Properties of Air Lime Mortar with Bio-Additives

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Abstract: Lime mortar has been a primary binding material in ancient mortar, and is one of the main reasons behind solid and stable constructions that remain stable even after thousands of years. The benefits of lime are innumerable: it is minimally processed and used with a lesser carbon footprint and embodied energy and, most crucially, it is a carbon absorbent. This research experiments with the strength properties (compression) of lime at 28, 56, and 100 days of air curing. The investigation studies the durability using water absorption, UPV test, and carbonation parameters after 100 days of exposure to air. The tested materials are subjected to SEM analysis to find the morphology of the reaction that takes place and the products that are formed. We also performed a comparative study of two different fermented additives by the duration of fermentation (1 day and 10 days) and two different doses of additives (Jaggery and Kadukkai) with air lime. The bio-additives were experimented with using gas chromatography and mass spectroscopy for the formation of new enriching compounds, which improved the qualities of traditional lime mortar. The formation of fat and protein in the additives was found using IS 7219-1973 (a method for the determination of protein in foods and feeds). Using the AOAC method, the presence of fat confirms the improvement in strength and durability properties. The phytochemical analysis details the alkaloids, terpenoids, steroids, phenols, flavonoids, tannins, glycosides, and saponins. Quantification of phenols and flavonoids adds to the beneficial aspects of the fermented additives. The experimental results indicate that using naturally fermented organic materials in the lime has made the structures stronger with the stable build of calcite and vaterite components. The self-healing capacity of lime mortar makes it time resistant.

Keywords: air lime; fermentation; compressive strength; carbonation; water absorption; UPV; mass spectroscopy

1. Introduction

Lime mortar construction is the most primitive initiative in the construction industry. The basic source of lime is the naturally occurring limestone resource in nature. With various trials and additives, our ancestors made numerous successful and stable structures with no reinforcement, which have stayed magnificent and grand until today. The introduction of lime mortar dates from 6500 BC in the Indus Valley region (now Pakistan) and later in Egypt on pyramids around 2500 BC. In addition, many mention its widespread use in the Roman Empire, which developed a way to make the whole process more convenient. Traditionally, mortars contain only lime and sand. They need carbon dioxide to harden into limestone [1]. As it ages, the more strength it gains. The Romans were the first to develop hydraulic mortars, used to mix lime with pozzolana of either volcanic ash or brick dust. The mixture hardens much faster and allows for its use in waterborne structures, heritage structures, and domestic purposes. In pyramid constructions, the Egyptians utilized limestones that were burnt and mixed with water to form plasters. The Pyramids of Egypt and the Great Wall of China are some of the living [2] examples of lime constructions...
with natural additives. These time-resistant constructions are located, maintained, and sustained throughout the world today as monuments [3].

This significant binder material is composed of hardened calcium carbonate heated to form calcium oxide, calcined locally by sprinkling water (hydration takes place). This calcined calcium carbonate is utilized in all construction works in its flexible form; it reacts with the carbon dioxide in the environment to form stable calcium carbonate, which has been doing wonders in the initial construction era [3]. Lime is available majorly in two natural forms; lime from Earth, through years of sedimentation of minerals commonly known as sedimentary rocks, and from seashells. The limestones are processed in limekilns for further use in the field, whereas the seashells are powdered by the mass grinding process to bring them into their usable form. Lime from the sedimentary rock is further classified into hydraulic lime, semi-hydraulic lime, fat lime, and magnesium/dolomitic lime [4]. Each type is used for various purposes, hydraulic lime plays a major role in the construction, whereas others are used for plastering, whitewashing, etc. [5]. In the purest form, containing a high percentage of calcium oxide, the air lime proves to be the best form of lime for its durability properties [6–8].

Carbon dioxide, present in the atmosphere, plays a vital role in the strengthening process of the lime mortar, which is one of the most beneficial aspects in today’s scenario of an over-polluted environment because of massive industrialization and a population that leads to the need for more buildings for the living (Figure 1). These buildings are concrete forests that cause deforestation and over-extraction of resources in and around the environment [9]. The need for building materials that capture CO$_2$, SO$_2$, and other greenhouse gases brings in a huge scope in this research area [2,10]. Carbon dioxide emissions by the increasing population and massive industrialization are to be keenly watched since they are highly responsible for the “climate change” happening right now, which is a long-term change in the usual seasons that becomes unpredictable due to dynamic changes. Unpredictability leads to various disasters that cause huge losses economically and are highly fatal [11]. The primary reason for this outbreak is due to high greenhouse gas emissions into the atmosphere by all the industrial sectors, giving rise to global warming [12].

