IJE TRANSACTIONS A: Basics Vol. 37 No. 04, (April 2024) 625-634

International Journal of Engineering

Journal Homepage: www.ije.ir

Experimental Study on Self-compacting and Self-healing Concrete with Recycled Coarse Aggregates

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P A P E R I N F O

Paper history:
Received 21 August 2023
Received in revised form 25 September 2023
Accepted 26 September 2023

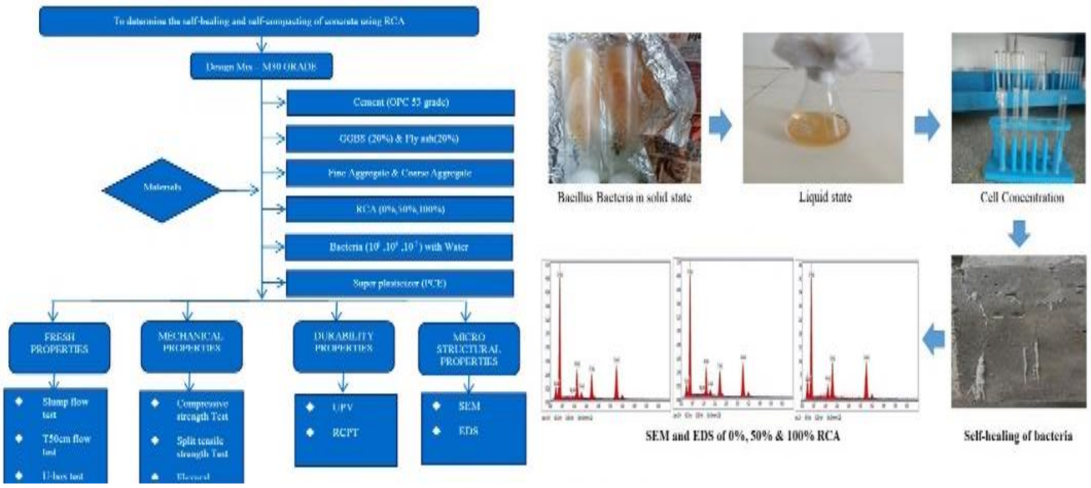
Keywords:
Bacteria
Self-healing
Cell Concentration
Bacillus Licheniformis
Fly Ash
Ground Granulated Blast Furnace Slag

A B S T R A C T

This study focuses on evaluating the effectiveness of various cell concentrations of bacillus bacteria in mending cracks within recycled concrete containing coarse aggregates. In this investigation, the introduction of bacillus bacterial sustainable concrete as a solution for addressing crack repairs. This innovative concrete formulation not only provides environmentally friendly alternatives but also offers economic benefits. This research involves the incorporation of coarse aggregates into the concrete mix, along with the partial substitution of cement by Fly ash and Ground Granulated Blast Furnace Slag (GGBS), each accounting for 20% of the mix. The coarse aggregates consist of Recycled Concrete Aggregate (RCA) in varying proportions: 0%, 50%, and 100%. Additionally, *Bacillus licheniformis* was used at concentrations of 10^3, 10^5, and 10^7 cells/mL, respectively. The findings indicate a positive correlation between the healing percentage of cracks, as measured by Ultrasonic Pulse Velocity (UPV), and the concentration of bacteria. Furthermore, it is observed that recycled aggregates possess inherent pores that allow for water absorption through these pores. Therefore, RCA is subjected to a 24-hour water immersion process before its incorporation into the concrete mix. While the compressive strength of the concrete remains consistent between RCA 0% and RCA 50%, it decreases significantly at RCA 100%. However, the performance of the bacteria exhibits proportionality to cell concentration. Notably, the effectiveness of the bacteria remains consistent regardless of changes in RCA proportions. This study underscores the promising potential of Bacillus bacteria in enhancing the durability and sustainability of concrete structures, with particular relevance to RCC applications.

doi: *10.5829/ije.2024.37.04a.05*

Graphical Abstract



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Please cite this article as: Sreenu R, Suryawanshi SR, Ashish A. Experimental Study on Self-compacting and Self-healing Concrete with Recycled Coarse Aggregates. International Journal of Engineering, Transactions A: Basics. 2024;37(04):625-34.

NOMENCLATURE

RCA	Recycled coarse aggregates	UPV	Ultrasonic Pulse Velocity
SCC	Self-compacting concrete	RCPT	Rapid Chloride Permeability Test
$CaCO_3$	Calcium carbonate	C	Calcite
SCMs	Supplementary cementitious materials	CSH	Calcium Silicate Hydrate

