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# EVALUATION OF AGENTS FOR DEVELOPMENT OF SELF-HEALING CONCRETE IN MODERN CONSTRUCTION

**[1]Ihenketu Christopher, [2]Iwudibiah Chidi Charles & [3]Ebube Ogbonna Christopher**
[1]Department of Building Technology, Akanu Ibiam Federal Polytechnic, Unwana Afikpo, Ebonyi State
[2]Department of Building Technology, Imo State Polytechnic, Umuagwo
[3]Department of Building Technology, Auchi Polytechnic, Auchi
**E-Mail:** xtopherihe@gmail.com
**Correspondent author: Ihenketu Christopher**

## ABSTRACT

*The study examined the agents responsible for self-healing concrete in modern construction. Survey research design was employed for the study; the study population was made up of 600 construction workers in the south-east geopolitical zone of Nigeria. 240 workers were used as sample using taro yammney formula to determine the sample size and simple random sampling technique to determine which of the 600 workers should be selected as sample. Mean and analysis of variance (ANOVA) were used for data analysis. From the findings, bacterial, mineral additives and adhesive agents are responsible for self-healing in concrete and no significant difference exist in the rating of the agents on different sizes of buildings. Therefore, self-healing agents are essential in the achievement of sustainable concrete in modern construction. Building professionals should be trained on self-healing concrete. Government should ensure the availability of the agents and subsidize its price. The public should be sensitized on self-healing concrete through seminars and advertisement by the Council Registered Builders of Nigeria (CORBON).*

**Keywords:** *self-healing agents; Self-healing process; Impact of self-healing concrete.*

## INTRODUCTION

Concrete is a strong and relatively cheap construction material and presently the most used construction material worldwide (Jonkers, Thijssen, Muyzer, Copuroglu & Schlangen, 2008). The massive production of concrete exerts negative effects on the environment due to its main ingredients ( cement and aggregate) need to be produced and mined on massive scale and transported over considerable distances, increasing energy consumption, greenhouse gas emissions, and landscape mutilation. Gerilla, Teknomo, and Hokao (2007) maintained that, concrete is not a sustainable material because of its negative effect on the environment. It is estimated that cement production alone contributes 7% to global anthropogenic $CO_2$ emissions, the slinking of limestone and clay at a temperature of 1500°C, calcium carbonate is converted to calcium oxide (CaO) releasing carbon dioxide (Jonkers *et al.,* 2008 citing Worrell, 2001).

Concrete is one of civilization's most durable building materials. The ancient Romans used concrete 2000 years ago to make structures that still stand today. People now use the material's modern version aggregates such as sand or gravel held together by a cement and water paste more than all other construction materials combined. The world produced 4.3 billion metric tons of cement in 2014, and this production will keep increasing as more sidewalks, buildings, and bridges get built in an increasing urban world (Patel, 2016). The word concrete is originated from the latin word "concretus" which means condensed and hardened. The earliest use of cement is dated back to twelve million years ago, while the early use of concrete is dated back to 6500BC. However, it wasn't formed as concrete until later during the Roman Empire (Alhalabi & Dopudja, 2017). To chronicle the history of concrete, it should be understood that concrete was accidentally discovered by the Romans while quarrying limestone for mortar which was being used to make cement. When silica and aluminum bearing mineral was mixed with limestone and burned, mixed with water and sand, it had remarkable properties. It was found to be able to harden underwater as well as in air. It replaced the lime mortar mix that had been used up to then. This mixture had all ingredients of today's Portland cement and the Romans invented concrete construction. After the fall of the Roman Empire, this construction knowledge was lost until the 18th century when reinvented by the English (Stanislaus, 2015). Concrete is the most commonly used building material which is recyclable. It is strong, durable, logically available and versatile. It is capable to resist the compressive load to a limit but if the load applied on the concrete is more than their limit of resisting load, it causes the strength reduction of concrete by producing cracks in concrete and the treatment of those cracks is very expensive (Dinesh, Shanmugapriyan & Sheen, 2017). Concrete strength was enhanced in the 1850s when it was reinforced with steel bars during the construction of concrete boats, concrete flower pots, water tanks and bridges in 1867. By the early 1900s when experimental pre-stressing tests were developed, concrete then began to be used in building structures (Stanislaus, 2015).