![Figure 1](image-url) (a) Carbon dioxide emission in the environment, (b) the lime cycle.

Traditional buildings made of lime also need periodic maintenance with compatible materials in repair works; incompatible materials will always cause accelerated deterioration of the structure [13].

As can be seen in various researches and manuscripts maintained in the oldest temples on construction methods and ingredients [14], using natural additives from the most available raw materials like vegetables and fruit extracts was very common [15]. These additives were usually locally and abundantly available materials in any area. Using locally available materials in these structures promoted eco-friendly constructions, commonly known as vernacular constructions. The use of the fermentation process makes a massive
difference in improving the properties of lime mortar compared to conventional lime mortar [16].

References [17,18] stated that vernacular constructions have preserved our ancient techniques of making the structure strong, durable, and maintaining the temperature according to the season [19]. Hence, using these extracts in the repair material becomes essential to produce a compatible material [20]. The environmental conditions around the structure should be studied in detail to find the sources of deterioration accelerators for perfect repair material [20]. Mortar, an essential binding matrix to hold on to a stable structure, aesthetic in appearance, and durable, needs to be made with a lot of trials with different extracts to give the best matching matrix for the ancient structure. The strength achievement, durability properties, and porosity of the lime mortar makes it highly a breathable material that lets air pass through it [21]. Hence, it eliminates the accumulation of any distress-causing agents inside the structure, making it an excellent solution to the problem of moisture, as it absorbs and releases water, reducing the chance of water being trapped and damaging the building.

This research concentrates on using bio-additives in their fermented form with two different doses and two different durations of fermentation additives with the comparison of conventional lime mortar for its strength and durability properties. The need for the process of fermentation of bio-additives can be seen from the strength and durability study to improve the use of this ancient process.

2. Materials and Methods

The experimental work was conducted as per IS codes and standard norms. The methodology was performed as a simulation of the mortar-making process from the site of the renovation works of ancient temples. Materials included fine aggregates and raw lime, which were further processed by sprinkling water, commonly known as slacking of lime. The reactive quick lime reacts with water to give alkaline lime material that can be used as construction material. The extract preparation for the bio-additive was prepared as seen in the site of renovation works of ancient structures.

2.1. Materials

2.1.1. Fine Aggregate

From the beginning of the construction era till now, river sand has been employed as a significant filling material, making a mortar matrix blend to form a homogenous matrix. Table 1 shows the results of basic experiments on fine aggregate to determine their qualities to improve their incorporation into the lime matrix. By enhancing the porous nature of the hardened mortar, fine aggregate plays a vital role in determining strength. The fine aggregates were sieved using 2.36 µ in size (as per the IS standards) in lime mortar making.

Table 1. Property of fine aggregate.

| Property       | Test Result | IS Codes                                           |
|----------------|-------------|----------------------------------------------------|
| Fineness modulus | 2.592       | IS: 2386 (Part I)–1963 [22]                        |
| Grading zone    | Zone II     | IS codes (IS: 383-1970) [23]                       |
| Specific gravity| 2.55         | IS 2386(Part-III): 1963 [24]                       |

2.1.2. Lime

Lime, being the preliminary binding material, was procured from the lime kilns of the Pollachi region, which provides lime for almost all of the ancient temple’s renovation work handled by the Hindu religious and charitable endowments, due to its high quality. The presence of percentage of calcium oxide was tested as per IS 712-1910 0 for its calcium oxide presence, and it was above 60%, fulfilling the standards for the hydraulic lime category. The maximum limit as per BIS 712 (BIS 1984) for air lime (%) is 60%, hence, from the results, the purity of lime utilized is seen and is known to be air lime. The XRF results of lime are mentioned in Table 2.
Table 2. XRF composition of lime powder.

| Constituents | % of Presence |
|--------------|---------------|
| MgO          | 2.3           |
| SiO₂         | 5.78          |
| CaO          | 60.22         |
| Al₂O₃        | 1.76          |
| Fe₂O₃        | 1.349         |
| Sulphur      | 0.37          |
| Potassium    | 0.21          |

The type of lime was identified using the formula given by Taylor and Eickel [25,26] from the CI (cementation index) and HI (hydraulic index), which indicated air lime with impurities. Air lime mortar is the most compatible form of the lime mortar used in ancient constructions; it is also known as hot lime mortar since a huge amount of heat energy is emitted when lime comes in contact with water.

