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Development of CO₂ Absorbing Coating with Lime and Demolished Concrete Waste

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Abstract

The continuous rise in atmospheric carbon dioxide (CO_2) has become a serious environmental concern, with cement production alone contributing nearly 7–8% of global CO_2 emissions. This situation has increased the need for simple, practical, and sustainable solutions in the construction industry to help reduce carbon emissions. In this context, the present study investigates the development of an eco-friendly surface coating made from lime and demolished concrete waste (DCW) powder to improve the CO_2 absorption capacity of concrete surfaces. The use of demolished concrete waste not only supports CO_2 sequestration through the carbonation process but also promotes the reuse of construction and demolition waste, making the approach more sustainable. In this study, concrete cubes were prepared and divided into coated and uncoated specimens. The coating mixture was applied to the surface of selected cubes, and all specimens were kept under natural environmental conditions for curing periods of 7, 14, and 28 days. The performance of the coating was evaluated through weight variation measurements, compressive strength testing, and carbonation depth analysis using the phenolphthalein indicator test. The results showed that the coated specimens absorbed more CO_2 compared to the uncoated cubes, with weight gains reaching up to 3.7% at 28 days. In addition, the compressive strength of the coated cubes improved by about 7% at 28 days, indicating that the coating did not negatively affect the structural performance of concrete. The phenolphthalein test also confirmed greater carbonation on the coated surfaces. Overall, the study demonstrates that a lime–demolished concrete waste coating can effectively enhance CO_2 sequestration while encouraging sustainable construction practices and the beneficial reuse of waste materials.

Keywords: Carbonation, CO_2 sequestration, Demolished concrete waste (DCW), Lime-based coating, Sustainable construction, Surface treatment of concrete, Construction waste reuse.

1. Introduction

Atmospheric carbon dioxide (CO_2) levels have risen to alarming concentrations, exceeding 420 ppm, largely due to rapid industrialization, urban growth, and fossil fuel consumption [1]. This increase has intensified global warming and led to serious environmental impacts such as rising sea levels and extreme climate events. The cement industry is a major contributor, responsible for nearly 7–8% of global CO_2 emissions [2], [3]. A significant portion of these emissions comes from limestone calcination during clinker production, along with the high-temperature fuel combustion required in cement kilns.

Although concrete naturally absorbs some CO_2 through carbonation, this process occurs very slowly under normal environmental conditions and cannot compensate for the large emissions generated during cement production [6]. To address this issue, researchers have explored methods such as accelerated carbonation and the use of calcium-rich materials such as lime, recycled concrete powder, industrial by-products (fly ash and slag), and demolished concrete waste (DCW) to enhance CO_2 sequestration in cement-based materials [4], [5], [7]. Lime-based materials are highly reactive with CO_2 due to their calcium content [8], and demolished concrete waste also contains calcium-rich compounds capable of further carbonation [10], [11], [13].

However, limited research has focused on combining lime and demolished concrete powder as a surface-applied coating to enhance CO_2 absorption in existing structures. Therefore, this study aims to develop and experimentally evaluate a novel lime–demolished concrete coating that accelerates atmospheric CO_2 uptake while promoting sustainable waste reuse and reducing the construction industry’s carbon footprint

2. Literature Review

The rapid increase in atmospheric carbon dioxide (CO_2) levels has become one of the most serious environmental challenges of the 21st century. Industrialization, urbanization, and infrastructure development have significantly increased CO_2 emissions, with the cement industry alone contributing nearly 7–8% of global emissions. While considerable efforts have been made to reduce emissions during cement production, comparatively less attention has been given to enhancing CO_2 absorption after construction. In this context, the development of CO_2-absorbing materials, particularly surface coatings made from lime and demolished concrete waste (DCW), offers a promising and sustainable solution.

Valerie Masson-Delmotte et al. (2021) [1] pointed out that industries like cement manufacturing significantly contribute to global CO_2 emissions. While they stress the need for carbon reduction strategies, they do not focus on materials that can actively absorb CO_2. This highlights the importance of our project, which aims to develop a lime and demolished concrete waste-based coating to help capture atmospheric CO_2 in the construction sector.

