Self-healing of concrete incorporating seashells as partial cement replacement

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Abstract. The current experimental study aims to evaluate the effectiveness of a bacteria-based self-healing admixture in low-carbon concrete to minimise maintenance demands on concrete structures. The implementation of such innovative technologies has the potential to enhance structural durability, reduce the frequency and extent of repairs, lower the consumption of additional repair materials, and consequently decrease the embodied carbon associated with maintenance activities. This research investigates the enhancement of concrete's self-healing capability through the incorporation of a bacterial healing agent, and the use of scallop seashells as a partial cement replacement at a substitution rate of 30 % to reduce carbon emissions. Furthermore, the study explores the synergistic effect of combining both the self-healing agent with an anti-corrosion inhibitor (NitCal) to improve the overall durability and performance of concrete. The experimental program comprises concrete specimens categorised into three sets. The first set includes control samples with 30 % scallop seashell replacement, serving as reference specimens. The second set consists of samples containing 30 % seashells and the self-healing agent, while the third set comprises samples incorporating 30 % seashells, the self-healing agent and NitCal. After 28 days of curing, controlled cracks of 0.4 mm width were introduced into all specimens. The second and third sets were then placed in an incubation chamber to facilitate and evaluate the biological self-healing process, in comparison to the control group. In addition to self-healing assessment, the study investigates fresh and hardened concrete properties, including compressive strength, modulus of elasticity and carbon emission, for mixtures containing 30 % scallop seashells with varying dosages of NitCal. The findings aim to support the development of more sustainable and resilient concrete materials.

Keywords: Self-healing, concrete structures, cracking, carbon emissions, mechanical properties, durability

1 Introduction

1.1 Overview

Concrete is a vital construction material renowned for its high compressive strength and versatility. However, its inherent brittle behaviour under tensile stress is prone to cracking due to several factors such as loading, shrinkage, thermal stress and settlement. These cracks can significantly impact the load-bearing capacity of concrete structures and allow the ingress of water and aggressive substances, leading to steel reinforcement corrosion and other durability issues [16].

Cracking in concrete is normal and manageable if it adheres to specified limits set by standards for different environments. BS EN 1992-1-1 "Eurocode 2: Design of concrete structures - General rules and rules for buildings" [50] recommends maximum crack widths of 0.4 mm is acceptable (no risk of corrosion), while a width of 0.2 mm is permissible in aggressive environments with the risk of carbonation, chlorides, or corrosion induced by chlorides from sea water.

Recent advancements in concrete construction have focused on addressing concrete cracking challenges. However, addressing the challenge of concrete cracking remains an ongoing issue. Detecting and repairing small cracks early in construction is challenging with traditional methods, such as crack injection, grouting process, and sealant are all performed manually. In recent years, the concept of self-healing concrete has emerged as a promising approach to address the crack issue in concrete. Self-healing concrete refers to a type of concrete that can autonomously repair its own cracks and damage, thereby extending the lifespan of structures and reducing maintenance costs. This novel approach leverages various mechanisms to achieve self-healing, including the incorporation of healing agents, bacteria, and encapsulated materials. Applying calcite precipitation through bacteria to concrete before the cracks appear could be both resource and budget-saving. This innovative approach allows concrete to autonomously repair cracks without the need for human intervention, offering a modern solution to enhance the durability and longevity of structures [14].

Self-healing in concrete (SHC) can be achieved either autogenously, through natural processes driven by the optimal mixing of cementitious materials and their inherent properties, or autonomously, by deliberately incorporating specific healing agents like bacteria and admixtures. Minor cracks up to 0.2 mm can be healed autogenously due to the presence of unhydrated cement particles in the concrete. Bacteria-based self-healing heals the crack width up to 0.8 mm [6]. Recent research has underscored the potential of bacterial self-healing concrete to autonomously mend cracks ranging from

0.3 mm to 1.5 mm in width. This healing process is mediated by bacterial agents embedded within the concrete matrix that produce calcium carbonate precipitates, effectively filling and sealing the cracks [9]. The natural self-healing ability is effective for small cracks, typically up to 0.2 mm in width. However, larger cracks require additional healing agents to ensure effective repair and restoration of structural integrity.