2.1.3. Extract Preparation

The use of extract has been seen from ancient times and has resulted in highly efficient structures [27]. The use of organic materials from plants and animals is most common worldwide. It has been proved in many types of research for its enhancing property role in lime mortar [28,29]. The extract was made using Kadukkai (Terminalia chebula) and jaggery as the main ingredient. It is hand pounded and soaked in water for 10 days (fermented), filtered, and used in a fermented form, similar to ancient time construction practices. Fermentation is a natural process of breakdown of complex organic sugar particles into simpler particles—sugar particles—that leads to the formation of new products. Traditionally, in almost all temple renovation works the fermentation process of additives is done before being used in the construction material.

2.1.4. Mortar Preparation

The mortar was prepared as per IS codes satisfied by the materials [30–33] in a mold of size 40 mm × 40 mm × 40 mm [34] for the measurement of compression strength. The mortar mix ratio was taken as 1:1, 1:2, and 1:3, since these were the ratios used in the site of ancient renovation works for various structural components. The mix was done by weight batching process. Table 3 above and Table 4 below give the details of various lime mortar mixes used in this research work, showing a comparative study between conventional lime mortar. Fermented additives with two doses and two different fermentation times have been used in the lime mortar. The water lime ratio was calculated by a number of trials with a flow table test (IS:6932: Part 9 1973) by maintaining the flow diameter to 110 cm as per the IS standards.

The process of mortar making was done as prepared in the renovation work sites of Tamil Nadu, using a grinder to give a homogenous mixture of lime mortar. The grinding process plays a vital role in improving the quality of the lime mortar by crushing the lime to finer particles and blending it with the fine aggregates. Figure 2 below gives a pictorial representation of the mortar-making process.

The process of grinding enhances the breakdown of unbroken lime particles into finer particles, giving a combined homogenous binding material.

2.2. Mechanical Evaluation (Compressive Strength)

The compressive strength was evaluated in a UTM made by Hounsfield model number S-0154-50KN from the Chemistry department of College of Engineering Guindy, Anna University Chennai was used for the measurement of compressive strength of the specimen with a size of 40 mm × 40 mm × 40 mm.
| Ratio | Mortar Mix Name | Mortar Details          | Extract Details | Fermentation Period |
|-------|-----------------|-------------------------|----------------|--------------------|
| 1:1   | LMA             | Conventional lime mortar| Only water      | -                  |
| 1:2   | LMB             |                         |                |                    |
| 1:3   | LMC             |                         |                |                    |
| 1:1   | FLM-1-D         | 1-day fermented dose 1  | Dose 1: 25 gm Jaggery and 25 gm of kadukkai for 1 L of water | 1 day |
| 1:2   | FLM-1-E         | 1-day fermented dose 2  | Dose 2: 50 gm Jaggery and 50 gm kadukkai for 1 L of water | 1 day |
| 1:3   | FLM-1-F         |                          |                |                    |
| 1:1   | FLM-2-D         |                          |                |                    |
| 1:2   | FLM-2-E         |                          |                |                    |
| 1:3   | FLM-2-F         |                          |                |                    |
| 1:1   | FLM-1-G         | 10-day fermented dose 1 | Dose 1: 25 gm Jaggery and 25 gm of kadukkai for 1 L of water | 10 days |
| 1:2   | FLM-1-H         | 10-day fermented dose 2 | Dose 2: 50 gm Jaggery and 50 gm kadukkai for 1 L of water | 10 days |

2.3. Durability of Mortar

A structure that can withstand all-natural calamities and external forces in such a way that it sustains over time without deteriorating or losing its stability, is known as the durable character of construction material. Various additives are being used to improve the qualities of the construction materials. Ancient construction materials are the most durable construction materials, as we see many 1000 years old wonders that stand magnificent till today with minimal maintenance. The lime mortar that is studied with various additives has undergone two mandatory durability tests after 100 days of natural exposure to the environment.

2.3.1. Carbonation (Phenolphthalein Indicator Test)

Carbonation is a spontaneous and natural process of carbon dioxide present in the air with the components of construction material of all kinds of structures. In the case of lime mortar, the carbonation process plays a vital role in improving its strength and durability properties. The carbonation depth of the specimen is measured by using an indicator solution of 0.2% of phenolphthalein indicator sprayed on the broken piece internal surface of the specimen, following the codes DIN EN 13295:2004-08 (Products and Systems for the Protection and Repair of Concrete Structures, Test Methods and Determination of Resistance to Carbonation, 2004) [1,36].
Figure 2. The process of mortar making. (a) Fine aggregate in the grinder. (b) Fermenting the bio-additives (kadukkai and jaggery hand pounded and tied in a cloth, soaked in water to give the extract). (c) The fermented bio-additives were added into the mortar mix and ground using a grinder to give a (d) homogenous mixture by a uniform combination of lime and fine aggregate. (e) Cast into cube specimens.