According to Restucca, Reggio, Giuseppe, and Tulliani (2017), concrete is the most used construction material on earth but it is susceptible to crack formation due to its limited tensile strength. Moreover, damage repair tends to be difficult when cracks are not visible or not easily accessible. Cracks in concrete affect the serviceability limit of concrete. The ingress of moisture and other harmful chemicals into the concrete may result in decrement of strength and life (Dinesh, Shanmugapriyan & Sheen, 2017). Cracking is a phenomenon that hampers that material's structural integrity and durability. The impact of durability-related problems on national economies can be substantial and is reflected by the sum of money spent on maintenance and repair of concrete structure (Jonkers *et al.,* 2008). Cracking of the surface layer of concrete reduces material durability as ingress water and detrimental chemicals processes takes place resulting to corrosion of the embedded steel reinforcement (Jonkers *et al.,* 2008 citing Neville, 1996). Ingress of aggressive chemicals such as chlorides, sulfates, and acids may result on the longer term concrete matrix degradation and premature corrosion of the embedded steel reinforcement and thus hamper the structure's durability on the long term (Jonkers, 2011).

Petal (2016) highlighted that, despite the strength and durability of concrete, it has problems. Stress from carrying loads gradually creates microscopic fissures in the material that allow in water, salts, and ice. These fissures can then turn into gaping exposing the steel bars often used to reinforce concrete to corrosive elements. Alhalabi and Dopudja (2017) maintained that, as revolutionary as it was, modern concrete has a short lifespan caused by the formation of cracks, shortening the longevity of a particular construction. Many researchers have been attempting to improve concrete in order to get a better longevity among many other things, that's how the concept of self-healing finds its way to concrete. Shanmugapriyan and Sheen (2007) maintained that, the ingress of sulphates and chlorides in concrete results in decrease of durability. These effects in concrete structures by cracking might be overcome by utilizing self-healing technology which has high potential to repair cracks in concrete and enhance the service life of concrete structures with a reduction of demand for repair and maintenance. Shanmugapriyan and Sheen also maintained that, self-healing agents such as epoxy resin, bacteria, fibre, sodium silicate are used to heal cracks in concrete. Tittelboom and DeBelie (2013), grouped the self-healing agent into self-healing by mineral additives, self-healing by means of bacteria, and self-healing based on encapsulated adhesives. Reinhardt and Jooss (2003) stated that, in several studies, indications have been found that concrete structures have a certain capacity for autonomous healing of micro cracks. The actual capacity of micro crack healing appears primarily related to the composition of the concrete mixture. Particularly, mixture based on high binder content show remarkable crack-healing properties due to delayed hydration of matrix embedded non-hydrated cement and binder particles upon reaction with crack ingress water. The limitation to application of high binder content mixtures solely for the purpose of increasing self-healing capacities are current cement production contributes about 7% to global anthropogenic $CO_2$ emission.

According to Mather and Warner (2003), developed countries including Germany, South Korea, and the U.S, are experiencing unprecedented amounts of civil infrastructure deterioration, that the annual outlay for repair and rehabilitation has outstripped the cost of new infrastructure construction. The annual economic impact associated with maintaining, repair, or replacing deteriorating structures is estimated at $18-21 billion in the U.S. alone. The American Society of Civil Engineers estimates that $2.2 trillion is needed over the next five years for repair and retrofit; a cost of $2 trillion has been estimated for Asian's infrastructure. Repair of concrete structures are often short-lived. The concerns related to civil infrastructure deterioration are not limited to the economic cost of repair and rehabilitation, but extend to social and environmental cost. While there is little documentation and quantification of the social and environmental cost, it is generally agreed that repeated repairs of structures over their service life is decidedly unsustainable (Li, Ranada, Kan & Li, 2010). Over the last decades, the concept of concrete infrastructure able to repair itself without human intervention has emerged as a possible cure for overcoming civil infrastructure deterioration. While the idea remains a novelty in practice, it has attracted a significant amount of attention in the research community. Many approaches to functionalizing concrete to possess self-healing ability have been investigated (Hosoda, Kishi, Arita, & Takakuwa, 2007). In few cases, field trials have been launched. Thus, self-healing concrete has significant implications in extending service life, and reducing economic, social and environmental cost of civil infrastructure. That is, self-healing concrete could be a major enabling technology towards sustainable civil infrastructure (Victor & Herbert, 2012).Self-healing concrete is a product which biological produces limestone by which cracks on the surface of the concrete is heal. The self-healing agents can lie dormant within the concrete for up to two hundred years (Dinesh, Shanmugapriyan & Sheen, 2017).