1. INTRODUCTION

The emergence of self-compacting concrete (SCC) has sparked a revolution in concrete technology, offering unparalleled filling capacity and ease of placement without the need for traditional compaction methods. SCC's unique properties make it adept at maintaining stability and workability while minimizing issues such as bleeding and segregation, resulting in significant labour and cost savings in construction processes (1). However, these advantages often come at the expense of durability and strength, critical design criteria for structural applications (2). One of the key challenges associated with SCC is the presence of free water, which can adversely affect the strength and durability of concrete. This is due to its impact on the microstructure of the aggregate paste's interfacial transition zone (ITZ) and increased capillary porosity of the hardened paste (3). To address this issue, supplementary cementitious materials (SCMs) like fly ash, ground granulated blast furnace slag (GGBS), pozzolans, cement kiln dust, sugarcane bagasse ash, and rice husk ash (RHA) are commonly employed to enhance both the mechanical and durability properties of concrete while reducing CO_2 emissions (4). The environmental concern surrounding construction waste management (CWM) has taken centre stage in many Indian municipalities, as they grapple with the disposal of an annual production of 150 million tons of construction waste, accounting for 35%–40% of the world's construction and demolition (C&D) trash (5). These wastes often end up in landfills, causing significant negative environmental impacts. Recycling concrete waste into aggregates provides an environmentally friendly solution, reducing construction costs while mitigating environmental issues. However, recycled concrete aggregate (RCA) presents challenges due to the presence of micro-cracks and increased porosity resulting from the crushing process (6). Moreover, the old cement paste in RCA accounts for approximately 30–35% of its volume, complicating the microstructure of RCA concrete/mortar by forming a dual ITZ when mixed with new mortar/cement (6). Previous research has shown that using RCA to replace natural aggregates, either partially or entirely, leads to a 20% reduction in compressive strength, further highlighting the need for innovative solutions. To enhance the properties of RCA concrete/mortar, various methods have been explored, including surface treatments to remove adhered mortar, bio-deposition techniques to reduce RCA porosity, and the use of SCMs such as fly ash, silica fume, and GGBS to densify the pore system by promoting the formation of calcium silicate hydrate. Additionally, immersing RCA in acidic solutions to reduce adhered mortar and allowing dehydrated cement paste to hydrate in water have shown promise in improving RCA's properties (7). Concrete cracks pose further challenges as they expose reinforcement to the environment, potentially leading to corrosion. To address this issue, bacteria have been harnessed to facilitate crack healing in what is commonly referred to as "Bio concrete" or "Bacterial concrete." These bacteria, including non-pathogenic species like *Bacillus subtilis*, *Bacillus cereus*, *Bacillus licheniformis*, and *Bacillus halodurans*, are incorporated into concrete to initiate bio-calcification, a process where microorganisms secrete calcium precipitate externally. This calcium precipitate, typically in the form of $CaCO_3$, fills the cracks, increasing the concrete's compactness and preventing the formation of new cracks (8). Moreover, this bio-calcification process reduces carbon dioxide emissions, aligning with sustainability goals. The effectiveness of these bacteria in crack repair has been demonstrated through increased strength in concrete samples containing them, and their indirect use allows for greater flexibility and cost-effectiveness (9). In summary, the concrete industry has seen a transformation with the advent of SCC and the pursuit of sustainable solutions in the face of CWM challenges and concrete cracks. These advancements, from the use of SCMs in SCC to the innovative approaches for improving RCA and the incorporation of bacteria for crack healing, offer promising avenues for enhancing the performance and sustainability of concrete in construction. This study explores these developments in detail and assesses their potential to shape the future of concrete technology.

2. RESEARCH SIGNIFICANCE

Pachaivannan et al. (10) conducted an experimental analysis of the self-healing properties of bacterial concrete, shedding light on the material's ability to autonomously repair cracks and fissures. The study provided valuable insights into the practical application of this innovative construction material.

Iswarya and Adalarasan (11) focused on the strength and durability of lightweight bacterial concrete, exploring its potential to meet the structural requirements of various construction projects. Their investigation emphasized the importance of optimizing bacterial concentration for improved performance. Jagannathan (12) studied the mechanical properties of bacterial concrete using two different bacterial species, expanding our understanding of the role of microorganisms in enhancing concrete strength and resilience. Ameri et al. (13) investigated the optimum content of rice husk ash and bacterial concentration in self-compacting concrete, contributing to the sustainability aspect of bacterial concrete production. David et al. (14) explored the utilization of medical vial glass waste in bio-concrete, showcasing the potential to incorporate waste materials into construction processes. Rautray et al. (15) delved into the performance of self-compacting geopolymer concrete using *Bacillus licheniformis*, offering an alternative perspective on the application of bacteria in sustainable construction materials. On silica-based immobilization, Agarwal et al. (16) investigated bacterial concrete with micronized biomass silica, highlighting the importance of immobilization techniques for ensuring bacterial activity and longevity. Druga et al. (17) conducted comprehensive microbiological studies to screen bacteria for self-healing concrete, emphasizing the significance of selecting suitable bacterial strains for optimal results. On impact of compressive strength, Rao et al. (18) explored the impact of bacteria on the compressive strength of cement mortar and concrete, providing valuable data for structural engineers and designers. Vaezi et al. (19) examined recycled microbial mortar and assessed the effects of bacterial concentration and calcium lactate content, contributing to the sustainable utilization of bacteria in construction. Rohini and Padmapriya (20) studied the effect of *Bacillus subtilis* on e-waste concrete, showcasing the versatility of bacterial concrete in diverse applications. About encapsulation in expanded clay, Lucas et al. (21) investigated self-healing properties in concrete with bacteria encapsulated in expanded clay, offering innovative approaches to delivering bacteria within the concrete matrix. Xu and Wang (22) explored the use of bacteria-containing low-alkali cementitious materials for the self-healing of concrete cracks, paving the way for novel approaches to bacterial concrete production. Rauf et al. (23) compared the performance of different bacteria immobilized in natural fibres, contributing to the development of modified bacterial concrete solutions. Wang et al. (24) studied polymeric healing materials, and bacterial $CaCO_3$ precipitation may also be exploited for self-healing. It is more environmentally friendly and more suited to the concrete matrix. Seifan et al. (25) highlighted the potential of bio concrete as the next generation of self-healing construction materials, emphasizing its role in sustainable and resilient infrastructure. Onyelowe et al. (26). carried out by studying the compressive strength of concrete formed from recycled aggregate and utilizing a unique artificial neural network (ANN), which makes use of a sigmoid function and allows the formulation of closed-form equations, an intelligent prediction is made. Akhtar et al. (27) investigated ways to improve the self-healing capacity of concrete by introducing various bacteria either separately or in combination with various mineral additions. It has been observed that a number of renovated approaches are awaiting approval in order to address the shortcomings of concrete and boost its toughness and longevity. Balamuralikrishnan et al. (28) conducted on a new ultrafine material called Alccofine (AF), produced from glass waste, and it was carried out as testing materials for the partial replacement. The vast array of experimental studies in the realm of self-healing concrete, coupled with advancements in sustainability and waste utilization, underscores the transformative potential of bacterial concrete in the construction industry. These studies not only expand our knowledge but also provide practical insights and solutions that hold the promise of a more resilient, eco-friendly, and durable infrastructure. The ongoing debate and exploration in this field signal an exciting future for construction materials and their impact on the built environment.