Scrivener et al. (2018) [2] explored eco-efficient cement systems aimed at reducing clinker content and lowering CO_2 emissions during production. Their work demonstrated that modifying cement composition can significantly reduce embodied carbon. However, their approach mainly targets emission reduction at the manufacturing stage rather than enhancing CO_2 uptake after the material is placed in service. This suggests the importance of complementary strategies such as CO_2-absorbing surface treatments.

Similarly, Huntzinger and Eatmon (2009) [3] conducted a life-cycle assessment of Portland cement manufacturing and confirmed that the production process is highly energy-intensive and carbon-intensive. Although alternative production technologies were evaluated, the study did not consider the potential of hardened concrete to reabsorb CO_2 during its lifespan. This leaves an opportunity to investigate methods that improve post-construction carbon sequestration.

Carbonation has long been recognized as a natural process in cement-based materials. Fernández Bertos et al. (2004) [4] reviewed accelerated carbonation technologies and showed that calcium hydroxide reacts with CO_2 to form stable calcium carbonate, effectively locking carbon into a solid mineral form. However, their research mainly focused on bulk materials and industrial waste stabilization, rather than practical surface coatings designed for field application.

Monkman and Shao (2010) [5] further investigated carbonation curing and reported improvements in both strength and CO_2 uptake. While promising, carbonation curing typically requires controlled environments such as sealed chambers with high CO_2 concentrations. Such systems may not be practical for large-scale or in-situ applications. This limitation indicates the need for simpler solutions that function effectively under natural atmospheric conditions.

Papadakis (2000) [6] studied carbonation primarily from a durability perspective, especially its influence on reinforcement corrosion. Traditionally, carbonation has been viewed as detrimental to reinforced concrete structures. However, in non-structural or surface applications, controlled carbonation can be beneficial for CO_2 capture. This shift in perspective opens the possibility of intentionally designing materials to enhance surface carbonation.

Li et al. (2020) [7] provided a detailed review of factors affecting accelerated carbonation, including porosity, moisture content, and calcium availability. Their findings highlight that materials rich in calcium compounds and with suitable pore structures are more effective in absorbing CO_2. However, the study did not explore the use of lime combined with recycled concrete waste as a surface-based carbonation system.

Mo et al. (2020) [8] examined the carbonation performance of concrete containing waste materials and found that calcium-rich wastes can enhance CO_2 uptake. Most existing studies, however, incorporate waste materials directly into concrete mixes. Very limited research has investigated using such waste as an external coating material specifically engineered for carbon absorption.

Andrade et al. (2021) [9] described carbonation as a natural sustainability mechanism in concrete, confirming that structures can act as long-term carbon sinks. Nevertheless, natural carbonation occurs slowly and is often limited to exposed surfaces. This suggests that engineered coatings could accelerate and intensify this natural process.

Zhan et al. (2014) [10] demonstrated that concrete slurry waste can effectively sequester CO_2 through mineral carbonation. Their work supports the idea that cement-based waste materials retain significant carbonation potential. However, the focus was on slurry waste treatment rather than developing a practical coating material.

Sanjuán et al. (2021) [11] quantified CO_2 uptake in cement-based materials and confirmed measurable long-term carbon absorption over the service life of concrete. Despite this, strategies to intentionally enhance or accelerate surface carbonation were not thoroughly investigated.

Mo et al. (2020) [12] investigated innovative surface treatments to enhance carbonation and increase CO_2 uptake in concrete. Their study showed that surface modification improved the interaction between reactive calcium compounds and atmospheric CO_2, leading to higher carbonation compared to untreated concrete. However, they did not explore the use of lime and demolished concrete waste as a combined surface coating for CO_2 absorption.

M. Rajvanshi (2024) [13] emphasized sustainable utilization of demolished concrete waste to reduce landfill disposal and promote recycling. While the project highlighted environmental benefits, it did not examine the potential of DCW as an active CO_2-absorbing material. This presents an opportunity to combine waste management and carbon sequestration in a single innovative solution.

The increase in atmospheric CO_2 has become a serious environmental issue, and the cement industry contributes about 7–8% of global emissions. The natural way to reduce CO_2 is through carbonation, where calcium-rich materials like lime and demolished concrete waste have good potential to capture CO_2 and convert it into stable calcium carbonate.

