for bacteria) such as yeast extract, peptone and calcium acetate were investigated and most of these compounds led to decrease of compressive strength of concrete except calcium lactate which resulted in a 10% increase in compressive strength (Jonkers et al., 2010). A comparative study of two components bio-chemical healing agent, bacterial spores with the use of porous expanded clay particles also known as light weight expanded clay aggregates (LECA or exclay) as a reservoir, revealed a decrease in permeability and thus self-healing capacity (Jonkers, 2011). Years later, various healing agents such as bacteria, sodium silicate, and fungi have been tested by scientists and engineers around the world to optimize self-healing in concrete (Ben, 2019). Tables 1 and 2 show Bacteria used in self-healing technology and characteristics of most commonly used bacteria respectively.

Table 1: Bacteria used in self-healing technology

S/N	Type of bacteria	Cement Replacement	Result
1	<i>Bacillus aerius</i>	Rice husk	Strength, durability
2	<i>Bacillus megaterium</i>	No replacement	Compressive strength
3	<i>Bacillus sphaericus</i>	Normal concrete	Durability
4	<i>Sporosarcina pasteurii</i>	Fly ash concrete	Strength, durability
5	<i>Sporosarcina pasteurii</i>	Silica fume	Improvement in strength and durability
6	<i>Bacillus sphaericus</i>	No replacement	Alternative surface treatment for concrete
7	<i>Shewanella species</i>	No replacement	Compressive strength
8	<i>Bacillus subtilis</i>		Compressive strength

Busari (et al., 2020)

Table 2: Characteristics of most commonly used bacteria

Bacteria	Characteristics
Sporosarcina pasteurii or Bacillus Pasteurii	Most commonly used microorganism in cement-based materials. It is alkaliphilic and endospore-forming, a bacterium. Its endospore helps it to endure an extreme environment. It has strong urease activity. It can produce CaCO_3 through biomineralization which helps in strength gain, reduce sorptivity, water absorption, water, and chloride permeability and increase resistance against freeze-thaw. It is also known as biological construction material which is ecologically sound.
Bacillus subtilis	It has the ability to form tough protective spores when subjected to unfavorable conditions which allow it to tolerate extreme environmental conditions and high mechanical pressure. It can produce CaCO_3 through biomineralization which helps in strength gain.
Bacillus sphaericus	It is aureolytic, alkali-tolerant spore-forming strain with high urease activity. It shows a pessimistic zeta-potential and a constant formation of heavy CaCO_3 crystals which helps in strength gain, reduce water absorption, water permeability and increase resistance against freeze-thaw.
Bacillus Cohnii	It is a non-ureolytic, alkaliphilic spore-forming bacteria which can survive up to 70°C . It also helps in strength gain and reduces orptivity.
Bacillus halodurans	It has ability to tolerant alkali-tolerant. It can increase strength and reduce water absorption and porosity as well as chloride permeability.

(Ankita and Purnachandra, 2019)

Self-healing in concrete can be measured based on physical, chemical or mechanical processes. Calcium carbonate precipitation is the most evidential factor which can influence the self-healing of concrete as well as sealing of micro-cracks. Crack healing or sealing or self-healing capacity of concrete decreases with increase in crack width and crack age (Ankita and Purnachandra, 2019). The emergence of cracks in reinforced concrete structures impairs the functionality, accelerating degradation, and decrease service life. When water comes in contact with steel reinforcements in concrete through cracks, corrosion develops in the fibres. This could lead to degradation of constituent materials of concrete and reduction in strength of concrete which might be a major contributing factor in collapse of buildings. Therefore, it is necessary to heal cracks as soon as they appear. Healing controls cracks that are detrimental to the functionality of concrete and reinforced concrete structures. Certain industrial wastes can be recycled to improve the sustainability of concrete, the production of cement is high-energy consuming as raw materials are burned at about $1,500^\circ\text{C}$; a process that contributes to a significant amount of atmospheric carbon dioxide release worldwide. Thus, for both economic and environmental reasons, cement production and use contribute to climate change. There is need to minimize the amount of cement for concrete production.