A self-healing agent is described as agent that is capable of repairing itself back to the original state. The concept of self-healing concrete (SHC) that happens over time (autogenic) has been noticed for over 200 years. It can be observed in many old structures which have remained standing for long periods of time in spite of the fact that they have limited maintenance. This observation concludes that the cracks heal when moisture interacts with non-hydrated cement clinker in the crack. Nevertheless, in present day constructions the cement is lowered as a result of modern construction methods. Hence, the amount of available non-hydrated cement is less and therefore, the natural healing effect is reduced (Paine, 2016). For the artificial way to repair cracks in concrete, which is man-made self-healing process was first invented in 1994. The main method and first approach was to use a healing agent which is encapsulated inside a micro capsule, once a crack forms, it causes the micro capsule to break, hence healing the crack. The adhesives can be stored in short fibre or in longer tubes. However, more effective mechanisms were later approached by researchers at Cardiff University, the University of Bath, and Korea Institute of Construction (Alhalabi & Dopudja, 2017).

Patel (2016) pointed out that, to reduce maintenance cost and make buildings and bridges safer, researchers are now giving concrete the power to heal itself. By extending the lifetime of structure, self-healing concrete could also reduce the use of concrete for rebuilding and cut concrete's impact on the environment. Jonker (2011), crack formation in concrete is a phenomenon that can hardly be completely avoided due to shrinkage, uneven settlement, reaction of setting concrete and tensile stresses occurring in set structures. Large cracks can potentially hamper a structure's integrity and therefore, require actions for remedy. Smaller cracks with width less than 0.2mm are generally considered unproblematic. Although such micro cracks do not affect strength properties of structures but on the other hand, they contribute to material porosity and permeability (Edvardsen, 1999). Bacterial spores and organic mineral precursor compounds are packed in porous expanded clay particles prior to addition to the concrete mixture. It is hypothesized that protection of bacterial spores within porous light weight aggregates extends there viability period and thus concrete self-healing functionality when embedded in the material matrix (Jonkers & Schlangan, 2008).

## STATEMENT OF THE PROBLEM

Concrete is the most used construction material on Earth but it is susceptible to crack formation which shorten the longevity of a particular construction due to its limited tensile strength, uneven settlement, and sudden vibration. The continuous repair and rehabilitation of cracks on concrete structures have to a large extend outstripped the cost of new construction and reduces the structure life-span. Despite the regular repair of cracks on concrete structures, damaged repair tends to be difficult when cracks are not visible or not accessible. Consequently, durability reduces and maintenance cost increase. Therefore, self-repair of fractures in concrete is of the highest interest. Despite all the problems caused by cracks on concrete structures, the agents responsible for self-healing towards the development of sustainable concrete are still unknown to many builders and contractors. The knowledge on how the agents assist in the self-repair of concrete is still at its elementary stage. The investigation into the agents for self-healing already present in the market with the aim of reducing as much as possible their incidence on use has not been giving adequate attention. Construction industry show less concern on the impact of self-healing concrete on building construction.

## AIM AND OBJECTIVES OF THE STUDY

The aim of this research is to ascertain the agents for the development of self-healing concrete through providing self-healing concrete information to construction professionals in an environment of resource constraints.

Based on the aim of the study, the main objectives are as follows:

- To determine the agents responsible for self-healing in concrete.
- To investigate how the agents assist in concrete self-healing.
- To assess the factors limiting the use of the agents.
- To examine the impact of self-healing concrete in modern construction.

## RESEARCH QUESTIONS

What are the agents responsible for self-healing in concrete?

## STATEMENT OF HYPOTHESIS

Ho: there is no significant difference in the mean rating of the agents responsible for self-healing concrete on different sizes of buildings.