However, most previous studies mainly focused on reducing CO_2 emissions during cement production, and very little attention was given to capturing CO_2 after construction. In addition, many carbonation studies were carried out only under controlled laboratory conditions, which limits their practical application in real environments. Waste materials were also mostly used as replacements in fresh concrete mixes rather than as surface treatments to enhance CO_2 absorption. Only a few studies have explored the combined use of lime and demolished concrete waste to develop a special surface coating for capturing atmospheric CO_2. Therefore, this project aims to develop a simple, sustainable, and low-cost CO_2-absorbing surface coating using lime and demolished concrete waste (DCW), while promoting construction waste reuse and supporting sustainable practices in the construction industry.

3. MATERIALS

The materials used in this study were chosen based on their easy availability and suitability for concrete. Both conventional materials and additional sustainable materials were used in the mix. These materials were selected to improve the performance of concrete and enhance CO_2 absorption.

3.1 Cement (OPC 53 Grade)

Ordinary Portland Cement (OPC 53 Grade) was used as the primary binding material.It is procured from a local authorized cement supplier. The properties of cement are shown in

Table *1*.

Table 1 Properties of OPC

Properties	Results
Specific gravity (g)	3.16
Fineness (%)	3.89
Consistency (%)	30
Setting time (min):	
Initial setting time	45
Final setting time	325

3.2 Fine Aggregate

Locally available river sand conforming to IS 383:2016. It was used as fine aggregate. It was obtained from a nearby supplier. its properties are presented in Table 2.

Table 2 Properties of fine aggregate

Properties	Result
Specific gravity	2.46
Sieve analysis	Zone -II
Water absorption (%)	1%

3.3 Coarse Aggregate

Coarse aggregate size 20 mm and 10 mm conforming to IS 383:2016. it was procured from a local quarry supplier. its properties are shown in Table *3*.

Table 3 Properties of Coarse aggregate

Properties	Results
Specific gravity	2.63
Sieve analysis	20
Water absorption (%)	0.99%
Fineness modulus	7.4

3.4 Superplasticizer

A commercially available polycarbonate ether (PCE)-based superplasticizer. It was obtained from a construction chemical supplier. its properties are given in

Table *4*.

Table 4 Properties of Superplasticizer

Properties	Result
Form	Liquid
Color	Light yellow to brownish liquid
Specific Gravity (at 25°C)	1.05 – 1.10
pH Value	4 – 7
Solid Content	30% – 40%

Water Solubility	Completely soluble in water

3.5 Lime ($Ca(OH)_2$)

Hydrated lime ($Ca(OH)_2$) used for the coating mix was purchased from a local building materials supplier.

3.6 Demolition Concrete Waste (DCW)

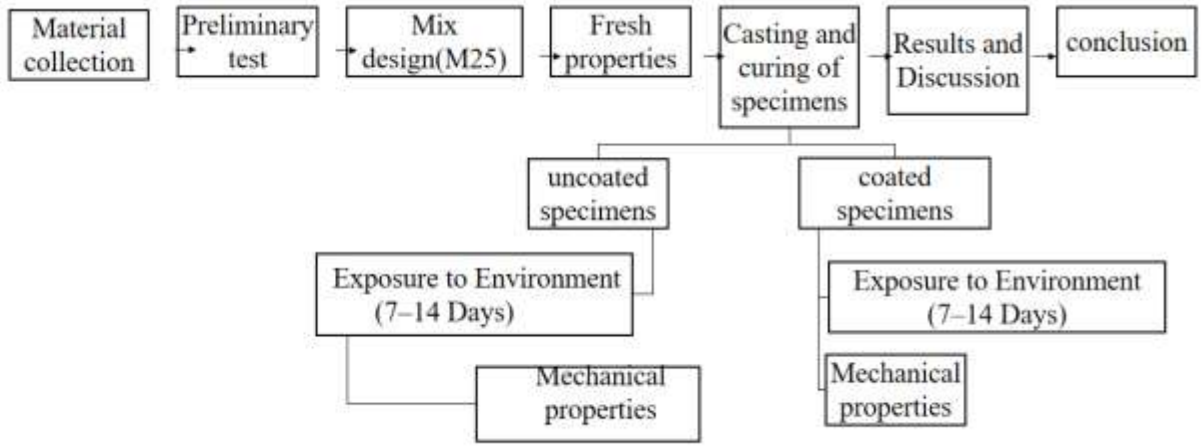
Demolished concrete waste collected from a nearby construction site. It was crushed and sieved to obtain powder. its properties are presented in Table 5.