3. EXPERIMENTAL PROGRAM

3. 1. Materials

3. 1. 1. Cement Grade 53 ordinary Portland cement (OPC) that complies with IS:269-2015 specifications has a specific gravity of 3.10, a fineness of 6%, a standard consistency of 34%, an initial setting time of 36.3 minutes, and a soundness of 9 mm.

3. 1. 2. Fly Ash From PRISM JOHNSON LIMITED, IDA Nacharam, the fly ash is collected. With a specific gravity of 2.91, fineness of 5%, standard consistency of 26%, and an initial setting of 30 minutes, Class-F fly ash is utilized.

3. 1. 3. GGBS PRISM JOHNSON LIMITED, IDA Nacharam, also contributes to the GGBS collection. The GGBS's initial setting was 38 minutes, with a specific gravity of 2.91, fineness of 5%, and standard consistency of 32%.

3. 1. 4. Fine Aggregate The river sand in grading zone 2 of IS:383-2016 has a fineness modulus of 2.56, specific gravity of 2.89, bulk density of 0.788 kg/m^3, void ratio of 5.549, porosity of 72, and water absorption of 2%. Therefore, fine aggregate forms the S-curve.

3. 1. 5. Coarse Aggregate According to IS:383-2016, with a maximum dimension of 16 mm for the crushed stone and the following specifications was utilized as coarse aggregate: specific gravity of 2.781, bulk density of 0.665 kg/m^3, void ratio of 5.959, porosity of 76, and water absorption of 0.4% (29).

3. 1. 6. Recycled Coarse Aggregates (RCA) The construction and demolition (C&D) company Nagole is where the recycled coarse aggregates (RCA) are gathered. 16mm-sized aggregates are used.

3. 1. 7. Water According to IS:456-2000, to combine and cure, portable water is employed and has a pH of 6.98, 360 mg/L of alkalinity, 45 mg/L of acidity, and 685.8 mg/L of total dissolved solids (TDS). The ratio of water to cement is 0.47.

3. 1. 8. Bacteria The microbial type culture collection (MTCC), Hyderabad, is where the bacteria *Bacillus licheniformis* (MTCC NO: 2588) was found. It is a mesophilic, gram-positive bacterium. The "Bacteria culturing" method is used to transfer and propagate the organism from nutrient agar media to both culture of the bacteria into a liquid phase. Cell concentration is then carried out to determine the capacity of cells/mL.

3. 2. Mix Design The SCC mixture ratios that were following the IS 10262:2019 process (30). In every combination, Fly ash and GGBS replace cement to the amount of 20%. At 0%, 50%, and 100%, RCA replaces the coarse aggregates. Bacteria are used in every mix at 10^3, 10^5, and 10^7 cells/mL proportions. As per IS: 516:2019, the freshly mixed composites are cast into cubes, cylinders, and prisms after being assessed for their fresh properties. The materials are cured for 7 and 28 days. Every bacterial sample is subjected to the UPV test to assess the bacteria's capacity for self-healing. The sample is once more put in a curing tank to repair the cracks after being tested under compression. The UPV test is then performed 28 days later. According to ASTM C1202, the RCPT is done to determine whether a material is resistant to chloride ions penetrating it. The RCA 0%, 50%, and 100% samples were cast for 28 days.

