International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

Self Healing Concrete using Hydrated Lime

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Abstract: The development of self-healing concrete has emerged as a promising solution to enhance the durability and sustainability of concrete structures. Cracking in concrete allows the ingress of water and harmful chemicals, leading to deterioration and increased maintenance costs. This study investigates the effectiveness of lime as a self-healing agent in concrete. Lime possesses the ability to react with moisture and atmospheric carbon dioxide to form calcium carbonate, which fills and seals microcracks naturally. Concrete specimens containing lime were prepared and evaluated for compressive strength, crack-healing capability, and durability performance. The healing efficiency was assessed through visual observations and strength recovery measurements after a specified curing period. The results demonstrated significant crack closure and improved resistance to water penetration compared with conventional concrete. Furthermore, the incorporation of lime contributed to enhanced long-term durability while reducing the need for frequent repairs. The findings indicate that lime-based self-healing concrete offers a cost-effective and environmentally sustainable approach for extending the service life of concrete infrastructure. This technology has considerable potential for application in modern construction projects requiring improved structural performance and reduced maintenance requirements.

Keywords: elf-healing concrete, lime, calcium carbonate, crack healing, durability, sustainable construction, concrete technology.

INTRODUCTION

Concrete is the most commonly used construction material around the world because of its strength, versatility, and low cost. It is used in almost every type of structure such as buildings, bridges, roads, and dams. However, one of the biggest problems with concrete is the development of cracks. These cracks may occur due to drying shrinkage, temperature changes, or heavy loads during its service life. Even small cracks can allow water and harmful chemicals to enter, which leads to corrosion of reinforcement and long-term damage. As a result, the structure becomes weak and its lifespan decreases. Regular maintenance and repair of these cracks require a lot of time, money, and labour. To solve this problem, researchers have developed the concept of self-healing concrete, which can automatically repair cracks without the need for external intervention. The main goal of self-healing concrete is to improve the durability and life span of structures by sealing cracks as soon as they appear. Different materials and techniques have been tried to achieve self-healing, such as bacteria, chemical capsules, and mineral-based additives. However, many of these methods are costly or complex to apply on a large scale.

In this project, hydrated lime (calcium hydroxide) is selected as a simple and natural self-healing material. hydrated Lime has been used in traditional construction for centuries and is known for its ability to react with carbon dioxide and moisture from the air to form calcium carbonate ($CaCO_3$). This reaction naturally fills the cracks in concrete, restoring its density and strength. Using hydrated lime as a self-healing agent is both cost-effective and eco-friendly, as it does not involve any harmful chemicals or expensive technology.

The study of self-healing concrete using hydrated lime aims to provide a practical solution for enhancing the durability of structures while reducing maintenance costs. It also supports the idea of sustainable construction by extending the life of materials and reducing resource wastage. Through this project, an

International Journal of Engineering Research & Technology (IJERT)
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effort is made to understand how hydrated lime can be effectively used to produce self-healing concrete suitable for modern infrastructure needs.

Problem Statement:

Concrete is the most widely used material in construction, but its major limitation is the formation of cracks during its service life. These cracks occur due to shrinkage, temperature variation, and external loading. Even small cracks can allow water, air, and harmful chemicals to penetrate into the structure, leading to corrosion of steel reinforcement and reduction in strength and durability. Regular repair and maintenance of these cracks require significant time, cost, and effort, making them impractical for largescale or inaccessible structures.

Therefore, there is a need to develop a type of concrete that can repair its own cracks automatically and increase its service life. The use of lime as a self-healing agent provides a simple, economical, and environmentally friendly approach. Lime reacts with carbon dioxide and moisture from the atmosphere to form calcium carbonate, which fills and seals the cracks naturally.

Objectives:

- To make concrete using hydrated lime for self-healing purpose.
- To study how hydrated lime helps in filling and sealing cracks.
- To test the strength and durability of self-healing concrete.
- To compare it with normal concrete.
- To develop a simple and eco-friendly method to increase concrete life.

Scope of the Project Work:

- This project focuses on using lime as a self-healing material in concrete.
- The study covers preparation of lime-based concrete samples and testing their strength and healing ability.
- It includes observation of crack healing under normal environmental conditions.
- The work is limited to small laboratory-scale experiments and comparison with normal concrete.
- The results will help to understand how lime can be used in future construction to make concrete more durable and long-lasting.