In addition to resolving the concrete cracking, there is a growing emphasis on improving the sustainability of concrete production. Cement, the key binding agent in the concrete, accounts for 4 to 7 % of global carbon dioxide emissions, with predictions indicating this could rise to 15 % in the next decade [8]. So, it is subsequently necessary to explore the alternatives to cement for the reduction of CO_2 emissions and enhance sustainability. In China, the world's largest shellfish producer, approximately 10 million tons of waste seashells, primarily comprising oyster, clam, scallop, and mussel shells, are discarded in landfills each year [20]. The global demand for concrete was 14.0 billion cubic meters in 2020 and is projected to reach 20 billion cubic meters by 2050 (Global Cement and Concrete Association). Using seashells as replacements for cement or aggregates in concrete can provide a sustainable alternative, reducing environmental impact and resource depletion [4, 12]. In the present experimental study, scallop seashells (depicted in Fig. 1) were ground to powder form and used to replace 30 % of the cement content.

Fig. 1. Scallop seashells.

1.2 Self-Healing Concrete (SHC)

SHC is designed to repair cracks on its own without requiring any external intervention. This capability is achieved by incorporating specific healing agents into the concrete mix. When cracks form, these agents are activated to fill and seal the gaps, preserving the concrete's strength and durability [5]. There are two types of SHC: Autogenous Healing of Concrete; and Autonomous Self-Healing Concrete.

Autogenous self-healing concrete capitalises on the concrete's inherent properties and the natural chemical reactions that occur within the mix. When mixed with water, unhydrated cement particles begin to hydrate, forming additional calcium silicate hydrate (C-S-H) gel and calcium hydroxide, which enhance the concrete's strength and durability. This self-healing method uses supplementary materials, such as fly ash or slag, which react with water and calcium hydroxide in the concrete to generate calcium carbonate. This process helps to close microcracks gradually over time [18]. Unlike other self-healing types, autogenous concrete does not depend on external agents or bacteria; it utilises the concrete's own chemical mechanisms for repair.

Autonomous self-healing concrete describes concrete systems engineered to repair cracks on their own through built-in mechanisms or materials. This type of concrete includes both bacterial and chemical self-healing approaches, focusing on the design and integration of these systems to ensure automatic healing when cracks develop. For instance, concrete that incorporates encapsulated bacteria or contains capsules of chemical healing agents falls into this category, as these systems function independently without requiring external intervention once the concrete is in use [1].

Among various techniques of SHC the bacteria-based approach has demonstrated the long-lasting effectiveness [10]. This long-lasting effectiveness is due to the bacteria's capability to sustain crack healing by transitioning from vegetative cells to spores, allowing them to remain viable potentially for over 200 years (Depending on the environmental conditions).

Alkali-resistant bacteria of the genus Bacillus are particularly noted for their ability to thrive in the harsh, i.e. alkaline environment of concrete, making them effective agents for SHC applications. When a crack forms, the dormant bacteria are activated by water ingress, which causes them to multiply and produce calcite ($CaCO_3$) to seal the crack. After the crack is repaired, the bacteria enter a dormant state. When new cracks appear, the bacteria can reactivate and continue the healing process. This process, known as microbially induced calcium carbonate precipitation (MICP), makes bacteria a durable and effective healing agent [11].

The concept of autogenous self-healing in concrete was first documented in 1836 by the French Academy of Sciences. Early observations identified that concrete possesses a natural ability to heal minor cracks over time through the deposition of calcium carbonate from the hydration process [21].

In conventional concrete, approximately 20-30 % of cement particles remain unhydrated. These unhydrated particles can react with water to produce calcium carbonate and heal the minor crack. This hydration process normally occurs at a pH higher than 7.5 [7]. This initial discovery set the stage for future research into self-healing mechanisms in concrete, highlighting that the inherent qualities of concrete could be used to fix minor cracks in concrete structures.

1.3 Seashell

Recently, researchers have been exploring seashells as a greener alternative to traditional cement. Seashells, composed of more than 90 % calcium carbonate, are abundant in coastal areas and seafood industries and are considered an inert substance in cement-based materials. This high calcium carbonate content offers a sustainable option for reducing cement's environmental impact [22]. While some studies have shown promise in using seashells as aggregate replacements in concrete, their potential as a direct cement substitute remains underexplored. This presents a valuable opportunity for further research to fully utilise this readily available resource.