Methods of repairing concrete cracks consist of complex technology, high cost with little or no large-scale application. Although several researchers have reported on this subject matter in other to formulate an alternative method of cracks repair. There had not been an agreement

as to how realistic these methods can be. Therefore, there is need to investigate these natural and or artificial substances for healing ability of concrete. Biological self-healing concrete is classified into Bacteria, Fungi and viruses. Among these microorganisms, some bacteria that are capable of precipitating specific chemicals are utilized to initiate biological self-healing in concrete. Precipitation of polymorphic iron-aluminum-silicate and calcium carbonate are the various significant processes applied in planning biological self-healing concrete. Concrete is greatly alkaline in nature. In addition, microorganisms ought to have the capacity to withstand the different natural states of concrete (Bashir et al., 2016). The aim of this research is to find self-healing ability of concrete using encapsulated Sodium Silicate and *Bacillus pasteurii*. The specific objectives are to:

- i. determine the physical properties of the aggregates.
- ii. determine the grading of the aggregates.
- iii. determine the healing ability of sodium silicate gel and *Bacillus pasteurii*.

Statement of the problem

Cracks pose a lot of challenges in concrete structures. They allow water or liquid to enter concrete and corrode steel reinforcement fibers. The menace of cracks could also render water-retaining structures to fail. Repairing or managing this defect has taken many dimensions in engineering technology.

Materials and Methods

The materials used for the research work are Portland Limestone Cement type II: 42.5N, fine aggregate obtained from River Benue Makurdi-Nigeria, crushed granite coarse aggregate with a maximum size of 12mm, Portable water from Joseph Sarwuan Tarka University Makurdi-Nigeria, sodium silicate and *Bacillus pasteurii* obtained in Makurdi.

Specific Gravity

The specific gravity (G_s) of the fine aggregate was determined using British Standard (BS) 1377 (1975) specifications.

$$G_s = \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)} \quad 3$$

Where w_1 is weight of bottle alone, w_2 weight of empty bottle and aggregate, w_3 is weight of empty bottle, aggregate and water, and w_4 is weight of bottle with water alone.

Particle Size Distribution

Sieve analysis of the aggregates was carried out as prescribed in BS 812 – Part 103. 1.

Concrete Mix

Concrete mix ratio of 1:2:4 was adopted for the ingredient mixes and water-cement ratio of 0.5 was used. Mixing of the fresh concrete was done manually.

Casting and Curing of the Concrete

Steel cube moulds of dimensions 150 x 150 x 150 mm, concrete beam moulds of size 100 x 100 x 450 mm, and steel cylinder moulds of size 300 x 150 mm were used to cast the concrete. The prepared healing agents were carefully placed in the fresh concrete already cast

and the moulds vibrated again. The specimens were allowed to set for 24 hours. Then, specimens were removed from moulds. Specimens containing sodium silicate were transferred to a freezer at about 10 degrees Celsius. The rest of the specimens were placed in curing tank at atmospheric temperature for 14 days.

Introduction of Cracks

The 14-day old concrete cubes, cylinders and beams were forced to develop cracks with the aid of compression testing machine. The load at which noticeable cracks appeared on the surface of specimen was recorded and the pictures of the cracks taken. These cracked concrete cube, cylinder, and beam samples were immersed in water and observed until healing would take place.

Compressive Strength Test

The compressive strength of the specimens was determined as specified in BS 1881 – part 116, 1983. Compressive strength is given by equation 4.

$$\text{Compressive Strength (N/mm}^2\text{)} = \frac{\text{Crushing Load (N)}}{\text{Surface area of cube}} \quad 4$$

Density of Concrete

The density of each cube specimen was determined in conformity with BS 1881 – 114. Equation 5 was used for calculation of cube density.

$$\text{Density (p)} = \frac{M}{V} \quad 5$$

Where M = mass (kg), and V = volume of specimen (m³)

Water absorption test

Water absorption (W.A.) test of the specimens was determined as specified in B.S 1881, part 122, 1983. Their weights were measured and bulk density determined. The percentage water absorption was calculated from equation 4.

$$\text{Percentage W.A.} = \frac{A-B}{B} \times 100 \quad 6$$

where A is the wet weight and B is the dry weight of specimen.