2.3.2. Water Absorption

A high percentage of water absorption indicates the presence of voids in a mortar. The water absorption test was performed to study the durability of mortar in water as per ASTM C 642-06 (Standard Test Method for 31 Density, Absorption, and Voids in Hardened Concrete). The lime mortar samples of cube size 70 × 70 × 70 mm were used for the durability study.

\[
\text{The % Water absorption} = \left(\frac{W_2 - W_1}{W_1}\right) \times 100,
\]

where \(W_1\) = Oven dry weight of cubes in grams \(W_2\) = After 24 h wet weight of cubes in grams.

2.3.3. Ultrasonic Pulse Velocity Test

The UPV test is a non-destructive test used to find the quality of the concrete used in this study for the porosity of mortar. As per IS 13311 (Part I; 1992), the ultrasonic pulse velocity test was done to find the porosity of the mortar, with the natural frequency of the transducer as 150 kHz as per the IS standards. The transducer produces the pulse of vibrations on one side of the sample, the other transducer converts it into electrical signals that reach the electronic circuit system that calculates the time traveled by the signals to reach the other side. The time travel is calculated by (Pulse Velocity) \(V = \frac{L}{T}\), where \(L\) is the length of the specimen and \(T\) is the time taken to travel.

The UPV test setup is as shown in Figure 3, where we find the homogeneity and quality of the mortar specimen [37]. From the IS-516 (Part 5/Sec 1): 2018 “Part 5 Non-Destructive Testing of Concrete-Section 1 Ultrasonic Pulse Velocity Testing” the quality of the mortar is better when added with fermented bio-additives compared to the non-fermented and conventional lime mortar.
3. Mineralogical Characterization of Lime Mortar—SEM Analysis

A mineralogical characterization study was done to find the mineral composition and mineral structure of the lime mortar matrix with various additives and combinations. The mineralogical formation was identified and studied with the research done on lime mortar [38–44]. The SEM analysis was performed using a VEGA3 TESCAN microscope to study the microstructural properties of the source materials and concrete specimens at the Centre for Nanoscience and Technology, Anna University.

4. Study on Bio-Additives and Its Composition

The study on bio-additives in their fermented and non-fermented form was analyzed using the following methods in Table 5.

Table 5. Tests for the composition.

| S. No | Parameters | Method                        |
|-------|------------|-------------------------------|
| 1     | Proteins   | IS 7219-1973 [45]             |
| 2     | Fat        | AOAC METHOD                   |
| 3     | Ethanol    | Gas chromatography            |

5. Results and Discussion

5.1. Strength Properties

The 40 mm × 40 mm × 40 mm cube specimens of age 28, 56, and 100 days of exposure to the environment were tested for compression. It is seen from the graph in Figure 4 that there is a gradual increase in the strength of the lime mortar samples. The conventional lime mortar without any additives exhibited marginal strength increment from the 28th to 56th to 100th day of exposure. Whereas a significant increase in compressive strength by adding fermented bio-additives with dose 1 was higher than the dose 2 addition of fermented bio-additives.

The increase in strength was achieved in both the doses of fermented additives, proving that additives improve the strength compared to the conventional lime mortar with no additives.

It is also noted from both Figures 4 and 5, that in the case of conventional lime mortar the strength was higher with the highest amount of lime content i.e., the 1:1 ratio offered higher strength compared to the 1:2, and the 1:3 dose exhibited the least strength, (1:1 > 1:2 > 1:3) whereas in addition to bio-additives commonly in the fermented case the increase in strength was seen as 1:1 < 1:2 < 1:3. Hence from the laboratory exposure conditions to the normal environment, the lime mortar that has absorbed the carbon dioxide present in the atmosphere has shown remarkable results when using additives and is the best compared to the fermented bio-additives. It is observed that the breaking load of conventional lime mortar improved very slowly when compared with the other mortar mix ratios. Whereas an excellent increase in the breaking load of bio-additives added specimens...
resulted in better breaking loads with the highest performance given by dose 1 fermented bio-additives added lime mortar.

Figure 4. Compressive strength of the lime mortar samples with 1-day fermented bio-additive.

Figure 5. Compressive strength of the lime mortar samples with 10 days of fermented bio-additive.