The main aim of this research is to study the bacterial self-healing properties of concrete by incorporating a bio-based healing agent, NitCal for enhanced corrosion resistance, and utilizing scallop seashell powder as a 30 % substitute for cement and analyse the mechanical properties, such as compressive strength and Young's modulus, of concrete samples incorporating 30 % scallop seashell powder, bacteria, and NitCal, and compare these properties across different sample combinations.

1.4 Development of Self-Healing Concrete

In the 1990s, due to the limitations of traditional crack repair methods, which were often insufficient for minor cracks, researchers began to investigate and develop autonomous healing methods. The concept of self-healing concrete began gaining attention in the early 2000s with the pioneering work of the Delft University of Technology in the Netherlands, where researchers first demonstrated the use of bacteria to induce calcium carbonate precipitation, effectively sealing cracks autonomously. These advancements led to the incorporation of various admixtures and bacterial agents, which further improved the self-healing capabilities of concrete [6].

This bacterial approach was further refined by Ghent University in Belgium, which enhanced the efficiency of microbial self-healing by embedding ureolytic bacteria and nutrients directly into the concrete matrix [1]. Further advancements came from Cardiff University in the UK, where researchers developed a vascular self-healing concrete system inspired by biological processes. This system featured networks of microchannels within the concrete that could deliver healing agents directly to damaged areas [2].

Bacteria-based healing is an effective method for repairing cracks. Depending on the bacterial strain used, the high pH levels found in concrete can cause the bacteria to become dormant for as long as 200 years [6]. Injecting bacteria into concrete cracks promotes the formation of a calcium carbonate layer, which helps in sealing the cracks and restoring the material's integrity. Ureolytic bacteria are considered more effective in this self-healing process compared to non-ureolytic bacteria, primarily because ureolytic bacteria can survive in the high pH environment of concrete, while non-ureolytic bacteria cannot [19]. Ureolytic bacteria like S. pasteurii, B. subtilis, B. sphaericus, and B. megaterium are capable of healing cracks that are between 0.85 and 0.97 mm in width [6]. In contrast, non-ureolytic bacteria such as B. halodurans, B. licheniformis, and B. thuringiensis can repair cracks up to 0.45 mm wide and restore only 65 % of the original strength of the concrete [6]. Additionally, bacteria are generally more effective at sealing wider cracks compared to autogenous healing [17].

The pH value of concrete typically ranges between 12 and 13, creating a highly alkaline environment in which only alkaliphile bacteria can survive and thrive [6]. Bacillus cereus can adapt to extreme environmental conditions, including high temperatures and pH levels. It effectively heals cracks in concrete and reduces water permeability. Sporosarcina pasteurii thrives in high pH and temperature conditions, where it precipitates calcium carbonate ($CaCO_3$), enhancing the mechanical strength of concrete [19]. Bacillus sphaericus not only precipitates $CaCO_3$, contributing to increased strength and reduced water absorption, but also forms resilient endospores under extreme environmental conditions. Bacillus subtilis is known for its high urease activity up to pH 9, withstanding harsh environments and continuously forming $CaCO_3$.

Different researchers have employed various bacteria strains for studying self-healing concrete. [10] utilised Bacillus cohnii to induce the precipitation of $CaCO_3$. In contrast, [10] focused on Bacillus pasteurii (formerly Sporosarcina pasteurii) for their investigations. Meanwhile, [10] utilized Bacillus licheniformis in their studies, incorporating spores of Sporosarcina halophila (a halophilic ureolytic bacterium) alongside calcium lactate and expanded perlite aggregate as healing agents. These mixtures were embedded in mortar specimens and exposed to submerged and tidal marine environments for 90 days to evaluate their self-healing efficacy under harsh conditions. The presence of bacteria, water, and oxygen facilitated the formation of aragonite and brucite, leading to a 50 % closure of cracks up to 800 μm in width. A related study examined Halobacillus halophilus bacteria, which also led to the formation of aragonite and brucite. This approach enhanced the self-healing capacity of concrete by 17 % under the marine conditions. [15] investigated microbial concrete incorporating Sporosarcina pasteurii and discovered that the bacteria induced calcium carbonate precipitation through the degradation of uric acid or urea, which effectively facilitated the healing of cracks in the concrete.