LITERATURE REVIEW

A. S.S. Karkera, Patrik Gaikwad, Arkaj Lahorkar, Harshwardhan Pathi, Atharva Malkundkar (2015) "*Experimental Investigation on Partial Lime Replacement in Cement."* This study investigated the effect of partially replacing cement with hydrated lime in concrete mixes. The primary objective was to evaluate the influence of lime on the mechanical and durability properties of concrete. Different percentages of lime were used as a replacement for cement, and various tests such as compressive strength, workability, and crack observation were conducted. The researchers observed that a moderate amount of lime improved the hydration process and reduced the formation of micro-cracks within the concrete matrix.

The study highlighted that lime particles act as fillers and contribute to a denser microstructure. During the curing process, calcium hydroxide present in lime reacts with atmospheric carbon dioxide, forming calcium carbonate crystals. These crystals fill small cracks and pores, resulting in improved durability and strength. The researchers concluded that lime can play an important role in enhancing self-healing behavior through carbonation reactions. The findings suggested that partial lime replacement could be an economical and sustainable approach to producing durable concrete with improved crack resistance.

B. O. Yildirim, M. Sabtan, H. A. Hame (2015)

"Influence of Hydrated Lime Addition on the Self-Healing Capability of High-Volume Fly Ash Incorporated Cementitious Composites." This research focused on the self-healing behavior of cementitious composites containing high volumes of fly ash and hydrated lime. The study aimed to determine whether hydrated lime could compensate for the reduced calcium content associated with fly ash-based concrete. Controlled cracks were introduced into specimens, and healing performance was evaluated under moist curing conditions.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

The results demonstrated that hydrated lime significantly improved crack closure and mechanical recovery. Lime provided an additional source of calcium ions that facilitated the formation of calcium carbonate deposits inside cracks. These deposits effectively reduced crack width and improved water tightness. The study further showed that healed specimens regained a considerable portion of their original strength. The researchers concluded that hydrated lime enhances autogenous healing mechanisms and improves the long-term durability of fly ash concrete. The study emphasized the importance of lime in promoting sustainable and self-healing construction materials.

C. Huda Shafiq (2018)

"Experimental Study on Lime–Cement Composite Self-Healing." The objective of this research was to investigate the self-healing potential of lime-cement composite materials. Different proportions of lime were incorporated into cementitious mixes, and specimens were subjected to controlled cracking followed by wet-dry curing cycles. The healing process was monitored through visual inspection, permeability tests, and mechanical strength evaluation.

The findings revealed that lime significantly enhanced crack closure and reduced water permeability. The repeated wetting and drying cycles promoted carbonation reactions, resulting in the formation of calcium carbonate within cracks. This process improved the impermeability and durability of the composite material. The study also reported better resistance against environmental deterioration compared to conventional cement mortar. The author concluded that lime-cement composites exhibit effective self-healing behavior and can be used in structures where crack control and durability are critical requirements. The research established the potential of lime as an economical self-healing additive.

D. Arijita Biswas, Amit Goel, Sandeep Poonia (2020)

"Case Studies on the Use of Lime and Mineral Additives for Autogenous Healing in Concrete." This study presented several case studies examining the influence of lime and mineral additives on autogenous healing in concrete. The researchers analyzed the ability of concrete to heal naturally through ongoing hydration and carbonation reactions. Different combinations of lime and supplementary cementitious materials were evaluated.

The investigation showed that lime enhances autogenous healing by supplying additional calcium compounds that participate in secondary hydration and carbonation processes. Surface cracks were observed to close gradually over time, reducing permeability and improving durability. The presence of lime also increased the efficiency of mineral additives by accelerating the formation of healing products. The authors concluded that lime is an effective additive for improving natural healing mechanisms in concrete. The study highlighted the potential for reducing maintenance costs and extending service life through the use of lime-enhanced concrete mixtures.

Summary

Across all studies (2015–2024), lime consistently proves to be an effective self-healing material in concrete and mortars. It promotes calcium carbonate formation, fills microcracks, and restores strength and water resistance. The research trend moves from basic experimental observation to advanced simulation models, reinforcing lime's value in sustainable concrete development.

METHODOLOGY

General:

This project is about studying self-healing concrete made by adding hydrated lime to normal M30 grade concrete. The main idea behind self-healing concrete is to make concrete that can repair small cracks on its own without the need for human repair. In normal concrete, cracks allow water and air to enter, which causes corrosion of steel and reduces the life of the structure. Using lime in concrete helps seal these small cracks naturally over time.