5.2. Durability Properties

The durability study was performed on cube specimens of size 70 mm × 70 mm × 70 mm after 100 days of exposure to the laboratory environmental conditions.
5.2.1. Water Absorption

From the graph in Figure 6, it can be seen the water absorption rate was highest in the conventional lime mortar with a 1:3 ratio of lime to fine aggregate. The bio-additives added lime mortar mix exhibited similar water absorption qualities with minor variation, which can be seen as the addition of additives made the porous nature of lime mortar reduced to a limit. Lime has been known for its “breathable character”, as it lets in and lets out air/water, i.e., allows the movement of air/water without holding it internally, which means the air quality inside a lime-based construction will be naturally ventilated for a healthy internal environment. Hence the porous nature of lime mortar is very encouraged and plays a vital role in its durability property.

![Figure 6. Water absorption graph.](image)

5.2.2. Carbonation (Phenolphthalein Indicator Test)

Carbonation is a natural process of lime reacting with carbon dioxide present in the atmosphere to form stable calcium carbonate for strength achievement. By spraying the indicator solution, the sample changes to a purple-red color (pH > 9.5); the presence of portlandite and calcite together means that the sample acquires a soft pink hue (8 < pH < 9.5); the presence of calcite only means that a colorless area is observed (pH < 8) [46].

The carbonation test results in Table 6 prove that the addition of fermented bio-additives has enhanced the carbonation process when compared with the conventional lime mortar. The exposure conditions had a minimum carbon dioxide content where carbonation is noted to be minimum. If exposed to polluted environments (for example: placing them in vehicle movement areas and industrial areas will give exposure to a higher amount of carbon dioxide).

5.2.3. UPV Test

The results of the ultrasonic pulse velocity test show that mortar with fermented additives gave better results, i.e., more than 3000 m/s UPV compared to the conventional mortar. The higher the UPV value, the higher the homogeneity, uniformity, and density of the mortar.

The UPV test details the marginal change in porosity of the lime mortar mixed with bio-additives and gives an improved version of a conventional lime mortar. Figure 7a compared with Figure 7b shows improved results indicating that the increased fermentation period improves the durability properties of the lime matrix.
Table 6. Carbonation test results.

| S. No | Sample Details | Phenolphthalein Indicator Test Results | Inference | Carbonation Depth (cm) |
|-------|----------------|---------------------------------------|-----------|-----------------------|
| 1     | LMA            | Unreacted Cao, yet to be activated by carbon dioxide absorption |          | 2 cm                  |
| 2     | LMB            | Unreacted Cao, yet to be activated by carbon dioxide absorption, the lower side is carbonated to some extent. |          | 2.5 cm                |
| 3     | LMC            | The upper exposed area is carbonated, while the other part is yet to be carbonated. |          | 2.2 cm                |
| 4     | FLM-1-D        | Portlandite and calcite |          | 2 cm                  |
| 5     | FLM-1-E        | Unreacted Cao, yet to be activated by carbon dioxide absorption |          | 3 cm                  |
| 6     | FLM-1-F        | Scattered carbonation process showing the presence of portlandite and calcite |          | 4 cm                  |
| S. No | Sample Details | Phenolphthalein Indicator Test Results | Inference | Carbonation Depth (cm) |
|-------|----------------|-------------------------------------|-----------|-----------------------|
| 7     | FLM-2-D        | Portlandite and calcite             |           | 4.2 cm                |
| 8     | FLM-2-E        | Formation of major amount of portlandite and calcite | 3.5 cm |
| 9     | FLM-2-F        | Almost all of the surrounding areas are carbonated while internally it is yet to be carbonated. | 2.9 cm |
| 10    | FLM-1-G        | Unreacted CaO, yet to be activated by carbon dioxide absorption | 2.4 cm |
| 11    | FLM-1-H        | Scattered carbonation process       |           | 3 cm                  |
| 12    | FLM-1-I        | Complete carbonation process with the formation of Calcite | Fully carbonated |
Table 6. Cont.

| S. No | Sample Details | Phenolphthalein Indicator Test Results | Inference | Carbonation Depth (cm) |
|-------|----------------|---------------------------------------|-----------|------------------------|
| 13    | FLM-2-G        | Partially carbonated sample            |           | 3.6 cm                 |
| 14    | FLM-2-H        | Presence of portlandite and calcite    |           | 2 cm                   |
| 15    | FLM-2-I        | Presence of portlandite and calcite    |           | 2.7 cm                 |

Figure 7. UPV test results of the mortar specimens (a) and (b).

5.3. Mineralogical Characterization of Lime Mortar

Ettringites are needle-shaded structures with the composition of calcium aluminum sulfate. These are also known as cement bacillus, and confirm that the hydration reaction has started. The deposits of botryoidal calcium phosphate in voids and acicular crystals of ettringite can be seen in Figure 8a in a larger quantity compared to the other two ratios.
1:2 in Figure 8b,c [38–40]. The alunite (A) and kaolinite (K) were found in the 1:1 ratio of samples SEM images [40].