## JUSTIFICATION AND SIGNIFICANT OF THE STUDY

Modern concrete are usually prone to cracks leading to its short life span and shortening the longevity of a particular construction. The amount for repair and rehabilitation of cracks formation on concrete outstripped the cost of constructing new concrete structure. Self-healing concrete could solve the problem of concrete deteriorating before the end of their service life. The research focuses on the use of agents for the development of sustainable concrete, thereby, reducing maintenance cost on the clients and making buildings safer for the occupants. The study educates the professionals in the construction industry and clients on the significant implications of self-healing concrete such as extension of service life, reducing economic, social and environmental cost of structures. The research is also important in promoting self-healing concrete to a higher level in the construction industry as a major enabling technology towards smart concrete production.

## SCOPE AND LIMITATION OF THE STUDY

This research work covered the agents responsible for self-healing in concrete such as mineral additives, bacteria, and encapsulated adhesives but no experimental work on the agents was done. The research also deals with the impact of self-healing concrete in modern construction and covered some experts in the construction industry. The study was limited to concrete used for building construction work, this decision was based on the fact that buildings accommodates occupants and involves much activity below and above the ground level and presents higher risk when it cracks.

### Self -Healing Agents

#### *Bacteria*

According to Prabhu (2016), bacteria producing the enzyme urease are used in bio-cement technology. Prabhu maintained that scientists have reported the use of bacteria proteus, klebsiella, staphylococcus, and bacillus (bacillus pasteurizing, bacillus sphaericus, Escherichia coli, bacillus subtilis, bacillus cohnii, bacillus balodurans) as bacteria for bio-cement. Certain bacteria can utilize urea present in the material by the production of enzyme urease. This enzyme hydrolyzes urea to ammonia and carbon dioxide. Ammonia increases the pH of the surrounding and carbon dioxide combines with calcium ions resulting in formation of calcium carbonate in the form of calcite. Jonkers (2010) highlighted that, the bacteria spores that have a life of about fifty years, when inserted directly into the concrete mix, undergo a drastic decrease in life expectancy. Wiktor and Jonkers

(2011) maintained that, the immobilization of bacteria in porous clay aggregate before the conglomerate mixing can greatly extend their life. The principle mechanism of bacterial crack healing is that the bacteria themselves act largely as a catalyst, and transform a precursor compound to a suitable filter material. For effective self-healing, both bacteria and a bio-cement precursor compound should be integrated in the material matrix. However, the presence of the matrix-embedded bacteria and precursor compounds should not negatively affect other wanted concrete characteristic.

Bacteria that can resist concrete matrix incorporation exist in nature and these appear related to a specialized group of alikali-resistant spore-forming bacteria (Jonkers, 2011). Interesting feature of these bacteria is that they are able to form spores, which are specialized spherical thick-walled cells homologous to plant seeds. These spores are viable and can withstand mechanical and chemical stresses and remain in dry state viable for periods over 50 years. Cement and water have a pH value of up to 13 when mixed together, usually a hostile environment for life (most organisms die in an environment with a pH value of 10 or above). Microbes that thrive in alkaline environment which can be found in natural environment such a alkali lakes in Russia, carbonate-rich soils in desert areas of spain, and soda lakes in Egypt (Jonkers, 2011). Jonkers maintained that, samples of endolithic bacteria (bacteria that can live inside stones) were collected along with bacteria found in sediments in the lakes. Strains of the bacteria genus bacillus were found to thrive in this high alkaline environment. Different types of bacteria were incorporated into a small block of concrete. Each concrete block would be left for two months to set hard. Then the blocks would be pulverized and the remains tested to see whether the bacteria had survived. The group of bacteria that were able to survive was the ones that produced spores comparable to plant seeds. Such spores have extremely thick cell walls that enable them to remain intact for up to 200 years while waiting for better environment to germinate. They would become activated when the concrete starts to crack, food is available (calcium lactate), and water seeps into the structure. This process lowers the pH of the highly alkaline concrete to values in the range (pH 10 to 11.5) where the bacterial spores become activated.

## *Encapsulated Chemical Agents*

Chemical agents could patch small cracks up to 0.2mm wide. According to Petal (2016), the Cambridge group makes microcapsules of polyurethane or calcium alginate and fills them with minerals such as sodium silicate, colloidal silicate, calcium oxide, or magnesium oxide that react with water and form cementitious materials to seal cracks. Chemicals can also be encapsulated in glass tubes. The use of glass tubing for self-healing is based on the concept of self-sensing and actuation when a concrete crack is intercepted by the glass tubing. The glass tubing approach may be considered a variant of chemical encapsulation with the advantage of potentially carrying a larger amount of healing agents compared with microcapsules (Li and Herbert, 2012). Li and Herbert also stated that, various chemicals including methyl methacrylate, ethyl cyanocrylate and polyurethane have demonstrated the ability of recovering concrete mechanical and transport properties.