2 Experimental study

An extensive programme of testing is currently underway to evaluate the effect of using seashell powder as a partial replacement for cement on carbon emissions and the performance of the bacterial self-healing capabilities of concrete by incorporating the bacteria and utilising scallop seashells as a 30 % partial replacement for cement.

2.1 Materials used

In this study, natural river sand is used from Jewson, a well-known UK construction material supplier, as the fine aggregate, with a particle size of 0 to 4 mm for improved workability (smaller particles (≤4 mm) fill voids between coarse aggregates, reducing internal friction and enabling smoother flow during mixing/placement) and mix cohesiveness (well-graded

0–4 mm range ensures sufficient fines (e.g., 0.075–0.6 mm) to bind the mix, minimizing segregation and bleeding). For coarse aggregate, uncrushed natural gravel from the same supplier, ranging from 5 to 20 mm in size, was selected for its structural integrity and interlocking properties, which enhance the concrete's mechanical strength [33]. The cement selected for the project is Hanson Portland Cement CEM I 52.5 N. Scallop seashells were selected as a replacement material for 30 % of the cement content in the concrete mix. The preparation of seashell powder involved several meticulous steps to ensure its suitability for concrete production.

The Scallop seashells, provided by the university, were first washed, oven-dried, and then crushed into powder by Los Angeles Machine. This powder underwent further refinement through sieving with a 63-micron sieve to achieve a particle size like cement, as recommended by existing literature [19]. Only particles passing through the 63-micron sieve were selected for the concrete mix, ensuring uniformity and suitability for use as a 30 % cement replacement by Scallop seashell.

For this research, Self-healing (HA) agent – commercially available as Basilisk – was used at a dosage of 1-4 % by weight of Portland cement clinker, approximately 4-7.5 kg/m^3 of concrete. The HA, which consists of yellow, crystal-like pellets under 2 mm in size, contains dormant bacterial spores and essential nutrients for self-healing cracks up to 1 mm wide through the formation of calcium carbonate. It should be stored below 40 °C in its original packaging to maintain effectiveness.

In this research, NitCal, a colourless concrete corrosion inhibitor, is utilised to assess its impact on enhancing concrete durability, especially within the framework of bacteria self-healing concrete that incorporates seashells. Applied at dosages between 1 and 4 % of the Portland cement weight, NitCal is evaluated for its effectiveness in preventing corrosion and extending the concrete's lifespan. The inhibitor works by lowering corrosion rates in steel reinforcement, thereby boosting the structural integrity and longevity of the concrete. The study explores how NitCal interacts with the bacterial and seashell components to enhance overall concrete performance.

2.2 Permeability test

The permeability test was carried out to examine the healing efficiency of adding the self-healing agent separately and in combination with an anticorrosion inhibitor. The permeability test was carried out by running water through the healed cracks for 20 minutes and measuring the volume of water (and comparing it to the volume from the control specimen to work out the healing efficiency).

The testing procedure suggested by [32] was followed to induce cracks in all samples (as can be seen in Fig. 3), aiming for crack widths up to 0.40mm. The following steps outline the detailed procedure for inducing cracks in the concrete specimens.

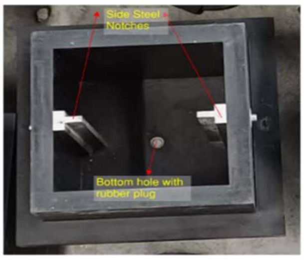
• The top and bottom surfaces of the concrete specimens were marked with grid lines spaced 1 cm apart. This preparation was essential for accurately measuring crack widths using computer-aided CAD software. The grid line arrangement on the specimens is illustrated in Fig. 2.

After preparing the grid lines on the concrete specimens, each sample was secured with plastic ties before inducing crack in order to prevent splitting during crack induction. This crucial step-maintained specimen integrity throughout the cracking process and until permeability tests were conducted. Alternatively, clamps could also be used to hold the specimens together.