Figure 8. SEM Images of conventional lime mortar with (a) 1:1 ratio, (b) 1:2 ratio, and (c) 1:3 ratio (100 days).

Figure 9 shows crystals agglomerates of calcium carbonate around aggregate in (a), biologic colonization, and crystals of calcium carbonate and calcium hydroxide particles in the ratios (b) 1:2 and (c) 1:3 [39,40]. The calcium carbonate formation is the ultimate aim of lime mortar making—a way to the formation of calcite [41].

Figure 9. SEM images of 1-day fermented bio-additives added to the lime mortar (a) 1:1 ratio, (b) 1:2 ratio, and (c) 1:3 ratio of dose 1 (100 days).

The altered feldspar grain was profoundly seen in all the mortar mixed with fermented bio-additives and altered quartz grains in Figures 10 and 11 [39]. The Feldspar grains improve the durability properties of the construction material, giving it hardness and making it corrosion resistant [42–44].
Figure 10. SEM images of 1-day fermented bio-additives dose 2 added in the lime mortar of (a) 1:1 ratio, (b) 1:2 ratio, and (c) 1:3 ratio (100 days).

Figure 11. SEM images of 10-day fermented bio-additives dose 1 added in the lime mortar of (a) 1:1 ratio, (b) 1:2 ratio, and (c) 1:3 ratio (100 days).

Figures 11 and 12 indicate the presence of a stable crystal formation in the lime matrix. The intensity of the stable formation of the polymorphs of calcium carbonate increased when using 10 days of fermented extracts of both doses 1 and 2.

5.4. Study on Fermentation of Additives

The study on fermented extracts as additives was analyzed using phytochemical analysis, mass spectrometry, and GCMS, and the protein and fat content present in the experimented extract.

5.4.1. Phytochemical Analysis

Phytochemical analysis was done to find the presence of alkaloids, terpenoids, steroids, phenols, flavonoids, tannins, glycosides, and saponins [47].
Figure 12. SEM images of 10-day fermented bio-additives dose 2 added in the lime mortar of (a) 1:1 ratio, (b) 1:2 ratio, and (c) 1:3 ratio (100 days).

The role of these constituents in Table 7, for the improvement of strength and durability properties, was vital. The self-healing nature of lime mortar for various climatic conditions and external factors of animals/birds/microbial activities was improved by the addition of these components to the resistant nature of lime mortar [48]. Tables 8 and 9 show the quantification of flavonoids and phenols in the additives.

Table 7. Phytochemical analysis results.

| Test         | Bio-Additives at 1 Day of Fermentation | Bio-Additives at 10 Days of Fermentation |
|--------------|---------------------------------------|------------------------------------------|
|              | Dose 1 | Dose 2 | Dose 1 | Dose 2 | Dose 1 | Dose 2 |
| Alkaloids    | −      | +      | +      | +      | +      |
| Terpenoids   | +      | +      | +      | +      | +      |
| Steroid      | −      | −      | −      | −      | −      |
| Phenol       | +      | +      | +      | +      | +      |
| Flavonoids   | +      | +      | +      | +      | +      |
| Tannins      | +      | +      | +      | +      | +      |
| Glycosides   | +      | +      | +      | +      | +      |
| Saponins     | −      | −      | +      | −      | −      |

Table 8. Quantitative presence of flavonoids at 10 days.

| Sample | OD AT 570 nm | QE (µg/mg) |
|--------|--------------|------------|
| Dose 1 | 0.128        | 15.31      |
| Dose 2 | 0.158        | 18.9       |

Table 9. Quantitative presence of phenols at 10 days.

| Sample | OD AT 765 nm | GAE (µg/mg) |
|--------|--------------|-------------|
| Dose 1 | 1.119        | 575.96      |
| Dose 2 | 1.115        | 573.89      |
The presence of flavonoids in Kadukkai (Terminalia chebula) with the CaCO$_3$ in the lime mortar indicates the formation of calcite and stable vaterite components that improve the mechanical properties of lime mortar over time [49]. It was observed that the flavonoid quantity increased with the dose of bio-additives on fermentation. Hence, it can be clearly seen that the addition of bio-additives to fermentation gives improved qualities to the conventional lime mortar. The presence of phenols tends to be a polymeric material of improvement to the composites it is added to [50]. The plant phenols content was high in dose 1 compared to dose 2, as mentioned in Table 6, which indicates the better properties of dose 1 lime mortar compared to the other dose and the other experimented mortar mix. The increase in the presence of phenols and flavonoids proves the self-healing capacity of lime mortars for their antibacterial nature [51].