Hydrated lime [$Ca(OH)_2$] reacts with carbon dioxide (CO_2) from the air and forms calcium carbonate ($CaCO_3$), which fills the cracks and blocks the entry of water. This makes the concrete more durable and long-lasting. The project aims to check how different amounts of lime (6.5% and 9% of cement weight) affect the strength and healing ability of concrete.

International Journal of Engineering Research & Technology (IJERT)
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In this work, we will prepare different mixes, cast and cure concrete specimens, create small cracks in them, and then observe how the cracks heal over a certain period. Later, tests like compressive strength and water permeability will be done to compare results. The overall goal is to find an eco-friendly, low-cost method to improve concrete's life and reduce repair costs.

This study will help in understanding how hydrated lime can be used in modern construction as a simple and natural self-healing material. It also supports sustainable construction practices by using traditional lime-based materials with new techniques.

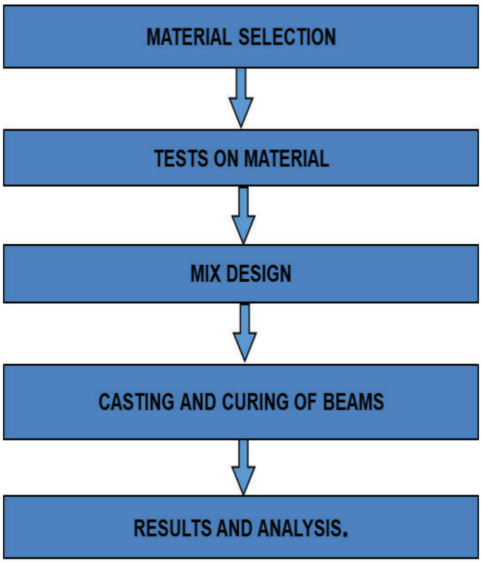

Figure 1: Flowchart of study

Material Selection and Characterization

Choosing the right materials is very important for getting good and consistent results. For this project, we will use Ordinary Portland Cement (OPC) 53 grade as per IS 12269. Hydrated lime ($Ca(OH)_2$) is used as the self-healing material. Lime should be of good purity and fine enough to mix properly with cement.

Fine aggregates will be river sand passing through a 4.75 mm sieve and conforming to IS 383. Coarse aggregates of 20 mm and 10 mm size will be used in a ratio of 60:40 for better packing. All aggregates will be tested for specific gravity, water absorption, impact value, and sieve analysis before use. The water used for mixing and curing will be clean and free from harmful salts (normal

tap water is acceptable).

Hydrated Lime

Hydrated lime is a dry, white, powdery material chemically known as calcium hydroxide ($Ca(OH)_2$). It is produced by adding a controlled amount of water to quicklime (calcium oxide), a process known as hydration or slaking.

Hydrated lime, also called slaked lime or calcium hydroxide, is one of the oldest building materials used by humans. Chemically it is written as $Ca(OH)_2$. While cement dominates modern construction, hydrated lime still plays a critical role in mortar, plaster, soil stabilization, and environmental applications because of its unique chemical behaviour.

Advantages:

- Improves workability and water retention of mortar.
- Increases durability by reducing cracking and improving bond with bricks.
- Has natural antibacterial properties due to high pH.
- Allows moisture movement, making it ideal for old buildings.
- Lower embodied carbon than cement because calcination temperature is similar but it re-absorbs CO_2 during carbonation over its life.

Limitations:

- Slow strength gain. Carbonation depends on CO_2 and moisture, so it takes months to years.
- Not suitable for fast-track projects.
- Low compressive strength compared to cement.
- Pure lime mortar gives only 1-3 MPa after 28 days.
- Needs protection from rain during curing because excess water washes out uncarbonated lime.

Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

Figure 2: Hydrated Lime

Before casting, we will check the slump and compaction factor to ensure all mixes have similar workability. If any batch shows segregation or bleeding, water or admixture quantity is slightly adjusted. This stage is very important because the correctness of mix proportions directly affects the test results.

Once the mix is finalized, it will be used to prepare the specimens for testing. This process ensures that comparisons between normal and lime-based concrete are fair and accurate.