After the sealant dried, the cube specimens were placed in an incubation chamber to evaluate their self-healing capabilities. Only the samples containing self-healing agent and 4% NitCal were incubated. In contrast, the control mix cubes were kept at room temperature to serve as a reference for measuring the self-healing efficiency of the treated samples.

The self-healing specimens were maintained in the incubation chamber for 6 weeks, or 42 days. The chamber was equipped with a thermostat heater set to 20 degrees Celsius and a mist spray system that activated every 4 hours for 6 minutes, ensuring optimal conditions for promoting the self-healing process.

Fig. 2. Concrete Sample with Grid lines.



(a)

(b)

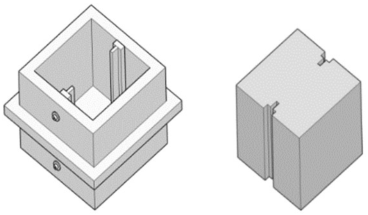


Fig. 3. (a) Mould for Self-Healing Sample; (b) samples for Self-Healing.

3 Results and discussion

This study presents a comprehensive analysis of the strength characteristics of the tested materials, focusing on compressive strength and the self-healing technique. The results of the experimental investigations are systematically analysed and discussed to assess their implications for the performance, durability, and self-healing capability of concrete. The findings offer valuable insights into the structural integrity and long-term behaviour of self-healing concrete under a range of environmental conditions.

3.1 Compressive strength test

In this research, the compressive strength of concrete cubes measuring 100 mm x 100 mm x 100 mm was tested in accordance with British Standard BS EN 12390-3:2019. After curing for 28 days, the cubes were removed from the curing tank, weighed, and then tested using a Universal Testing Machine (UTM) at a loading rate of 0.4 MPa/s until failure. Each specimen was placed centrally in the machine, and the failure load was recorded. The compressive strength was calculated by dividing the recorded load by the cross-sectional area of each specimen. A total of 12 cubes of different samples were subjected to compression testing.

The Control Mix, incorporating 30% scallop seashells as a partial cement replacement, achieved a baseline compressive strength of 42 MPa, serving as the reference for evaluating the effects of self-healing additives and NitCal.

The following outcomes were observed in modified mixes:

3.1.1 Self-Healing Agent Only:

Compressive strength remained comparable to the Control Mix, averaging 42 MPa, indicating no significant impact from the bacterial spores alone.

3.1.2 Self-Healing Agent + 4% NitCal:

The addition of NitCal did not alter compressive strength, with results closely matching the Control Mix (42 MPa).

These findings suggest that neither the self-healing agent (bacterial spores) nor the combined use of spores with 4% NitCal significantly affects the compressive strength of seashell-modified concrete. The 30% seashell replacement itself appears to govern the mechanical performance, with additives primarily influencing self-healing functionality rather than structural integrity.

In summary, given that the values are well within the discrepancy range associated with concrete testing and thus it is concluded that the compressive strength is practically unaffected by the addition of NitCal and the self-healing agent.

3.2 Modulus of elasticity

The experimental results for Young's modulus across different concrete mixes reveal a significant impact of self-healing additives on concrete stiffness. The control mix, with a Young's modulus of 35 GPa, serves as the baseline for evaluating changes. The modulus of elasticity, representing the maximum stress concrete can withstand, offers key insights into its stiffness and structural integrity, which are critical for assessing its behaviour under load. The data reveal how the inclusion of the self-healing agent and varying proportions of NitCal influence this property. A control mix, where 30% of cement is replaced with seashells, serves as the benchmark, exhibiting a maximum stress of 35 MPa. The stiffness of mixes containing the self-healing agent with and without the corrosion inhibitor (4% NitCal) had a similar trend.

Overall, the results demonstrate that optimum concentration value of NitCal for combination with the self-healing agent is around 4% in terms of compressive strength, modulus of elasticity trends and carbon emission.

3.3 Permeability test for Self-Healing

In this paper, in order to the investigate the benefits of the bacterial self-healing technique, a series of test of permeability were performed for quantification of the functional self-healing performance. The samples were prepared according to BS 8500-1:2015+A2:2019.