Table 5 Properties of Demolition Concrete Waste Powder

Properties	Result
Specific Gravity	2.45
Fineness (90 µm sieve)	92% passing
Water Absorption (%)	4.2%
pH Value	11.3

4. Methodology

This study was carried out to develop and evaluate a sustainable CO_2-absorbing surface coating using lime and demolished concrete waste (DCW). The experimental work involved collecting and preparing the materials, preparing the coating mixture, casting and curing concrete specimens, exposing the specimens to natural atmospheric conditions, and evaluating their performance through weight variation, compressive strength, and carbonation tests.



4.1 Collection and Processing of Materials

Demolished concrete waste (DCW) was collected from nearby construction and demolition sites. The collected material was carefully cleaned to remove impurities such as steel pieces, wood, plastics, and dust. The cleaned concrete was then crushed and ground into fine powder. After grinding, the powder was sieved to obtain a uniform particle size suitable for preparing the coating mixture. Commercially available hydrated lime ($Ca(OH)_2$) was used as the main calcium-rich material because of its high alkalinity and strong ability to react with atmospheric CO_2.

4.2 Preliminary Characterization of Materials

Before preparing the coating, preliminary tests were conducted to understand the basic properties of lime and DCW powder. These tests included specific gravity, fineness, water absorption, and pH tests. The results helped in evaluating the physical and chemical characteristics of the materials and confirming their suitability for carbonation.

4.3 Preparation of CO_2-Absorbing Coating

The coating mixture was prepared by dry mixing lime and DCW powder in predetermined proportions to ensure proper blending. Water was then added slowly while mixing to obtain a smooth and workable paste suitable for surface application. The mixture was prepared just before application to avoid early carbonation.

4.4 Casting and Curing of Concrete Specimens

Concrete cube specimens of size 150 mm × 150 mm × 150 mm were cast using an M25 concrete mix. After 24 hours, the specimens were removed from the molds and cured in water for 28 days to achieve the required strength. After curing, the specimens were divided into three groups based on exposure duration: 7 days, 14 days, and 28 days. Each group consisted of three coated cubes and three uncoated cubes for comparison.

4.5 Application of Coating and Exposure

The prepared lime–DCW coating was applied uniformly on the surface of selected concrete cubes using a brush to ensure complete coverage. After the coating dried, both coated and uncoated specimens were placed under natural atmospheric conditions for 7, 14, and 28 days. During this period, carbonation occurred as atmospheric CO_2 reacted with the calcium compounds present in the coating and on the concrete surface.

4.6 Testing and Evaluation

The performance of the specimens was evaluated through weight measurement, compressive strength testing, and carbonation depth analysis using the phenolphthalein indicator method. For each test, the average values of three coated and three uncoated specimens were considered. The results were then compared to assess the CO_2 absorption capability and strength development of the coated concrete.

5. Results and Discussion

The performance of the lime–DCW coating was evaluated at 7, 14, and 28 days using weight variation, compressive strength, and carbonation tests. The results presented are the average of three specimens for both coated and uncoated concrete cubes.

5.1 Weight Variation

The weight variation results are shown in Figure 1. The coated cubes showed a gradual increase in weight from 7 to 28 days, while the uncoated cubes showed only small changes. This increase in weight indicates greater CO_2 absorption in the coated specimens due to carbonation.