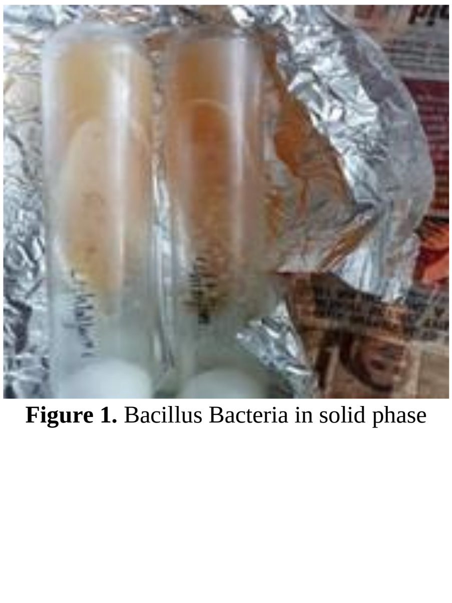

Figure 1. Bacillus Bacteria in solid phase

Figure 2. Liquide phase

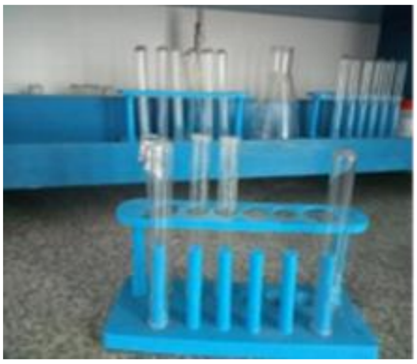

Figure 3. Cell Concentration

3. 3. METHODOLOGY The main focus of the current experiment was RCA in self-healing and self-compacting concrete. The study's primary interest was in the physical, fresh, mechanical, durability and microstructural characteristics of various RCA mix percentages and bacterial cell concentrations. M30 grade concrete was taken into consideration since an additional parametric study included a rise in the percentage of RCA in SCC. The majority of the characteristics of SCC is fresh features. The basic objective of the mix design is to preserve uniformity without segregation, flow through densely packed reinforcement without vibrating, and flow under its own weight. SCC is more workable than what is meant by "very high" workability in IS: 456: 2000 (30). For concrete that is referred to as self-complicating, it must have the following qualities: "Filling ability," "Passing ability," and "Resistance to segregation." In an effort to define these qualities, many test procedures have been developed. Nevertheless, the EFNARC standard and recommendations served as the basis for, the set of test procedures for the SCC's workability qualities. The permeability of the surface layer, which should prevent the entry of substances that can start or spread possibly harmful processes, is closely linked to the durability of a concrete structure. (CO_2, chloride, sulphate, water, oxygen, alkalis, acids, etc.). In fact, resilience is influenced by the type of materials used, the composition of the concrete, and the level of supervision utilized during placement, compaction, finishing, and curing. The formwork and re-bars or other components are in close proximity, which causes vibration issues, honeycomb and lack of compaction of the surface layer have been linked in part to the inferior durability performance of reinforced concrete structures subjected to hard circumstances. To prevent this, SCC was initially created in Japan for several reasons, among them. Tamping is a discontinuous procedure that vibrates the material to compact it in traditional vibrated concrete. Internal vibration, even when done correctly, does not lead to an even distribution of compaction energy across the whole volume of concrete inside the vibrator's area of effect. This suggests that there is still area of vibrated concrete that are over and under-vibrated. Depending on where the vibration sources are located, external vibration produces essentially heterogeneous compaction, much like internal vibration does. The vibration causes the concrete in the structure to have uneven compaction and varying permeabilities, which makes it easier for harmful substances to be absorbed selectively. It should go without saying that inappropriate vibration's effects segregation, honeycombing, bleeding, etc. have a significantly higher detrimental effect on permeability and, consequently, durability. Self-compacting concrete will be free of these problems provided it possesses the necessary characteristics. It will also offer a material with consistently low and uniform permeability, fewer weak spots for the damaging impacts of the environment, and improved durability. The greater durability of self-compacting concrete satisfies the need for sustainability because maintenance and repairs can be delayed or minimized. As a result, it can be argued that SCC structures and elements endure longer because of the material's increased durability, which comes directly from its higher interfacial transition zone quality and lower inclination to crack in comparison to standard concrete. The various materials used to mix the concrete, mixed design and test conducted on bacterial concrete are clearly shown in Figure 4.

4. BACTERIA CULTURING

Bacteria exhibited greater strength. The usage of bacteria is indirect. There is an improvement in healing by employing bacteria in cell concentration. Using this procedure, we can employ more bacteria, and the cost is

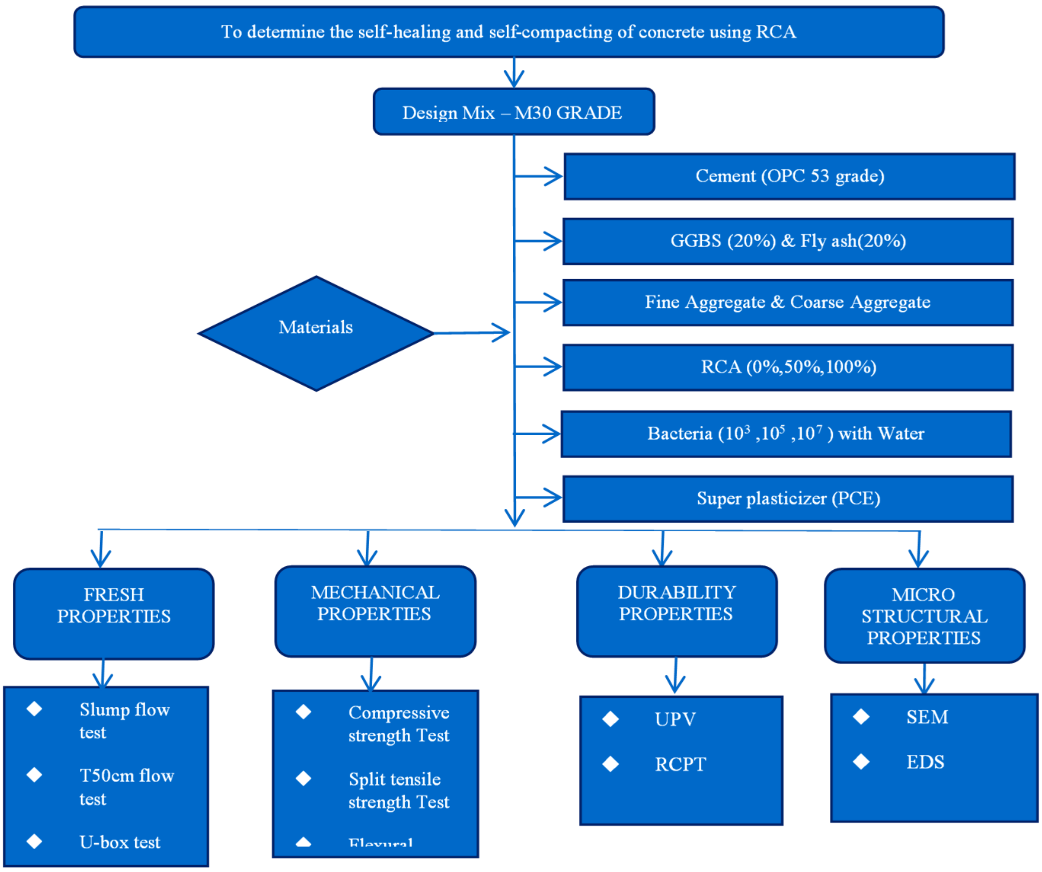

Figure 4. Schematic representation of methodology and characterizations

lower. Liquid culture is one way to cultivate bacteria. In this technique, in an upright flask, the preferred bacteria are suspended in a liquid nutrient media, such as Luria Broth. This enables the growth of numerous microorganisms for use in numerous subsequent processes. Liquid cultures are perfect for the preparation of an antimicrobial assay, which entails inoculating liquid broth with bacteria and allowing it to grow overnight. They may use a shaker for uniform growth. Afterwards, they would remove a piece of the sample to conduct a particular drug or protein's antibacterial activity (antimicrobial peptides). These cultures don't shake and offer an oxygen gradient to the microorganisms. The microbial type culture collection (MTCC), Hyderabad, is where the bacteria *Bacillus licheniformis* (MTCC NO: 2588) was supplied. It is a mesophilic, gram-positive bacterium. The "Bacteria culturing" method is used to change the solid phase of the bacteria into a liquid phase. As shown in Figures 1, 2 and 3. Cell concentration is then conducted to ascertain the capacity of cells/mL.