### *Mineral Admixture*

Mineral admixture have been deployed as an approach for self-sealing of concrete cracks. According to Kishi, Ahn, Hosoda, Suzuki, and Takaoka (2007), the use of a tailored mix of expansive agents ($C_4A_3S$, $CaSO_4$ and CaO), swelling geo-materials (mainly silicon dioxide and sodium aluminium silicate hydroxide, and montmorillonite clay) as an admixture that can seal cracks in concrete. Calcium sulfoaluminate (CSA) has also been utilized as expansive agent for self-healing.

## Self-Healing Processes in Concrete

### *Bacteria Self-Healing Process*

Specially selected types of bacteria genus bacillus along with a calcium lactate, nitrogen and phosphorous are added to the ingredients of the concrete when it is being mixed. These self-healing agents can lie dormant within the concrete for up to 200 years. When a concrete structure is damaged and water starts to seep through the cracks that appears in the concrete, the spores of the bacteria starts to feed on the calcium lactate, oxygen is consumed and the soluble calcium lactate is converted to insoluble limestone. The limestone solidifies on the cracked surface, thereby sealing it up (Jonkers, 2011).

### *Encapsulated Chemical Agents*

According to Li and Herbert (2012), chemical encapsulation includes all approaches that utilize self-healing chemical agents contained in microcapsules or glass tubes that are dispersed uniformly in concrete. The reason is to isolate the healing chemicals from the concrete until a concrete crack breaks them open. Leaking of the chemicals either seals the crack or bonds the crack faces.

### *Mineral Additives*

Self-healing process can be attributed to the reaction of the mineral additives dispersed in cementitious materials (Ahn & Kishi, 2010). These minerals additives are added to the concrete mixture during preparation. When a crack occurs, the additives are on the surface of the break, when water penetrates inside, the additives react with it and the slit is filled with the reaction products (Restuccia *et al.*, 2017).

## Factors Affecting the Use of Self-Healing Concrete

There are many factors that intervene with the usage of this kind of concrete. As it is noticed, it is not yet used in all new constructions as most of the agents are still under development. Self-healing bacteria-based concrete has been successfully tested on a full scale in the University of Bath in the UK yet usage still remains an issue (Alhalabi and Dopudja, 2017).

Alhalabi and Dopudja also stated some factors that will definitely determine whether self-healing concrete will be used as a replacement of concrete as:

i. Economic factor (cost)
ii. Long-term efficiency
iii. Prospect suppliers
iv. Safety factors

## Impact of Self-Healing Concrete in Modern Construction

Concrete will continue to be the most important building material for infrastructure but most concrete structures are prone to cracking. Repairs can be particularly time consuming and expensive because it is often very difficult to gain access to the structure to make repairs especially if they are underground or at a great height (Jonkers, 2011).

### *Positive Impact of Self-Healing Concrete*

Some direct benefit of self-healing include the reduction of the rate of deterioration, extension of service life, and reduction of repair frequency and cost over the life cycle of a concrete infrastructure (Li & Herbert, 2012).

According to Alhalabi and Dupudja (2017), there is still an going research regarding self-healing concrete; many scientists are trying different approaches that ensure the same outcome which is closing cracks with minimum intervention while keeping cost at reasonable rates. Alhalabi and Dupudja also highlighted safety, cost (maintenance cost), durability, availability, effects on architectural design, and environmental impact as the positive impact of self-healing concrete. Li and Herbert (2012) opined that, the benefits from self-healing concrete may be expected to lead to enhanced environmental sustainability since fewer repairs implies lower rate of material resources usage, reduction in energy consumption and pollutant emission in material production and transport, as well as that associated with traffic alterations in transportation during repair and reconstruction events.

### *Negative Impact of Self-Healing Concrete*

The clay pellets holding the self-healing agents comprise 20% of the volume of the concrete. The 20% of clay would normally comprise harder aggregate such as gravel. The clay is much weaker than normal aggregate and this weakens the concrete by 25% and significantly reduces its compressive strength. In many structures, this would not be a problem but in specialized applications where higher compressive strength is needed such as high rise buildings, it will not be viable (Jonkers, 2011).