Cement

Cement is one of the important key ingredients used to make concrete which behave as a binding material which have both cohesive and adhesive properties. It is manufactured by using clinkers which is pulverized by utilizing raw materials like silica, alumina, calcium oxide, ferric oxide combined with some other oxides. These Portland cement contains four main components such as tricalcium silicate (3CaO. SiO2), dicalcium silicate (2CaO. SiO2), tricalcium aluminate (3CaO. Al2O3), tetra calcium alumin of errite (4CaO. Al2O3Fe2O3). The properties of these main components were affected due to the proportion of raw materials and oxides. These affect the behaviour of the Portland cement which classifies it into different types. This various type of Portland cement are effectively used in various requirements and conditions of the structures.

Figure 3: Cement

PROPERTIES	RESULTS
Specific gravity	3.15
Consistency	33%
Initial Setting Time	32 min
Final Settling Time	605 min
Fineness	92%

Fine Aggregate

Fine aggregate is the widely used in the construction field, this material is granular which is used to manufacture mortar or concrete. The aggregates are fine when it passes through a 4.75 mm sieve. The fine aggregate that is used in concrete is either natural sand or crushed stone. The density and quality of the fine aggregate affect the hardened properties of the concrete. If the selection of the fine aggregate is based on the particle shape, skid resistance, surface moisture, absorption, abrasion, surface texture and grading zone then the concrete which are made up of that fine aggregate will be stronger, durable and cheaper.

Figure 4: Fine Aggregate

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

PROPERTIES	RESULT
Particle size	4.75 mm
Silt content	1.67%
Specific gravity	2.89
Bulk density	1515 kg/m3
Water absorption	1.45

Coarse Aggregate

Coarse aggregate is one of the important materials and widely used as building material in construction industries. It is the key component in concrete and gains volume to the concrete. It is chemically inactive and serves as the filler material and gives strength to the concrete which will provide a homogeneous mass of the concrete The aggregate sized more than 4.75 mm are meant to be coarse aggregate. The natural rocks are crushed to form the coarse aggregates. The rocks can be sedimentary, igneous or metamorphic.

The igneous rocks are strong, dense and fine grained which is gained by cooling down the parts of the molten materials which is commonly called as igneous rocks. These rocks are crushed to form the aggregate which are black in colour and mainly used for works done by concrete and it is known to be black trap. Sedimentary rocks are deposited ages ago gained through the wind, water and ice action and it is also known as derivative rocks. Three quarters of the earth's land surface are covered by these rocks. One of the rocks used for concrete production is sandstone which is durable and hard and it will be available in the form of strips which is used in slab construction. The metamorphic rocks are formed by both igneous and sedimentary rocks. It transforms from the existing rocks to the new rocks due to heat and pressure causing chemical and physical changes.

Fig 5: Coarse Aggregate

Water

Water is one of the main ingredients in preparing concrete, when the water is mixed with the cement it forms a paste which helps the aggregates to bind together. Hydration is the process which causes the hardening of the concrete by using water. In this hydration process the chemical reaction formed between the compounds in cements and water molecules to become hydrates. The water used in the concrete should be pure so that it would not affect the concrete to weaken or else it will interfere with the process of hydration. The water plays the important role because the most critical factor in concrete is water to cement ratio to produce the best concrete. If too much water is mixed in the concrete, then it leads to the reduction of concrete strength and if too little water is mixed in the concrete, then it leads to the unworkable of the concrete. The concrete should be workable so that it can molded in to different shapes. Due to this reason the careful consideration in water to cement ratio is required while manufacturing concrete.

Experimental Test

Some important material tests include:

- Cement: consistency, setting time, and specific gravity
- Lime: fineness and purity
- Aggregates: sieve analysis and specific gravity

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

The mix design is done as per IS 10262:2019 and IS 456:2000 for M30 grade concrete, which means the target strength is 35 MPa. The water–cement ratio is kept around 0.45. First, a control mix (without lime) is prepared. Then three trial mixes are made by replacing cement with 6.5% and 9% hydrated lime.

Superplasticizer (around 0.5–1% of cement weight) can be added to maintain workability because lime increases water demand slightly. The mix should have a slump of 75–100 mm for easy placing.

These tests are done to make sure that all the materials are of good quality and suitable for concrete. The results help ensure that the mix behaves consistently and gives accurate comparisons when lime is added. Proper material selection and testing form the base of the whole experimental work.

Slump Cone Test

Slump cone test on concrete is to find out the workability which is a property of the fresh concrete.

Workability is the property of the fresh concrete which means it is easy to place and the workable

concrete is the concrete which shall be placed and compacted with ease and without any segregation. Workability is the capable of working without any extra labour and strength loss. The

concrete strength depends upon the water percentage. Water percentage and slump are taken from this slump test. It is the vertical height of the fresh concrete compared to its mould height. The workability is determined by using slump cone test in fresh concrete. The code book IS: 1199 1959

is referred.