4. 1. Fresh Properties All combinations are picked to fall in the SF2 class of slump. The range of the slump flow is from a diameter of 710 to 745. To improve the slump flow, the superplasticizer PCE is utilized. There is an increase in slump flow depending on how much RCA is used. This is because RCA aggregates are entirely different from natural aggregates. Natural aggregates have sharp edges, whereas RCA has smooth edges. Because RCA contains materials that have been used before. Because of its smooth surface, it flows readily, increasing the slump. However, RCA notices more water because of its porous nature. In this instance, the RCA is cleaned and soaked in water for a day before casting. According to the addition of RCA, the time of T50 flow differs. It received a range of 3.2 to 3.9 seconds. The amount of RCA increases as the time decreases. According to EFNARC, it corresponds to VF2 in the V-funnel. The data spans between 9 and 10 seconds. As the RCA rises, the outcomes of the V-funnel duration shorten. U-box is used to determine the filling capacity. It includes data between 20 and 25. The U-box values drop as the RCA rises. The passing ability is located using the L-box method. The values, which fall within the PA2 class, range from 0.88 to 0.96. L-box values are raised as the RCA rises. EFNARC regulations are applied to all fresh properties.

4. 2. Mechanical Properties Results for the SCC mixes with RCA's 7 and 28 days, the results of experiments for compressive strength, with values ranging from 19.84 to 51.84 Mpa. The 50% RCA addition has strength that is roughly equivalent to that of a conventional mix, but a 100% RCA addition has the

Figure 5. Self-healing of bacteria

least strength. Up to 50% can be used with RCA. Bacteria in this instance have no impact on strength. Samples including and excluding bacteria both have equivalent strengths. The samples had good results because Flyash and GGBS work to increase the strength. The split tensile strength test results for SCC mixes with RCA, demonstrate that 50% RCA produces better results than 100% RCA. The results fall in the 1.74 to 4.14 MPa range. It shows that an increase in RCA decreases the strength. The flexural strength tests for the RCA SCC mixtures, with results in the range of 2.16 to 5.46 MPa according to the findings, a rise in RCA reduces concrete's strength.

4. 3. Durability Properties To find bacteria that are capable of self-healing, ultrasonic pulse velocity (UPV) is been used. The quality of concrete is produced by transmitting electronic waves. On these bacterial cubes, UPV is tested. The UPV value drops when a crack appears in concrete; after that, bacteria fill the gap and it heals itself. $CaCO_3$ precipitation takes place to repair the cracks. The cube is tested before and after the compressive test. The curing tank is next used to preserve it. The same sample is analyzed after 7 and 28 days.

Bacteria cell concentrations of 10^3, 10^5, and 10^7 are tested using the UPV method. The self-healing cube after 28 days is shown in Figure 5. Due to its ease of use and speed, the Rapid Chloride Permeability Test (RCPT) gauges concrete's resistance to chloride ion infiltration. The RCA 0%, 50%, and 100% samples were evaluated. It demonstrates that a rise in RCA decreases chloride permeability.

4. 4. Microstructural Properties

4. 4. 1. SEM Analysis From Figure 6, it is observed that the control mix's SEM image of 0% RCA, where precipitation of calcite (C) and calcium silicate hydrate (CSH) can be seen. Due to the normal aggregate's presence in the mix, the binding properties between gel and aggregates are more effective, these are leads to better- resisting properties. Figure 7 demonstrates the