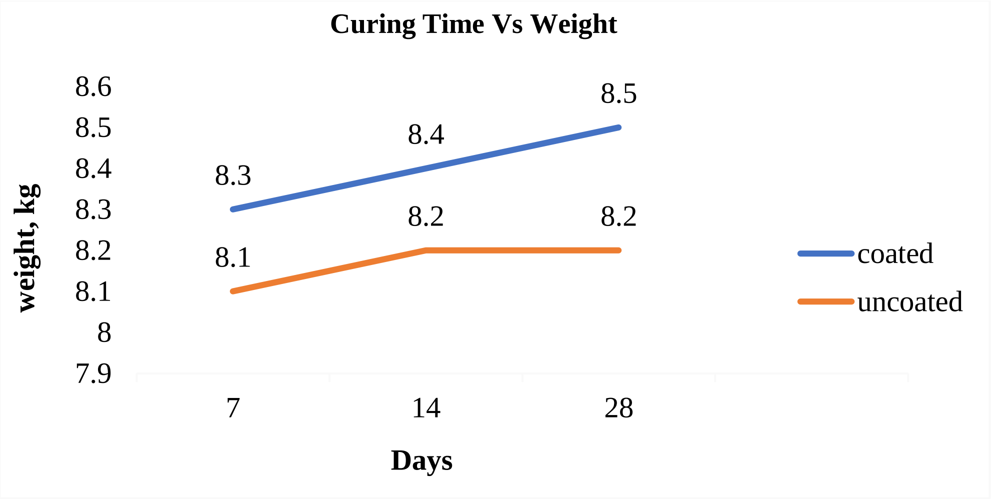


Figure 1 Weight variation of coated and uncoated concrete cubes.

5.2 Compressive Strength

The compressive strength results are presented in Figure 2 . Strength increased with curing age for both coated and uncoated cubes. However, the coated specimens showed slightly higher compressive strength at all ages. This may be due to the formation of calcium carbonate during carbonation, which makes the surface layer denser.

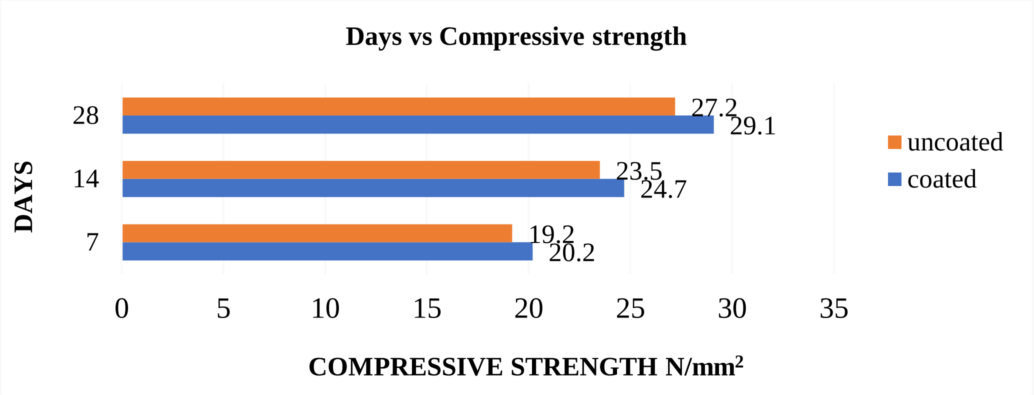


Figure 2 Compressive strength development of coated and uncoated cubes.

5.3 Carbonation Test

The carbonation test results are shown in Table 6. The coated cubes turned colourless when sprayed with phenolphthalein, indicating carbonation on the surface. In contrast, the uncoated cubes remained pink, showing limited carbonation.

Table 6 Carbonation test comparison between coated and uncoated specimens.

Days	Coated	Uncoated
7	Colour less	Pink
14	Colour less	Pink
28	Colour less	Pink

Overall, the results show that the lime–DCW coating improves CO_2 absorption while maintaining the strength of concrete. The coating also supports the reuse of demolished concrete waste, making it a sustainable and environmentally friendly solution for construction.

5.4 Regression Analysis

5.4.1 Regression Analysis of Uncoated Concrete Cubes

Regression analysis was carried out using Microsoft Excel to study the relationship between curing time and compressive strength of plain (uncoated) concrete cubes. The results show that the strength increases from about 19.2 MPa at 7 days to nearly 27.2 MPa at 28 days, indicating a steady and consistent gain in strength over time.

The regression line shows a strong correlation between curing time and strength, with an R^2 value of 0.96, confirming that the data is reliable and follows a clear trend. Since the specimens are uncoated, no CO_2 absorption or carbonation effect is involved. The increase in strength is mainly due to the continuous hydration of cement, which gradually improves the bonding and density of the concrete.