The computer-aided design software (AutoCAD) was used to measure crack widths. The images were inserted to AutoCAD and the image was scaled to real size by using the 10 mm grid shown in Fig. 4. Crack widths were measured in all samples twice.

The crack was measured at three different positions along before and after healing. After healing time, the healing efficiency will be calculated using the following formula suggested by (https://basiliskconcrete.com, 2021):

$$\mathrm{HE} = \frac{\mathrm{w_{unhealed}}(t) - \mathrm{w_{healed}}(t)}{\mathrm{w_{unhealed}}(t)} \times 100\%$$

where:
HE = Healing efficiency calculated at test time (t) (42 days);
$w_{unhealed}(t)$ = Rate of water passing the crack (g/min) without healing, reference specimen;
$w_{healed}(t)$ = Rate of water passing the crack (g/min) after a healing period (t) (42 days).

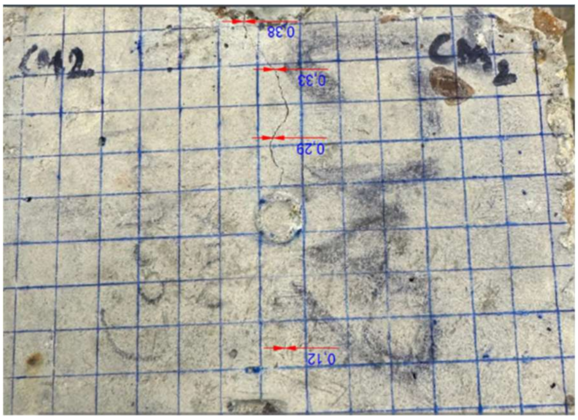
The test data highlights the effective closure of cracks in samples treated with bacteria and 4% NitCal. The control sample (CM) showed a large weight increase of 248.7 g after the permeability test, indicating poor crack closure and significant water collection. In contrast, samples with bacteria and NitCal (S1, S2, and S3) exhibited much smaller weight differences 0.5 g (S1), 1.4 g (S2), and 0.8 g (S3) reflecting better crack sealing. This minimal weight change after further testing confirms that the addition of NitCal enhanced the bacteria's ability to close cracks, leading to reduced water collection and improved resistance to permeability.

Table 1 shows that the average healing efficiency through permeability highlights both the effectiveness of the crack closure process and the improvement brought by the addition of 4% NitCal to the CM+B (bacteria) mixture. In the sample of (CM+B), the average healing efficiency was 99.25%, with individual efficiencies of 99.60% (S1), 98.89% (S2), and 99.37% (S3). These values demonstrate that the bacteria alone were highly effective in healing cracks and reducing water permeability. The healing efficiency increased slightly when 4% NitCal was added, with an average efficiency of 99.63%, and individual values of 99.68% (S1), 99.76% (S2), and 99.45% (S3).

Table. 1. Permeability test results

CM+Basilisk(B)				
ID	Sample	Wt of water gm/min	Healing Efficiency	Average Healing Efficiency
CM	Unhealed	126.3	**Taken as Reference Sample average**	
S1	Healed	0.5	99.60%	99.25%
S2	Healed	1.4	98.89%	
S3	Healed	0.8	99.37%	
CM+Basilisk(B)+4% Yara				
ID	Sample	Wt of water gm/min	Healing Efficiency	Average Healing Efficiency
CM	Unhealed	126.3	**Taken as Reference Sample average**	
S1	Healed	0.4	99.68%	99.63%
S2	Healed	0.3	99.76%	
S3	Healed	0.7	99.45%	

The test result shows that the addition of NitCal resulted in better crack closure, reflected by a reduced water flow rate through the healed cracks. This consistent improvement across all samples emphasizes the enhanced ability of the bacteria to close cracks more efficiently when NitCal is present. The improved healing efficiency in the NitCal group signifies not just a reduction in permeability, but also a more complete and effective sealing of the cracks. Therefore, the test reinforces the conclusion that crack closure was more thorough in the presence of NitCal, leading to higher healing performance and better long-term durability of the concrete.



(a)

(b)

Fig. 4. (a) Crack sample before healing; (b) Crack sample after healing.