Results and Discussion

Results for particles size distribution for the crushed granite and the river sand are shown in figures 1 and 2 respectively. The granite aggregate is within the range prescribed for single-sized coarse aggregate of 20mm, as specified in BS 882 (1992). The river sand distribution curve falls within the overall limits for fine aggregates from natural sources for concrete as specified in BS EN 12620, 2002. It is observed that coefficient of uniformity (Cu) and coefficient of curvature (Cc) of the river sand are 2.25 and 1.00 respectively. These values agree with the results of Nwogu (2022). The soil particles with coefficient of curvature between 1 and 3 are said to be well-graded. The soil is poorly graded when it is less than 1 and uniformly graded at 1. The soil is uniformly graded when Cu is less than 4. All the aggregates used have Cc approximately 1 and Cu less than 4. The aggregates are therefore, uniformly graded and suitable for making quality concrete.

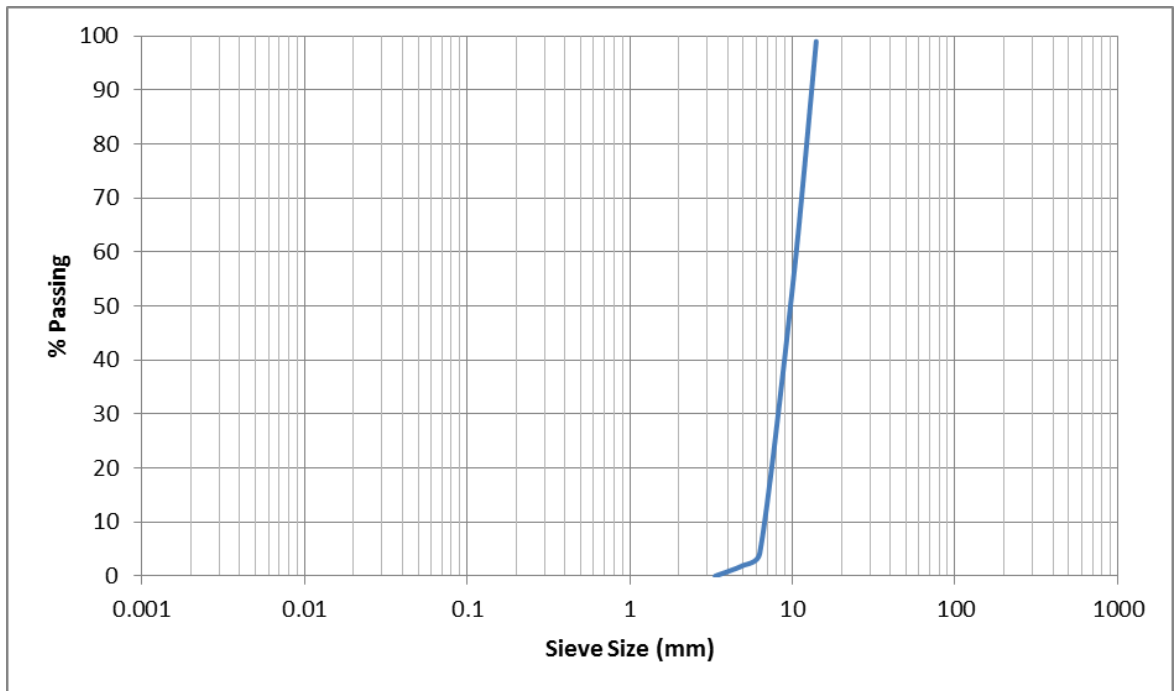


Figure 1: Grading of the Crushed Granite Aggregate

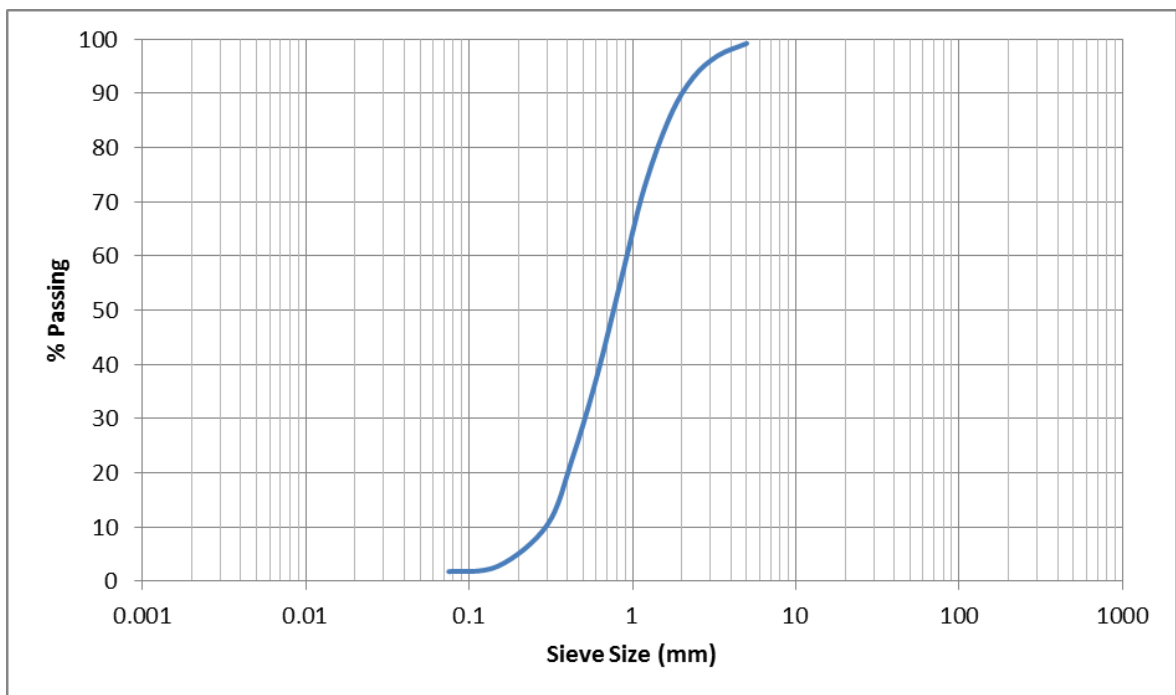


Figure 2: Grading of the River Sand Aggregate

Specific Gravity

The specific gravity for the river sand and the crushed granite are found to be 2.86 and 2.78 respectively. The specific gravity values obtained in this study are similar to the values obtained by Obam, et al, (2023). The values also fall within the specifications of ASTM C33 (2003).

Water Absorption

The results of water absorption test are shown in Table 3. The cube control specimens show reduction of water absorption of 2.42 from 2.62 percent (about 7.6 percent decrease). The control beam and cylinder specimens indicate reduction of 36.3 and 5.6 percent in average water absorption respectively. Cube specimens containing Sodium silicate has no significant