## RESEARCH METHODOLOGY

### Research Design

The study adapted a survey research design. Therefore, it was be used to appraise the opinion of the respondents.

### Area of the Study

The study was carried out in south-east geopolitical zone of Nigeria. The zone is presented by five states: Abia with 17 local government areas, Imo with 27 local government areas, Ebonyi with 13 local government areas, Enugu with 17 local government, and Anambra with 21 local government areas. Enugu State is the largest with 7,161km$^2$ landmass while Anambra is the smallest with 4,844km$^2$ landmass. South-east has a landmass of 29,385km$^2$ which is 3.2% of the landmass of Nigeria (923,768km$^2$). The largest cities in the zone are Abakaliki, Owerri, Enugu, Onitsha and Aba. South-east is populated by Igbos and speak only the Igbo language

### Study Population

The population of interest is construction industry workers. The total participants were 600 workers.

### Sample and Sampling Technique

The sample size was made up of 240 respondents which are purely construction industry workers since the entire population cannot be studied. The researcher used Taro Yarmnay formula to determine the sample size and simple random sampling technique to determine which of the 600 participants should be chosen in the sample.

Using Taro Yarmnay formula, $n = N/1+N(e)^2$
n = sample size
N = population of the study
1 = constant
e= acceptable level of significant (5%)
$n = 600/1+600(0.05)^2$
$= 240$

### Instrument of Data Collection

The instrument for the study was "Self-Healing Concrete Questionnaire"

## Reliability of the Instrument

The questionnaire items were designed with the assistance of experts. Other measurement and evaluation experts also assist in constructing the reliability of the instrument.

## Validity of Data Collection

The test-retest validity estimate at interval of two weeks and the Pearson Product Moment Correlation Co-efficient was used for determining the level of validity of data collected in the study.

## Method of Data Analysis

Mean as descriptive statistic was used to analyze the data realized for the study. Analysis of variance (ANOVA) at 0.05 (5%) level of significant was employed to test the hypothesis of the study.

## Sources of Data

### *Primary Data*

Primary data was collected through survey questionnaire which was administered to the respondents.

### *Secondary Data*

Secondary data was collected through websites, journals, books, conferences, and unpublished materials.

**Table 1: Scores and Mean Responses of the Agents Responsible for the Self-Healing Concrete on Different Building Size**

| S/N | Items | Small-sizes buildings | | Medium-sized buildings | | Large-Sized Buildings | |
|---|---|---|---|---|---|---|---|
| | The following are agents responsible for self-healing in concrete | scores | ẋ | scores | ẋ | scores | ẋ |
| 1 | Bacteria | 815 | 3.40 | 898 | 3.74 | 898 | 3.74 |
| 2 | Sodium Silicate | 914 | 3.81 | 935 | 3.90 | 935 | 3.90 |
| 3 | Collodal Silicate | 935 | 3.90 | 815 | 3.40 | 898 | 3.74 |
| 4 | Calcium Oxide | 947 | 3.95 | 815 | 3.40 | 947 | 3.95 |
| 5 | Magnesium Oxide | 898 | 3.74 | 947 | 3.95 | 815 | 3.40 |
| 6 | Calcium Sulfoaluminate | 927 | 3.86 | 927 | 3.86 | 935 | 3.90 |
| 7 | Silicon dioxide | 935 | 3.90 | 914 | 3.81 | 815 | 3.40 |
| 8 | Montmorillonite Clay | 898 | 3.74 | 935 | 3.90 | 927 | 3.86 |
| 9 | Methyl Methacrylate | 815 | 3.40 | 914 | 3.81 | 914 | 3.81 |
| 10 | Ethyl Cyanocrylate | 927 | 3.86 | 898 | 3.74 | 914 | 3.81 |
| 11 | Polyurethane | 914 | 3.81 | 947 | 3.95 | 914 | 3.81 |