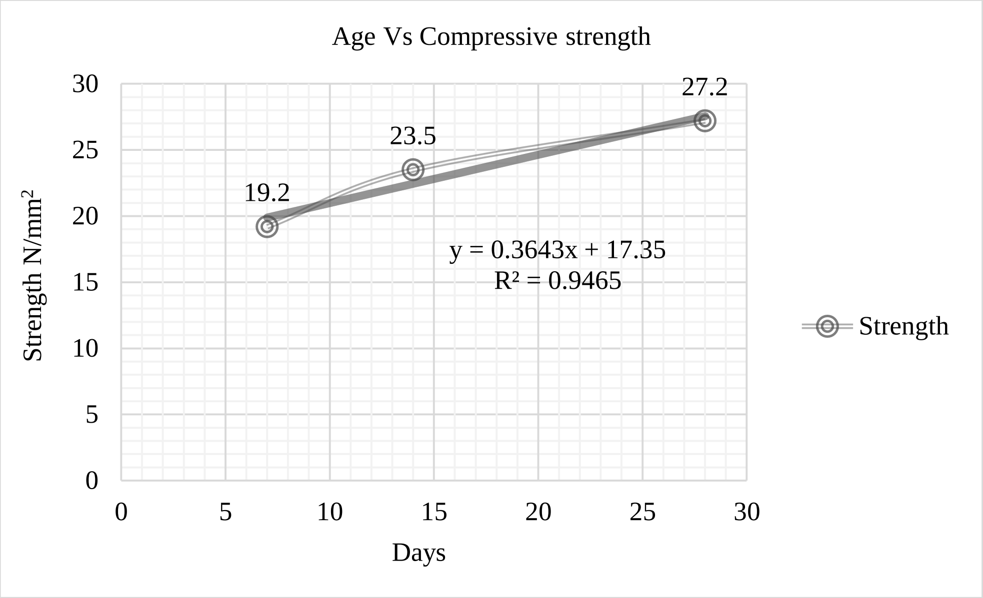


Figure 3 Relationship between curing days and compressive strength

Overall, the analysis confirms that curing time significantly influences compressive strength and that the uncoating enhances concrete performance.

The material starts with a strength of 18 units and increases steadily by about 2.5% per day. The linear equation $y = 0.4082x + 18$ can predict its strength on any day, and Table 7 shows an R² value of 0.9, indicating that the model fits the data very well. Overall, the strength gain is consistent and predictable over time, making it easy to plan construction or stabilization work. The results also indicate that the material behaves in a reliable and uniform manner as it gains strength.

Table7 Interpretation of R² Values in Regression Analysis

R² Value Range	Interpretation	Description
0 – 0.5	Poor Fit	Model does not explain the data well
0.5 – 0.7	Moderate Fit	Model shows some relationship with the data
0.7 – 0.9	Good Fit	Model explains most of the variation in the data
0.9 – 1.0	Very High Fit	Model fits the data almost perfectly and predictions are highly reliable

5.4.2 Regression Analysis of coated Concrete Cubes

Regression analysis was carried out using Microsoft Excel to study the relationship between exposure time (days) and compressive strength of coated concrete cubes kept under natural environmental conditions. The results show that the strength increases from about 20.2 MPa at 7 days to 24.7 MPa at 14 days and reaches nearly 29.1 MPa at 28 days, indicating a steady improvement over time.

The regression line shows a strong positive relationship between exposure duration and strength gain, confirming that the data follows a consistent trend. This increase in strength is influenced not only by cement hydration but also by the effect of the surface coating. When exposed to the natural environment, the coating enhances CO_2 absorption, leading to carbonation, which forms calcium carbonate and helps in densifying the concrete. As a result, the coated specimens show improved strength with increasing exposure time.