difference in its average water absorption but the beam specimens show a decrease of about 20.0 percent in its average water absorption. The cubes containing spore of bacillus pasteurii show decrease of 55.0 percent in average water absorption while cubes with solution of the bacillus pasteurii show decrease of 21.0 percent in average water absorption. Similarly, the cylinder specimens containing spore and solution of the bacillus pasteurii show decrease of about 99.8 and 82.0 percent respectively, in average water absorption. The beam specimens containing spore and solution of bacillus pasteurii show reduction of 54.5 and 6.4 respectively, in average water absorption. The beam specimens containing sodium silicate show decrease of 20.5 percent in water absorption. The decrease in water absorption in specimens containing spore, solution of bacillus pasteurii, and sodium silicate is an indication of autogenous healing (Reinhardt and Jooss, 2003). The self-healing process seals the induced cracks in the concrete specimen as could be observed in Plate 1. This healing process in the pulverized concrete is as a result of unreacted cement particles within the concrete mix which later got hydrated when water entered through the cracks. Neville (1999), Edvarseen, (1999), Ben (2019), and Reinhardt and Jooss, (2003) gave similar results. Li and Yang (2007), explained that the decrease in water absorption in the specimens containing Bacillus pasteurii bacteria is as a result of precipitation of calcium carbonate which solidifies in the cracks developed during the feeding process of the bacteria on the precursor. The average decrease in water absorption of the specimens containing the bacteria agents is about 50 percent higher than the control specimens. This shows that the bacteria agents and Sodium silicate are capable of inducing self-healing of concrete.