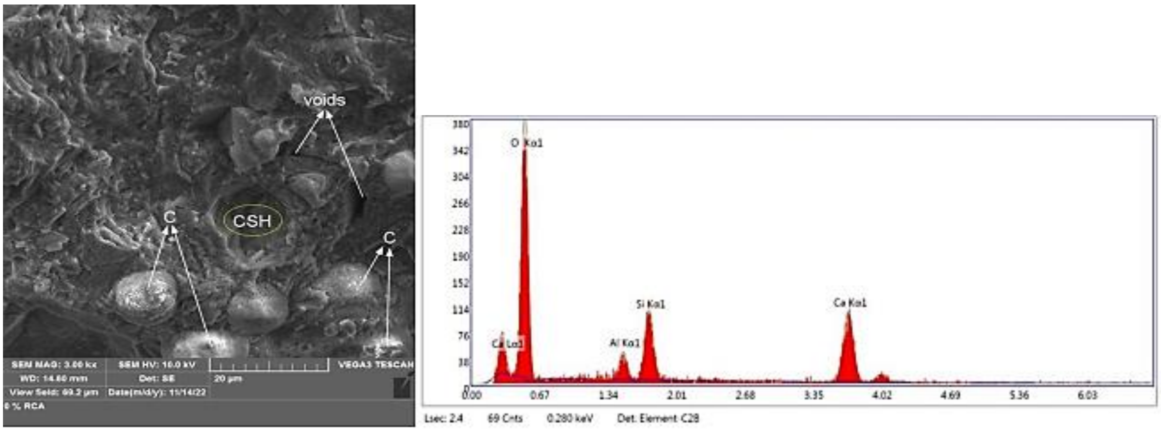

Figure 6. SEM and EDS of 0% RCA

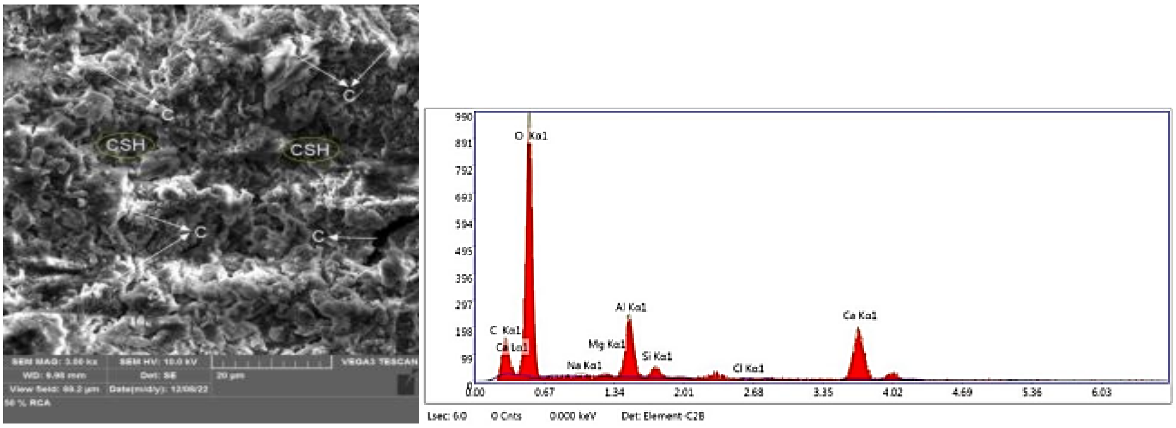

Figure 7. SEM and EDS of 50% RCA

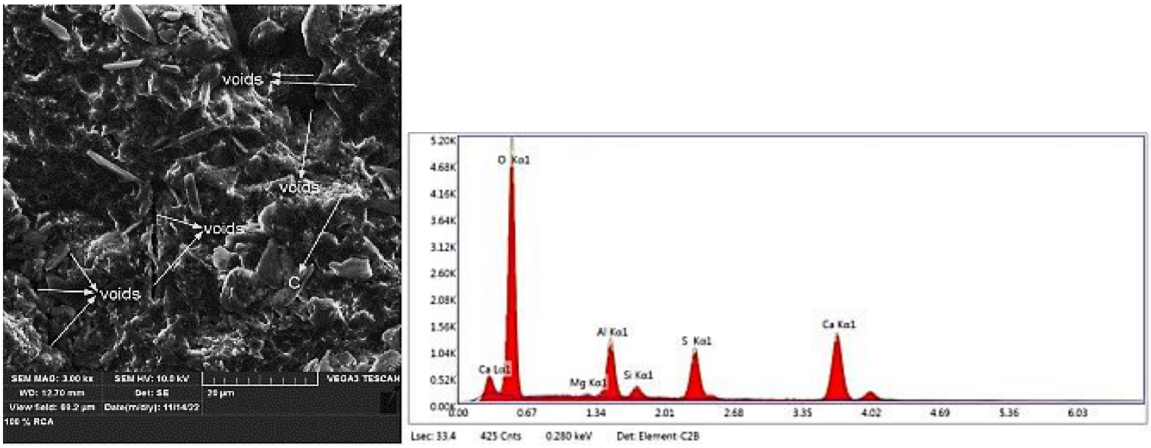

Figure 8. SEM and EDS of 100% RCA

increased CSH gel formation and calcite (C) precipitation by bacterial cells in the sample with 50% RCA. The 50% RCA concrete's pore reinforcing, water absorption, and permeability were all dramatically reduced as a result of the CSH gel formation, and a higher strength was attained. Calcite filled in spaces and pores in the concrete, improving the pore structure, which led to increased strength development and decreased permeability. There are numerous voids and microspores visible in Figure 7, which is 100% RCA. Due to the Recycled Aggregate presence in the mix, the binding properties between gel and aggregates are less effective, which leads to a reduction in resisting properties. In comparison to mixtures of 10^3 and 10^5 cells/mL, more densification pore structure, and a uniform concrete matrix were created as a result created. Because of this, a larger cell concentration causes more calcite to precipitate. This is a result of how quickly bacteria's cell membranes cause calcium hydroxide to carbonate. Even yet, several pores and cracks are visible, which may have developed during the compression test due to the RCA's complete replacement with a less dense matrix. As seen in the above Figures, the EDS spectra match the sample's scanned areas. The elements that were found and their associated percentages.

4. 4. 2. EDS Spectra Together with the discovered elements and their associated percentages, EDS spectra for the scanned areas of RCA 0% (control concrete), RCA 50%, and RCA 100% containing bacteria are displayed. The primary elements in the control concrete were silicon (Si; 9.24%), calcium (Ca; 36.97%), and oxygen (O_2; 50.45%). The amount of O_2 was raised in the RCA of 50% and the amount of O_2 was reduced in the RCA of 100%. For illustrative purposes, the calcium content was reduced from 36.94% in RCA0% to 30.86% in RCA 50% correspondingly. However, there was a decrease in the silicon concentration of the RCA mix, going from 9.24% in RCA 0% to 1.63%. As was previously mentioned, pore obstruction at the specimen's surface prevented the formation of calcite and CSH gel.

The calcium content and silicon content of the RCA 100% mix were lower than those of the RCA 50% and RCA 100% as samples were obtained from the inside of the concrete specimens for SEM and EDS analyses.