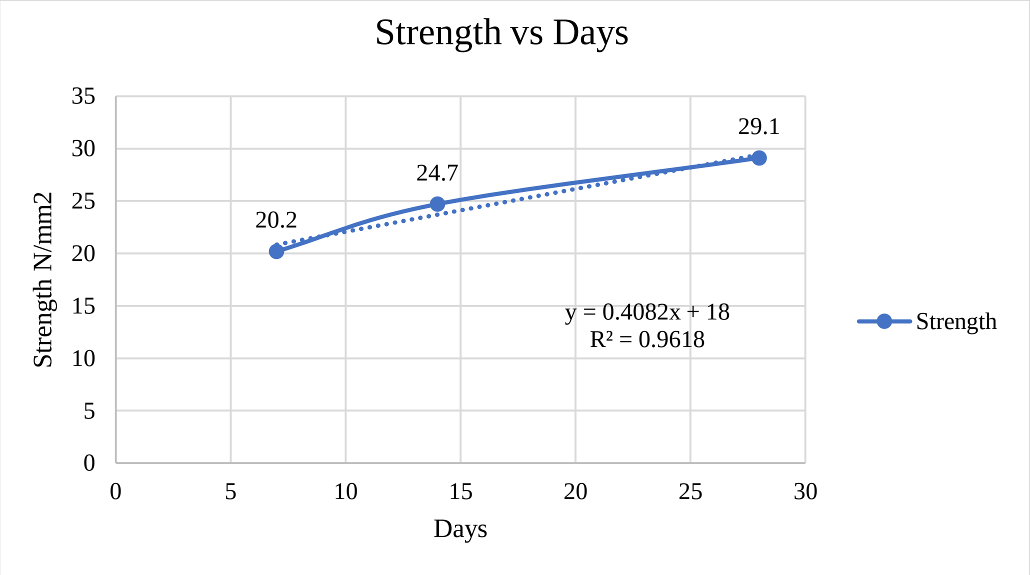


Figure 4 Relationship between exposure days and compressive strength

. The compressive strength of the coated concrete increases from about 20.2 MPa at 7 days to 24.7 MPa at 14 days and reaches nearly 29.1 MPa at 28 days, showing an overall strength gain of approximately 44%. The increase is about 22% between 7 and 14 days and around 18% from 14 to 28 days, indicating a steady and gradual improvement under natural environmental exposure. The linear regression equation $y = 0.4082x + 18$can be used to predict strength at any given day, and the R² value of 0.9618 confirms that the model fits the data very well.

Overall, the strength gain is consistent and predictable, mainly due to continuous hydration along with the coating effect, which enhances carbonation and improves the density and strength of the concrete over time.

5.4.3 Regression Analysis of strengths of cubes

Regression analysis was carried out using Microsoft Excel to study the relationship between the compressive strength of coated and uncoated concrete cubes. The results show that the strength of coated concrete increases proportionally with the strength of uncoated concrete, indicating a clear positive trend.

The fitted regression line shows a strong correlation between coated and uncoated strengths, with an R² value of about 0.99, confirming that the experimental data is consistent and reliable. The coated cubes exhibit higher strength values compared to uncoated cubes, which is mainly due to carbonation, where the formation of calcium carbonate improves the surface density of the concrete.

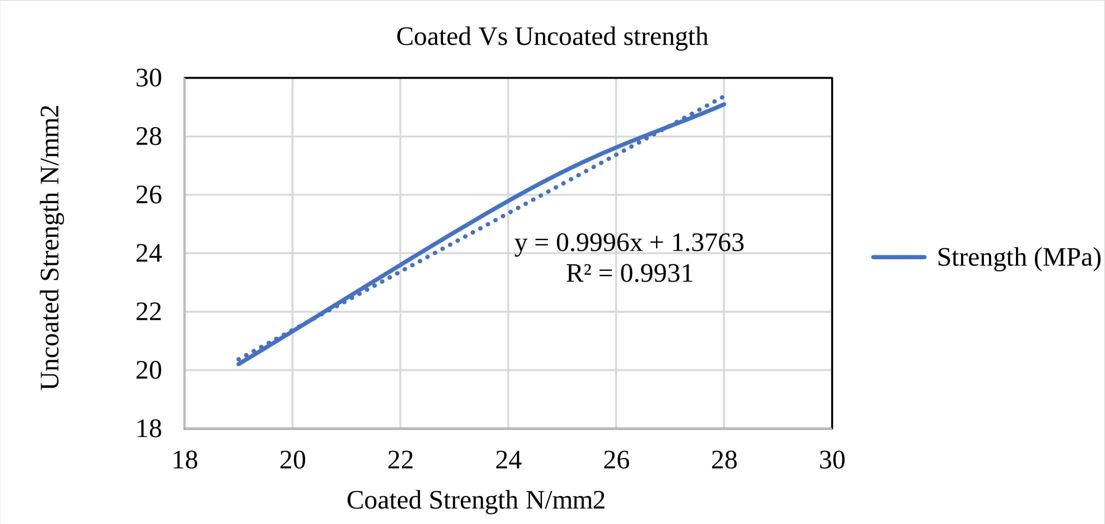


Figure 3 Relation between coated and uncoated strength

Overall, the analysis confirms that there is a strong relationship between coated and uncoated concrete strengths, and the coating significantly enhances the performance of concrete.