Table 3: Results for water absorption test of the specimens

Sample Name	Sample	Wet mass (kg)	Dry mass (kg)	Cracked mass (kg)	Wet mass after healing (kg)	Dry mass after healing (kg)	Water absorption before intro. of cracks (%)		Water absorption after healing (%)	
Control Specimen (Cube)	1	8200	8000	7950	8200	8000	2.5	Av.	2.5	Av.
	2	8450	8200	8150	8400	8200	3.05	2.62	2.44	2.42
	3	9000	8800	8650	8900	8700	2.27		2.33	
Control Specimen (Beam)	1	11,900	11,400	11,000	11,600	11,500	3.48	Av.	0.87	Av.
	2	12,400	12,00	11,750	12,100	11,750	3.33	3.405	2.98	1.920
Control Specimen (Cylinder)	1	1,339	1,300	1,285	1,332.5	1,314.90	3.00	Av.	1.34	Av.
	2	1,292.7	1,250	1,200	1,285.0	1,268.00	3.42	3.37	1.34	1.47
	3	1,279.4	1,234	1,200	1,270.0	1,248.50	3.68		1.72	
Spore of Bacillus pasteurii (Cube)	1	8,300	8,150	8,100	8,200	8,150	1.84	Av.	0.613	Av.
	2	8,300	8,100	8,100	8,200	8,100	2.47	2.26	1.235	1.02
	3	8,300	8,100	8,100	8,300	8,200	2.47		1.219	
Solution of Bacillus pasteurii (Cube)	1	8,600	8,500	8,400	8,600	8,500	1.18	Av.	1.88	Av.
	2	8,200	8,000	8,000	8,200	8,100	2.50	2.02	1.235	1.60
	3	8,650	8,450	8,350	8,600	8,400	2.37		2.38	

Table 3: Results for water absorption of the specimens Continued

Sample Name	Sample	Wet mass (kg)	Dry mass (kg)	Cracked mass (kg)	Wet mass after healing (kg)	Dry mass after healing (kg)	Water absorption before intro. of cracks (%)	Water absorption after healing (%)		
Sodium Silicate (Cube)	1	8,200	8,100	8,100	8,200	8,100	1.23	Av.	1.23	
	2	8,500	8,400	8,350	8,500	8,300	1.19	1.205	1.23	Av.
	3	8,400	8300	8,200	8,400	8,200	1.20		1.22	1.22
	4	8,400	8,300	8,300	8,400	8,300	1.20		1.20	
Spore of Bacillus pasteurii (Cylinder)	1	1,200	1,106	1,100.2	1,138.4	1,104.3	8.50	Av.	3.09	
	2	1,300	1,167	1,270.5	1,3115	1,272.5	11.40	10.77	3.07	Av.
	3	1,250	1,112	1,209.3	1,249.6	1,214.4	12.41		2.90	3.02
Sol. of Bacillus pasteurii (Cylinder)	1	1,200	1,100	1,200.0	1,235.3	1,213.6	9.09	Av.	1.79	Av.
	2	1,300	1,200	1,250.9	1,279.1	1,262.1	8.33	8.71	1.35	1.57
Spore Basilluspasteurii (Beam)	1	12,600	12,250	12,400	12,600	12,400	2.86	Av.	1.61	Av.
	2	12,700	12,400	12,600	12,700	12,600	2.42	2.64	0.79	1.20
Sol. Basilluspasteurii (Beam)	1	13,200	13,000	12,900	13,100	12,900	1.54	Av.	1.55	Av.
	2	12,800	12,600	12,600	12,900	12,600	1.59	1.565	2.38	1.465
Beam sodium silicate	1	12,000	12,500	12,000	12,400	12,000	4.17	Av.	3.33	Av.
	2	12,000	12,500	12,000	12,400	12,000	4.17	4.17	3.33	3.33