3.4 Carbon Factor for Scallop Seashell

To calculate the carbon factor for Scallop seashell powder, the CO_2 emissions from the energy used in the grinding and sieving processes was determined. The emissions were estimated by converting the energy usage into CO_2 emissions, based on the carbon intensity of electricity in the UK, which is 170 grams of CO_2 per kilowatt-hour, as reported by Nowtricity (2024). The process involved gathering data on energy consumption, particularly electricity usage, and determining the corresponding emission factors to convert energy use into CO_2 emissions. These factors were applied to the total energy consumed to calculate the resulting CO_2 emissions. The emissions data was then normalized using a relevant unit such as tonnes of seashells processed or cubic meters of concrete produced. Finally, the carbon factor was calculated by dividing the total CO_2 emissions by the selected unit, yielding a standardized metric for evaluating the project's sustainability performance.

The calculations showed that replacing 30 % of cement with seashells can significantly reduce carbon emissions, as cement has a much higher carbon factor compared to seashells. By substituting part of the cement with seashells, the carbon footprint of the mix is lowered, making it a more sustainable option. This approach not only decreases the environmental impact associated with cement production but also promotes the use of alternative materials, contributing to overall sustainability in construction practices.

The calculation data indicates that replacing 30 % of the cement with seashells in the Control Mix (CM) results in a significant reduction in the overall carbon footprint, as can be seen in Fig. 5. The total embedded carbon for the Normal Mix (NM) is 29% higher than for CM. This reduction is due to the much lower carbon footprint of seashells compared to conventional cement. By using seashells, which have a far smaller carbon footprint, the Control Mix benefits from a more environmentally friendly composition. Thus, incorporating seashells into the concrete mix effectively decreases the carbon footprint compared to using cement alone.

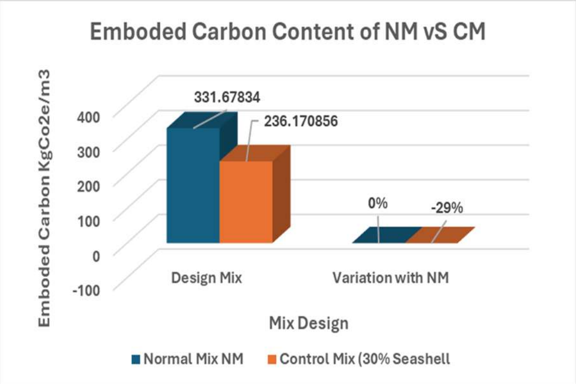


Fig. 5. Embodied Carbon Content of seashell concrete vs conventional concrete mix.

4 Conclusions

This research examines the potential of incorporating bacteria-based specifically, and a fixed percentage of scallop seashells (30 %) as partial replacements for cement in concrete. The experimental program was designed to evaluate how the addition of self-healing bacteria, in combination with varying concentrations of NitCal (4 % and 8 %), affects the physical, mechanical, and durability properties of the concrete. The research employed cement, concrete sand, coarse aggregates, and sustainably sourced scallop seashells. Key standardised tests, including slump tests, compressive strength tests, Modulus of Elasticity were conducted to assess the impact of these additions on concrete self-healing performance and strength.

This study demonstrates an evaluation of mechanical and durability properties when incorporating the self-healing agent and the corrosion inhibitor additive into concrete with 30 % seashell powder replacement. Overall, the results demonstrate that optimum concentration value of NitCal for combination with the self-healing agent is around 4 % in terms of compressive strength and stiffness.

The permeability results indicate a complete internal healing of the concrete samples, with no water passing through. The average healing efficiency improved from 99.25% in the specimens containing the self-healing admixture to 99.63% with the addition of 4 % NitCal. This slight increase demonstrates a more effective crack closure and enhanced sealing performance, reflecting the higher durability and thorough healing achieved with 4% NitCal. The reference sample has the same initial crack as they were in the induction of cracking this shows that the adding as healing agent can heal the crack in incubation chamber with the 4% NitCal concentration.

The partial replacement of 30% of the cement with ground seashell powder led to 29% reduction of carbon emissions, which is a significant environmental saving. The examination of strength and durability characteristics has demonstrated that the carbon emission reductions can be achieved without compromising the performance of the concrete material.

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