**Source:** Fieldwork, 2018.

**Table 2: ANOVA Table**

| S/N | A. Small-Sized Building | | B. Medium-Sized Building | | C. Large-Sized Building | |
|---|---|---|---|---|---|---|
| | $X_A$ | $X_A^2$ | $X_B$ | $X_B^2$ | $X_C$ | $X_C^2$ |
| 1 | 815 | 664225 | 898 | 806404 | 898 | 806404 |
| 2 | 914 | 835396 | 935 | 874225 | 935 | 874225 |
| 3 | 935 | 874225 | 815 | 664225 | 898 | 806404 |
| 4 | 947 | 896809 | 815 | 664225 | 947 | 896809 |
| 5 | 898 | 806404 | 947 | 896809 | 815 | 664225 |
| 6 | 927 | 859329 | 927 | 859329 | 935 | 874225 |
| 7 | 935 | 874225 | 914 | 835396 | 815 | 664225 |
| 8 | 898 | 806404 | 935 | 874225 | 927 | 859329 |
| 9 | 815 | 664225 | 914 | 835396 | 914 | 835396 |
| 10 | 927 | 859329 | 898 | 806404 | 914 | 835396 |
| 11 | 914 | 835396 | 914 | 835396 | 914 | 835396 |

**Source:** Fieldwork, 2018

$\sum X_A=9925$ $\sum X_B= 9892$ $\sum X_C= 9912$
$\sum X_A^2=14955967$ $\sum X_B^2= 14894554$ $\sum X_C^2= 8952034-$
$XA = \sum X_A/n \quad =9925/11 =902.3$
$XB=\sum X_B/n \quad =9892/11 =899.3$
$XC =\sum X_C/n \quad =9912/11 =901.1$
Sum of mean = 902.3+899.3+901.1/3 =900.90

The sum of Squares Between various groups (SSB)
$SSB=\sum(x\text{-}xt)_n^2 =(902.3-900.9)+(899.3-900.90)+(901.1-900.90)$
$=1.4+ (-1.6) + 0.2 = 0$
Sum of Within (SSW) = $\sum X^2\text{-}(\sum X)^2/n$
For group A= $14955967\text{-}(9925)^2/11 \quad =14955967\text{-}8955056.9= 6000910.2$
For group B= $14894554\text{-}(9892)^2/11 \quad =5998948.2$
For group C =$8952034 – (9912)^2/11 \quad =20420.9$
SSW = 6000910.2+599898.2+20420.9 =12020279.3
Sum of Squares Total (SST) = SSB+SSW =0+12020279.3 = 12020279.3

Degrees of Freedom (df)
df for Total = 33-1 =32
df for Between =3-1 =2
df for Within = (11-1)+ (11-1)+(11-1)= 10+10+10 = 30

**Table 3: Summary of ANOVA Table**

| Sources of variation | Df | Sum of squares (SS) | Mean squares (MS) | F - Calculated | Critical value of F | significance | Decision |
|---|---|---|---|---|---|---|---|
| Between group | (K-1)<br>2 | 0 | 0<br>(SS/df) | MSB/MSW<br>0/400676.0=0 | 3.32 | 0.05 | Accepted |
| Within group | (N-K)<br>30 | 12020279.3 | 400676.0<br>(SS/df) | | | | |
| Total | 32 | 12020279.3 | | | | | |

**Source:** Fieldwork, 2018

**Findings:** From the F-ratio distribution, the critical value of F with 2 and 30 degrees of freedom at 0.05 level of significant is 3.32. Since the computed value of 0 is less than the critical value of 3.32, the null hypothesis is accepted and concluded that there is no significant difference on the agents responsible for self-healing in concrete on different sizes of buildings.

## CONCLUSION

Concrete is the most popular building materials in construction industry but is prone to cracking and causes environmental issues because of its pH value. Certain bacterial and chemicals have been concluded to have the ability to seal cracks in concrete and making it environmentally sustainable, thereby, reducing cost of maintenance, dilapidation of buildings, and increasing the life-span of the structure. From the findings, the self-healing agents can be use on different sizes of buildings and infrastructure. Therefore, self-healing agents are very essential in the achievement of sustainable concrete in modern construction.

## RECOMMENDATIONS

i. Professionals in the construction industry should be train on self-healing agents in concrete through collaboration with experts in other countries.
ii. Government should subsidize the cost of self-healing agents and ensure its availability
iii. Council of Registered Builders of Nigeria (CORBON) should sensitize the public on the impact of self-healing agents through advertisement and seminars.

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