Density and Compressive Strength

The results of density and compressive strength tests are shown in Table 4. The control cube specimens show average density of 2449 kg/m^3 on the 14-day (i.e., after healing). The average compressive strength of the control cube specimens is 25.18 N/mm^2 on the 14-day. The control specimens had no sodium silicate, spore and solution of *Bacillus pasteurii* bacteria or calcium lactate agents. The strength values recorded could be as a result of hydration reaction when water penetrates the cracks and the unreacted cement particles within the concrete later got hydrated when it made contact with water. This is an indication of autogenous healing in the control concrete specimens as observed by Neville, (1999), Edvarseen, (1999), and Reinhardt and Jooss (2003). The specimens containing sodium silicate has average compressive strength of 25.56 N/mm^2 . The strength represents 1.5% gain compared to the control specimens. This is similar to the results obtained by Luciana, Anna, Guiseppe and Jean, (2017). The solution of *Bacillus pasteurii* cube specimens has average compressive strength of 26.30 N/mm^2 . This represents 4.45 % gain in compressive strength. Similarly, the cube specimens containing spore of *Bacillus pasteurii* has average compressive strength of 27.67 N/mm^2 , about 10.00 % higher than the control specimens. This is similar to results of Ankita and Purnachandra, (2019). This increase could be as a result of precipitation of calcium carbonate which solidified in the cracks during the feeding process of the bacteria on the precursor, that is, calcium lactate (Li and Yang (2007), and Jonkers et al (2010)). The agent (calcium lactate) was used as food supplement for both spore and solution of *Bacillus pasteurii* in the cube specimens.

Table 4: Results for density and compressive strength tests of the specimen

Sample Name	Sample	Cracked mass (kg)	Dry mass after healing (kg)	Density before healing (kg/m ³)	Density after healing (kg/m ³)	Crack load before healing (kN)	Crack load after Healing (kN)	Crushing Load (kN)	Compressive Strength (N/mm ²)			
Control Specimen (Cube)	1	7950	8000	2355.56	Av.	2,370.37	Av.	240	350	550	24.44	Av.
	2	8150	8200	2414.81	2426	2,429.63	2,449	380	400	550	24.44	25.18
	3	8650	8700	2508.15		2,548.14		420	400	600	26.67	
Spore of Bacillus pasteurii (Cube)	1	8,100	8,150	2400	Av.	2414.82	Av.	360	400	560	24.89	Av.
	2	8,100	8,150	2400	2400	2414.82	2419	280	450	700	31.11	27.67
	3	8,100	8,200	2400		2429.63		392	400	600	26.67	
Solution of Bacillus pasteurii (Cube)	1	8,400	8,500	2488.89	Av.	2518.51	Av.	360	400	600	26.67	Av.
	2	8,000	8,100	2370.37	2444	2400.00	2467	280	350	575	25.56	26.30
	3	8,350	8,400	2474.07		2488.89		392	400	600	26.67	
Sodium Silicate (Cube)	1	8,100	8,100	2400.00	Av.	2400.00	Av.	-	-	-	-	Av.
	2	8,350	8,300	2474.07	2440	2459.26	2437	400	400	550	24.44	25.56
	3	8,200	8,200	2429.63		2429.63		400	450	600	26.67	
	4	8,300	8,300	2459.26		2459.26		-	-	-		



a. Cracked Specimen



b. Healed Specimen



c. Cracked specimen



d. Healed specimen



e. Cracked specimen



f. Healed specimen

Plate 1: Cracked and Healed Cylinder Specimens

Conclusion

Results obtained from this research have indicated that over 92 percent of specimen tested showed reduction in water absorption including the control specimens which had no healing agents embedded within the concrete. This is an evidence of autogenous healing in the concrete specimens. The specimens containing sodium silicate gel showed 20.0 percent increase in its average water absorption. The sodium silicate specimen had an average density of 2440 kg/m^3 before healing and decreased to 2437 kg/m^3 after healing. Its average compressive strength is

25.56 N/mm², approximately equal to the control cube specimen strength of 25.18 N/mm². None of the control specimens as well as specimens containing sodium silicate gel showed signs of physical healing of the induced cracks. Therefore, sodium silicate gel could have poor self-healing ability of concrete.

The reduction in water absorption of all the specimens containing bacillus pasteurii both in spore and solution state indicate autogenous as well as autonomous healing. The evidence is shown in the increase of their average densities after healing and increase in their average compressive strength. The cube specimens that contained spore of *Bacillus pasteurii* have average gain of 10 percent in compressive strength higher than the control specimens. All specimens containing spore and solution *Bacillus pasteurii* showed physical evidence of cracks sealing, as could be observed in Plate 1. Cracks that appear wide were not totally sealed.

Recommendations

1. Bacteria *Bacillus pasteurii*, capable of surviving in an extreme alkaline environment and is able to form spore without contamination (mucus) should be adopted for self-healing of concrete.
2. There is need for research on other materials or bacteria to be used in concrete to reduce cracks.

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