5.4.2. Presence of Proteins, Total Fat, and Ethanol

The presence of proteins, fats, and ethanol plays a vital role in improving the durability properties of lime mortar. This was experimented with to find their formation from the 1-day fermented extract and 10-day fermented extract, as shown in Table 10.

Table 10. Presence of proteins, total fat, and ethanol.

| S. No | Parameters | Method               | Results (%) |
|-------|------------|----------------------|-------------|
|       |            | Fermented (1 Day)    | Fermented (1 Day) | Fermented (10 Days) | Fermented (10 Days) |
|       |            | Dose 1   | Dose 2   | Dose 1   | Dose 1   | Dose 2   |
| 1     | Proteins  | IS 7219-1973        | 0.2885  | 0.2885  | 0.162   | 0.538    |
| 2     | Total Fat | AOAC METHOD         | 3.723   | 3.453   | 1.3433  | 1.395    |
| 3     | Ethanol   | Gas Chromatography  | Not Detected | Not Detected | Not Detected | 34.1    |

The ethanol formation did not occur in day 1, whereas it occurred on day 10 of the extract fermentation, which indicates the action of microorganisms that broke down particles to react and form ethanol. These organic compounds react and produce organic constituents that give solid construction materials.

5.4.3. Mass Spectroscopy of the Bio-Additives

The bio-additives were experimented with using a triple quadrupole gas chromatograph-mass spectrometer by GCMS-TQ8040 NX from the Tamil Nadu test house, Chennai. Mass spectroscopy identifies the formation of various compounds that play a vital role in improving the properties of lime mortar.

The 1-day fermentation of both the doses exhibited a similar composition as mentioned in the chromatogram Figure 13 and explained in Table 11 with the role of components formed from Figure 14.

The chromatogram peaks in Figures 15 and 16 are discussed in Tables 12 and 13 with the role of the constituents formed by fermentation in Figures 15 and 17.

Every constituent in the additives in Figures 14, 16 and 18 improved the properties of the lime mortar matrix, and the tables denote the role of every constituent formation in the fermentation process.
Figure 13. Chromatogram of fermented bio-additive extract (1 day fermented).

Table 11. Chromatogram peak constituents in the fermented bio-additive extract (1 day fermented).

| S. No | R. Time | Peak Height % | Constituent                                           | Molecular Weight | Role of the Constituent                                                                 |
|-------|---------|---------------|------------------------------------------------------|------------------|----------------------------------------------------------------------------------------|
| 1     | 0.054   | 2.59          | 1,2-Epoxynonane                                      | 142.24           | Solvent stabilizers, plasticizers, organics synthesis                                  |
| 2     | 3.364   | 10.29         | Formamide, N,N-dimethyl-                             | 73.038           | Solvent                                                                                |
| 3     | 6.964   | 7.01          | Alpha.-Terpineol                                     | 154              | Anti-bacterial adhesion and anti-biofilm agent [52]                                  |
| 4     | 9.273   | 1.89          | Benzene, 1,3-dibromo-2-methoxy-                      | 264              | Photocatalyst                                                                          |
| 5     | 9.504   | 2.03          | Beta.-D-Fructopyranose, 2,3,4,5-bis-O-(1-met)-hexan-3-ol | 260              | Odor                                                                                   |
| 6     | 10.645  | 5.31          | Tetrahydroionyl acetate                              | 240              | Odor                                                                                   |
| 7     | 10.903  | 7.55          | 1-(2,2,6-Trimethylcyclohexyl) hexan-3-ol             | 226              | Odor [53]                                                                              |
| 8     | 15.340  | 4.77          | Pentadecanoic acid,14-methyl-, methyl ester          | 270              | Fatty acid [54]                                                                       |
| 9     | 15.471  | 6.57          | Pentadecanoic acid,14-methyl-, methyl ester          | 270              | Fatty acid [54]                                                                       |
| 10    | 17.310  | 3.45          | 11,14-Eicosadienoic acid                            | 322              | Omega fatty acid                                                                      |
| 11    | 17.376  | 9.23          | 6-Octadecanoic acid, methyl [53] ester, (Z)-         | 296              | The solvent in herbicide and pesticide                                                 |
| 12    | 17.428  | 6.94          | 7-Octadecanoic acid, methyl ester                    | 296              | The solvent in herbicide and pesticide                                                 |
| 13    | 17.570  | 18.24         | Methyl stearate                                      | 298              | A fatty acid ester [55]                                                               |
| 14    | 17.601  | 14.12         | Methyl stearate                                      | 298              | A fatty acid ester [55]                                                               |
Figure 14. Structures of identified compounds in the fermented bio-additives on day 1 fermentation.