Apparatus required

- slump cone
- tamping rod
- metallic sheet

Figure 6: Slump Cone Test

Mix design of Concrete:

- **Design Parameters**

Parameter	Value
Grade of Concrete	M30
Type of Cement	OPC 53 Grade
Maximum Nominal Size of Aggregate	20 mm
Specific Gravity of Cement	3.15
Specific Gravity of Lime	2.24
Specific Gravity of Fine Aggregate	2.89
Specific Gravity of Coarse Aggregate	2.91
Water Absorption (FA)	1%
Water Absorption (CA)	0.5%

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

Workability (Slump)	75–100 mm
Exposure Condition	Moderate
Method of Mixing	Machine Mixing

- **Target Mean Strength:**

fck' = fck + 1.65 × S = 35 + 1.65 × 5 = 43.25 Mpa

- **Water Cement Ratio:**

For M30 = 0.43 (16pprox.)

- **Water Content:**

For 20 mm aggregate and 75 mm slump: 186 L

For machine mixing and plasticizer use (reduce by 10%): 186 × 0.9 = 167 L

- **Cementitious Material Content:**

Cementitious material = 167 / 0.40 = 417.5 kg/m³

Cement = 0.9 × 417.5 = 376 kg/m³

Lime = 0.1 × 417.5 = 42 kg/m³

- **Aggregate Proportioning:**

From IS 10262 for 20 mm aggregate and Zone II sand:

Volume of coarse aggregate = 0.62

Volume of fine aggregate = 0.38

- **Mix Calculations (per 1m^3concrete)**

Volume of cementitious materials = 0.135 m³

Volume of water = 0.167 m³

Volume of air = 0.02 m³

Volume of aggregates = 0.678 m³

Coarse aggregate = 1137 kg/m³

Fine aggregate = 682 kg/m³

- **Final Mix Proportion (by weight):**

Material	9 Cube (kg) (M30)	9 Cube (kg) (M30 add 6.5%lime)	9 Cube (kg) (M30 add 9%lime)
Lime	0	0.75	1.02
Cement	10.64	10.65	10.38
Fine Aggregate (Sand)	11.78	12.55	12.53
Coarse Aggregate	18.71	19.93	19.90
Water content	5.63	6.03	6.03
w/c ratio	0.45		

- **Notes on lime for Self-healing:**

• Lime (Ca (OH)3) promotes autogenous healing by forming calcium carbonate crystals when reacting with CO3.

• Maintain moist curing for at least 14 days to enhance self-healing.

• You can add bacteria or crystalline admixtures for advanced self-healing versions.

Specimen Casting and Curing

After preparing the mixes, the next step is to cast the concrete specimens. The materials are weighed accurately and mixed in a drum mixer for 3–5 minutes to get a uniform mix.

The mix is then poured into clean and oiled steel Molds of standard sizes — cubes (150×150×150 mm)

Figure 7: Casting of the concrete and curing

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

Concrete is filled in layers, and each layer is compacted using a tamping rod or vibration to remove air voids. The surface is leveled and smoothed properly. After casting, the specimens are covered with wet gunny bags to prevent moisture loss.

After 24 hours, the specimens are demoulded carefully and placed in a curing tank with clean water at 27 ± 2°C. They are cured for 7, 14, and 28 days. Proper curing is necessary for the concrete to gain strength and for the hydration process to complete.

Curing also ensures that the concrete develops a dense structure. Lime remains dormant initially but plays a major role when cracks develop later. Proper curing gives a fair base condition before testing the self-healing behaviour.

Inducing Controlled Cracks

After curing the concrete specimens for 28 days, we will take them out from the curing tank and dry them properly before testing. To study self-healing behaviour, we will create small and controlled cracks in the samples. This will be done using a compression testing machine or a flexural testing setup. The specimens will be loaded gradually up to around 70–80% of their ultimate load so that fine cracks are formed, but the specimen does not fail completely.

For beams, a three-point bending test will be used to produce surface cracks, while cubes and cylinders will be cracked under compressive load. The width of the cracks is expected to be between 0.1 mm and 0.3 mm, which represents real-life conditions of microcracking in structures.