The coated and uncoated strengths have an almost 1:1 relationship, with a small base difference of about 5%. The linear equation $y = 0.9996x + 1.3763$ can predict coated strength from uncoated strength, and the R² value of 0.99 shows the model is very accurate and reliable. This means the coating has a consistent effect on strength, and the results can be confidently used for design or quality control purposes. Overall, it shows that the material behaves predictably, making planning and decision-making much easier.

The graphs show that the models are highly reliable. Strength over time (Graph 1) and coated vs uncoated strength (Graph 2) both follow predictable patterns, with R^2 values of 0.9618 and 0.9931, indicating a very strong and almost perfect fit. This means the results can be used confidently for planning, design, and quality control.

5.6 Standard Deviation Analysis

The graph represents the variation of compressive strength with curing time. It can be observed that the strength increases gradually from 7 days to 28 days. The plotted values are distributed around the mean line with slight variation. The standard deviation value of 5.5 indicates a moderate spread of data, showing that the results are fairly consistent. Most of the data points lie close to the mean, confirming that there is no significant fluctuation in the results.

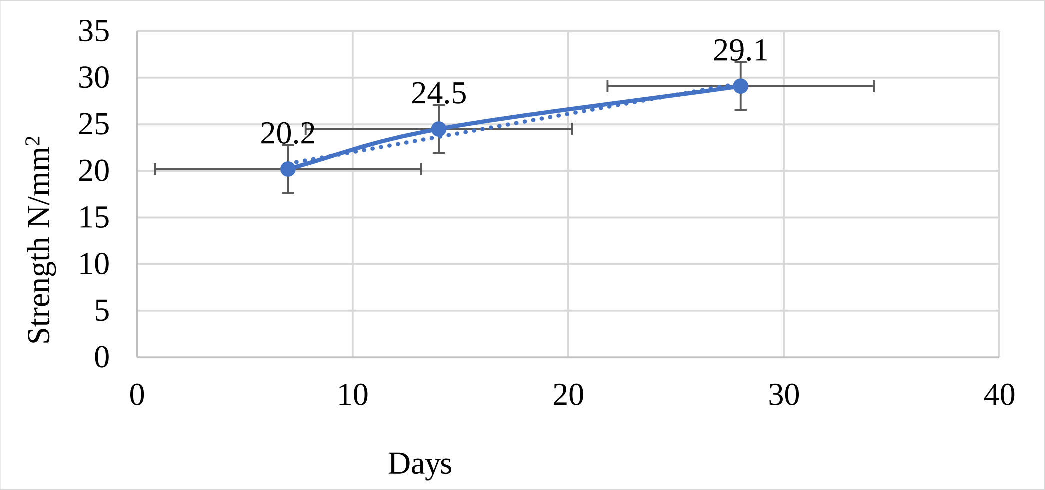


Figure4 Standard Deviation analysis of compressive strength with curing time

Overall, the graph demonstrates a stable trend with acceptable variation, indicating reliable experimental performance.

7. Conclusion

A simple and sustainable CO_2-absorbing surface coating was developed using lime and demolished concrete waste (DCW).

- The results show that the lime–DCW coating enhances surface carbonation under normal atmospheric conditions.
- The coated concrete specimens showed a slight increase in weight, indicating improved CO_2 absorption.
- The compressive strength of coated specimens was higher compared to uncoated specimens.
- The phenolphthalein carbonation test confirmed deeper carbonation on the coated surfaces.
- The developed coating helps capture atmospheric CO_2 while maintaining the strength and performance of concrete.
- The use of demolished concrete waste promotes recycling and reduces construction waste.

Overall, the lime–DCW coating provides a practical, low-cost, and eco-friendly solution for improving CO_2 absorption in concrete structures. This approach also supports sustainable and environmentally friendly construction practices.

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