5. CONCLUSION

The results of the presented parametric experimental study enable the following inferences:

- While the amount of material produced from some of the mixes surpassed the EFNARC's maximum limit, all of the mixes had acceptable flowability and self-compaction properties. Addition of RCA increased the fresh characteristics by 5%. The filling and passing performance of concrete that uses RCA as a partial replacement for coarse aggregates is good. The fresh concrete's characteristics are not dramatically changed by addition of bacteria cells.
- Compared to 100% RCA, RCA of 50% replacement has good strength. Nearly equal to conventional concrete is the 50% RCA. Similar to mechanical characteristics, 50% RCA content yields the optimum durability characteristics.
- The durability and strength of the concrete are unaffected by the addition of bacteria. Bacteria recover faster when cell concentration is higher. Compared to 10^3 and 10^5, a bacterial cell concentration of 10^7 has greater healing potential.
- According to the UPV test, the cracks have healed more for the 28-day sample than for the 7-day sample. The bacteria, therefore, requires time to recover. The period of time increases the rate of bacterial growth increases.
- SEM examination findings reveal that concrete with an RCA concentration of 50% has a denser matrix than concrete with an RCA level of 100%. The pores and spaces within the specimen are further diminished by the addition of bacterial cells through calcite precipitation.
- However, the results of the EDS analysis show that the excessive precipitated calcite on the specimen's surface stops water from penetrating into the inner matrix, lowering the hydration of cement and calcite precipitation inside the specimen, even at a high bacterial cell concentration of 10^7 cells/ mL.
- The result of this study demonstrates that higher bacterial cell concentration increases concrete's resistance to water infiltration and other damaging substances. The experimental analysis of self-healing properties in concrete using recycled coarse aggregates and bacteria presents a compelling case for the feasibility and advantages of this innovative construction material. These findings suggest that such concrete formulations can offer structural robustness and self-healing capabilities, contributing to the sustainability and longevity of concrete structures in various applications such as buildings and other civil engineering structures.

The future scope of experimental studies on self-compacting and self-healing concrete with recycled coarse aggregates holds significant potential. Research in this field can evolve to address critical challenges, such as fine-tuning the incorporation of recycled aggregates for optimal mechanical properties, advancing bacterial strains and immobilization techniques for improved healing efficiency, and expanding the application of this innovative concrete in large-scale infrastructure projects. Furthermore, exploring the integration of smart technologies for real-time monitoring, standardizing production processes, and conducting extensive field trials can pave the way for the widespread adoption of this sustainable and resilient construction material, making a substantial contribution to the construction industry's environmental and structural advancements.

6. REFERENCES

1. Santos S, Da Silva P, De Brito J. Self-compacting concrete with recycled aggregates–a literature review. Journal of Building Engineering. 2019;22:349-71. https://doi.org/10.1016/j.jobe.2019.01.001
2. Faraj RH, Ali HFH, Sherwani AFH, Hassan BR, Karim H. Use of recycled plastic in self-compacting concrete: A comprehensive review on fresh and mechanical properties. Journal of Building Engineering. 2020;30:101283. https://doi.org/10.1016/j.jobe.2020.101283
3. Kavyateja BV, Jawahar J, Sashidhar C. Durability performance of self compacting concrete incorporating alccofine and fly ash. International Journal of Engineering, Transactions B: Applications. 2020;33(8):1522-8. 10.5829/IJE.2020.33.08B.10
4. Ndahirwa D, Zmamou H, Lenormand H, Leblanc N. The role of supplementary cementitious materials in hydration, durability and shrinkage of cement-based materials, their environmental and economic benefits: A review. Cleaner Materials. 2022:100123. https://doi.org/10.1016/j.clema.2022.100123
5. Elshaboury N, Al-Sakkaf A, Mohammed Abdelkader E, Alfalah G. Construction and demolition waste management research: A science mapping analysis. International journal of environmental research and public health. 2022;19(8):4496. https://doi.org/10.3390/ijerph19084496
6. Kim J, Grabiec AM, Ubysz A. An experimental study on structural concrete containing recycled aggregates and powder from construction and demolition waste. Materials. 2022;15(7):2458. https://doi.org/10.3390/ma15072458
7. Senaratne S, Lambrousis G, Mirza O, Tam VW, Kang W-H. Recycled concrete in structural applications for sustainable construction practices in Australia. Procedia engineering. 2017;180:751-8. https://doi.org/10.1016/j.proeng.2017.04.235
8. Mahmod AK, Al-Jabbar LA, Salman MM, editors. Bacteria Based Self-Healing Concrete: A Review. 2 nd online Scientific conference for Graduate Engineering Students, Journal of Engineering and Sustainable Development; 2021.
9. Van Tittelboom K, De Belie N, De Muynck W, Verstraete W. Use of bacteria to repair cracks in concrete. Cement and concrete research. 2010;40(1):157-66. https://doi.org/10.1016/j.cemconres.2009.08.025
10. Pachaivannan P, Hariharasudhan C, Mohanasundram M, Bhavani MA. Experimental anaylsis of self healing properties of bacterial concrete. Materials Today: Proceedings. 2020;33:3148-54. 10.1016/j.matpr.2020.03.782
11. Iswarya N, Adalarasan R. Experimental investigation on strength and durability of light weight bacterial concrete. Materials Today: Proceedings. 2020;22:2808-13. https://doi.org/10.1016/j.matpr.2020.03.412
12. Jagannathan P. Studies on the mechanical properties of bacterial concrete with two bacterial species. Materials Today: Proceedings. 2018;5(2):8875-9. https://doi.org/10.1016/j.matpr.2017.12.320
13. Ameri F, Shoaei P, Bahrami N, Vaezi M, Ozbakkaloglu T. Optimum rice husk ash content and bacterial concentration in self-compacting concrete. Construction and Building Materials. 2019;222:796-813. 10.1016/j.conbuildmat.2019.06.190
14. Franchis David M, Mohan kumar G, Raambalaji C, Subaranjani S, Muthusivashankar A, Chandra Bose J. Experimental investigation on bio-concrete with medical vial glass waste. Asian Journal of Civil Engineering. 2021;22:59-71. 10.1007/s42107-020-00298-0
15. Rautray SS, Mohanty BN, Das MR. Performance of self-compacting geopolymer concrete using Bacillus Licheniformis. Materials Today: Proceedings. 2020;26:2817-24. 10.1016/j.matpr.2020.02.587
16. Agarwal A, Bhusnur S, Chaudhary K, Priya TS. Experimental investigation on bacterial concrete with micronized biomass silica. Materials Today: Proceedings. 2020;22:2475-81. 10.1016/j.matpr.2020.03.375
17. Durga CSS, Ruben N, Chand MSR, Indira M, Venkatesh C. Comprehensive microbiological studies on screening bacteria for self-healing concrete. Materialia. 2021;15:101051. 10.1016/j.mtla.2021.101051
18. Rao PP, Asadi S, Krishna MR, Babu AS, Alla S. An experimental investigation of bacteria impact on compressive strength of cement mortar and concrete. Materials Today: Proceedings. 2021;43:1949-55. 10.1016/j.matpr.2020.11.213
19. Vaezi M, Zareei SA, Jahadi M. Recycled microbial mortar: Effects of bacterial concentration and calcium lactate content. Construction and Building Materials. 2020;234:117349. https://doi.org/10.1016/j.conbuildmat.2019.117349
20. Rohini I, Padmapriya R. Effect of bacteria subtilis on e-waste concrete. Materials Today: Proceedings. 2021;42:465-74. https://doi.org/10.1016/j.matpr.2020.10.192
21. Lucas SS, Moxham C, Tziviloglou E, Jonkers H. Study of self-healing properties in concrete with bacteria encapsulated in expanded clay. Science and Technology of Materials. 2018;30:93-8. 10.1016/j.stmat.2018.11.006
22. Xu J, Wang X. Self-healing of concrete cracks by use of bacteria-containing low alkali cementitious material. Construction and Building Materials. 2018;167:1-14. https://doi.org/10.1016/j.conbuildmat.2018.02.020
23. Rauf M, Khaliq W, Khushnood RA, Ahmed I. Comparative performance of different bacteria immobilized in natural fibers for self-healing in concrete. Construction and Building Materials. 2020;258:119578. 10.1016/j.conbuildmat.2020.119578
24. Wang J, Van Tittelboom K, De Belie N, Verstraete W. Use of silica gel or polyurethane immobilized bacteria for self-healing concrete. Construction and building materials. 2012;26(1):532-40. https://doi.org/10.1016/j.conbuildmat.2011.06.054
25. Seifan M, Samani AK, Berenjian A. Bioconcrete: next generation of self-healing concrete. Applied microbiology and biotechnology. 2016;100:2591-602. 10.1007/s00253-016-7316-z
26. Onyelowe KC, Gnananandarao T, Ebid AM, Mahdi HA, Ghadikolaee MR, Al-Ajamee M. Evaluating the compressive strength of recycled aggregate concrete using novel artificial neural network. Civil Engineering Journal. 2022;8(8):1679-93. 10.28991/CEJ-2022-08-08-011
27. Akhtar J, Khan RA, Khan RA, Akhtar MN, Nejem JK. Influence of natural zeolite and mineral additive on bacterial self-healing concrete: a review. Civil Engineering Journal. 2022;8(5):1069-85. 10.28991/CEJ-2022-08-05-015
28. Balamuralikrishnan R, Saravanan J. Effect of addition of alccofine on the compressive strength of cement mortar cubes. Emerging Science Journal. 2021;5(2):155-70. 10.28991/esj-2021-01265
29. Standard I. IS: 383 (2016) Coarse and fine aggregate for concrete-specification. Bureau of Indian Standards, New Delhi. 2016. http://icikbc.org/docs/IS383-2016.pdf
30. Standard I. Plain and reinforced concrete-code of practice. New Delhi: Bureau of Indian Standards. 2000. https://law.resource.org/pub/in/bis/S03/is.456.2000.pdf