The crack width will be measured using a crack detection microscope or magnifier, and all details such as specimen ID, crack location, and width will be recorded carefully. After cracking, the samples will be stored safely to prevent additional cracking. This step will simulate the kind of damage that might happen in actual concrete structures and prepare the specimens for the healing phase.

Self-Healing Observation Period

Once the cracks are developed, the specimens will be kept under conditions that allow natural healing to occur. They will be placed in a moist environment or under alternate wet and dry cycles for a period of 7, 14, and 28 days. These conditions are selected to promote the reaction of hydrated lime with water and carbon dioxide in the air, which forms calcium carbonate ($CaCO_3$) that helps fill up the cracks.

During this observation period, we will record changes in the crack width and surface appearance at regular intervals. The specimens will be partially immersed in water or kept in a humid chamber to simulate realistic environmental exposure. After 7 days, 14 days, and 28 days, and more days to healing each specimen will be inspected visually and using a crack microscope.

We expect that a white crystalline substance will start forming inside the cracks after the first week, indicating calcium carbonate deposition. This process is expected to continue gradually until most of the smaller cracks are sealed by the end of the observation period. All findings will be recorded with photographs and notes for later comparison with strength results.

Testing and Evaluation

After the healing period, we will perform various tests to check the improvement in strength and durability due to the self-healing process. The following tests will be carried out as per IS codes:

- Compressive Strength Test on cube specimens (IS 516)
- Water Permeability and Sorptivity Tests to evaluate the reduction in water absorption and flow through cracks We will compare the results of lime-based concrete with those of the control mix (without lime). The aim is to determine how much strength is regained after healing and how effectively lime reduces permeability.

We expect that the 10% lime mix will show the best performance with noticeable crack sealing and moderate strength improvement.

The test results will help us confirm whether lime truly enhances self-healing and improves the long-term performance of M30 grade concrete.

RESULTS AND DISCUSSIONS

Ultrasonic Pulse Velocity Test

The objective of the Ultrasonic Pulse Velocity test is to determine the quality, homogeneity, and crack healing performance of self-healing concrete containing lime. Ultrasonic Pulse Velocity test is a **non-destructive**

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

test (NDT) used to check the quality, uniformity, cracks, and internal condition of concrete.

Ultrasonic Pulse Velocity test works on the principle that the velocity of ultrasonic waves passing through concrete depends upon its density and elastic properties. Good quality concrete allows faster transmission of waves, whereas cracked or damaged concrete reduces pulse velocity. In self-healing concrete, improvement in UPV value after healing indicates crack repair and densification due to lime reaction.

In this test:

- An ultrasonic pulse is sent through concrete.
- The time taken by the pulse to travel is measured.
- Velocity is calculated.

Procedure Format

1. Concrete specimens were cured for 28 days.
2. Artificial cracks were developed in specimens.
3. Transducers were placed on opposite sides of the cube.
4. Coupling gel was applied for proper transmission.
5. Pulse travel time was recorded.
6. Velocity was calculated using:

$$V = \frac{L}{T}$$

Where:

- **V** = Pulse velocity (km/s or m/s)
- **L** = Path length between transducers (m)
- **T** = Time taken by pulse (seconds)

Sr. No.	ID Mark	Time (µs)	Velocity (km/s)
1	6.5% Cement Replace	70.1	2.14
2	9% Cement Replace	40.0	3.75
3	6.5% Cement Replace	37.9	3.96
4	9% Cement Replace	48.5	3.09

*Test conducted on 13/05/26

Sr. No.	ID Mark	Time (µs)	Velocity (km/s)
1	6.5% Cement Replace	60.6	2.48
2	9% Cement Replace	36.2	4.14
3	6.5% Cement Replace	30.9	4.85
4	9% Cement Replace	34.8	4.31

*Test conducted on 13/05/26

Figure 8: Ultrasonic Pulse Velocity Test

Compressive Strength Test

Compressive strength is the ability of a material to resist compressive (pushing) forces without failure. It tells how much load a material can bear before crushing.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

Figure 9: Test on cube

Compression Strength Test on concrete cube

- Totally 18 concrete cube specimens of M30 grade and of size 150 mm x 150mm X 150 mm were casted and cured for 7days & 28 days then the test is conducted using compressive testing machine.
- The concrete cube specimens were dried before placing it in the space between bearing surfaces and it was aligned properly with the centre of thrust in the testing machine plates.
- When the load was applied constantly on the concrete cube specimens, it started to crack and finally, the breakdown of the concrete cube specimen was noted.

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