Persian Abstract

چکیده

این مطالعه بر ارزیابی اثربخشی غلظت‌های مختلف سلولی باکتری‌های باسیلوس در ترمیم ترک‌های بتن بازیافتی حاوی سنگدانه‌های درشت تمرکز دارد. در این تحقیق، معرفی بتن پایدار باکتریایی باسیلوس به عنوان راه حلی برای پرداختن به ترمیم ترک است. این فرمول ابتکاری بتن نه تنها جایگزین های سازگار با محیط زیست را ارائه می دهد، بلکه مزایای اقتصادی نیز ارائه می دهد. این تحقیق شامل ادغام سنگدانه های درشت به مخلوط بتن، همراه با جایگزینی جزئی سیمان با خاکستر بادی و سرباره کوره بلند دانه بندی شده زمینی ((GGBSاست که هر کدام ۲۰ درصد از مخلوط را تشکیل می دهند. سنگدانه های درشت از سنگدانه های بتن بازیافتی ((RCAدر نسبت های مختلف تشکیل شده اند: ۰٪، ۵۰٪، و ۱۰۰٪. علاوه بر این، باسیلوس لیکنیفورمیس به ترتیب در غلظت های ۱۰۳، ۱۰۵ و ۱۰۷ سلول در میلی لیتر استفاده شد. یافته‌ها نشان‌دهنده همبستگی مثبت بین درصد بهبودی ترک‌ها، همانطور که با سرعت پالس اولتراسونیک ((UPVاندازه‌گیری می‌شود، و غلظت باکتری‌ها است. علاوه بر این، مشاهده می شود که سنگدانه های بازیافتی دارای منافذ ذاتی هستند که امکان جذب آب از طریق این منافذ را فراهم می کند. بنابراین، RCA قبل از ادغام آن در مخلوط بتن تحت یک فرآیند غوطه وری ۲٤ ساعته در آب قرار می گیرد. در حالی که مقاومت فشاری بتن بین RCA 0٪ و RCA 50٪ ثابت می ماند، در RCA 100٪ به طور قابل توجهی کاهش می یابد. با این حال، عملکرد باکتری نسبت به غلظت سلولی را نشان می دهد. قابل ذکر است، اثربخشی باکتری بدون توجه به تغییرات در نسبت RCA ثابت باقی می ماند. این مطالعه بر پتانسیل امیدوارکننده باکتری باسیلوس در افزایش دوام و پایداری سازه‌های بتنی، با ارتباط خاص با کاربردهای RCC تاکید می‌کند.