Figure 15. Chromatogram of fermented bio-additive extract (10 days fermented), dose 1.

Figure 16. Chromatogram of fermented bio-additive extract (10 days fermented), dose 2.
Table 12. Chromatogram peak constituents in fermented bio-additive extract (10 days fermented), dose 1.

| S. No | R.Time | Peak Height % | Constituent | Molecular Weight | Role of the Constituent |
|-------|--------|---------------|-------------|------------------|-------------------------|
| 1     | 0.052  | 14            | 2-Piperidinone, N-[4-bromo-n-butyl]- | 233               | Antimicrobial quality [56] |
| 2     | 3.226  | 63            | Toluene     | 92               | As a solvent and in organic synthesis |
| 3     | 3.369  | 6.25          | Formamide, N, N-dimethyl- | 73               | Odor |
| 4     | 4.168  | 3.61          | Ethylbenzene | 106              | Helps in the formation of styrene |
| 5     | 4.446  | 6.23          | Styrene     | 104              | Odor |
| 6     | 5.670  | 2.64          | Cyclobutene, 1,2-bis(1-methylethenyl)-, trans- | 136            | Antioxidant [57] |
| 7     | 6.029  | 3.37          | Cyclobutene, 1,2-bis(1-methylethenyl)-, trans- | 136            | Antioxidant [57] |

Table 13. Chromatogram peak constituents in fermented bio-additive extract (10 days fermented), dose 2.

| S. No | R. Time | Peak Height % | Constituent | Molecular Weight | Role of the Constituent |
|-------|---------|---------------|-------------|------------------|-------------------------|
| 1     | 1.573   | 35.44         | Ethanol     | 46               | Enhances carbonation [58] |
| 2     | 3.225   | 28.75         | 1,3,5-Cycloheptatriene | 92            | Odor |
| 3     | 4.169   | 5.89          | 3-Pyridinecarboxiamide, N-[3-Methyl-1-(phenylmethyl) | 292           | Glucokinase activators [59] |
| 4     | 4.464   | 18.86         | Styrene     | 104              | Aromatic liquid hydrocarbon |
| 5     | 13.644  | 11.06         | Azacyclohexacosane | 365          | Helps in ethanol group formation |

Figure 17. Constituents formed on the 10th day of fermentation in dose 1 additives.
6. Conclusions

The research concludes the following points from this experimental work on lime mortar with fermented bio-additives compared with the conventional lime mortar.

- The experimental analysis resulted in increased compressive strength of air lime mortar added with bio-additives compared to the conventional air lime mortar. The additives improved the lime matrix property with minimum lime content (1:3 > 1:2 > 1:1) compared to the conventional lime matrix, which depended on the binder content of the matrix (1:1 > 1:2 > 1:3). The use of binder content can be minimized by using fermented additives. The dose 1 fermented bio-additives gave higher strength compared to dose 2, whereas in durability the dose 2 additives had improved carbonation results from the phenolphthalein indicator test;

- The SEM image explains the formation of ettringites all over the sample, proving that hydration happened with the C-S-H phase products, calcium aluminum sulfate, and calcium phosphate, which is the sole reason for the improved strength and durability properties. The SEM analysis relates to the formation of a homogeneous bonding of ingredients present in the lime because these additives led to improved properties. The amorphous crystal formation of calcium oxides depicts the reaction taking place with the carbon dioxide present in the atmosphere. The calcium carbonate, aragonite, and stable forms of vaterite and calcium oxalates prove the carbonation process, as they are excellent carbon-capturing agents in the environmental exposure conditions [60];

- The process of carbonation depends on the capillary pores present in the atmosphere, which lets air move inside the sample. Hence, the UPV test results show that the addition of fermented bio-additives improved the quality of the mortar sample with higher results;

- The in-depth study on fermented bio-additives indicates the presence of proteins and fats. Protein is known for its air-entraining enhancement qualities in the lime mortar and makes it durable in various climatic conditions [61–63]. The use of jaggery has been the most primitive way of construction, which has given excellent results in the hardening process in the matrix material [64]. The fat content in the additives is soluble in alcohol forms, as the fermentation time of the extract increases the lime mortar, which gains an increased carbonation process, and the carbohydrates are soluble in water and improve the carbonation rate. Hence, both fats and carbohydrates improve the strengthening process overall [65];

- The 3-Pyridinecarboxamide, N-[3-Methyl-1-((phenylmethyl) are glucokinase activators that activate the carbohydrate metabolism, leading to improved carbonation in the lime mortar, resulting in increased strength achievement;
• The process of fermentation is hence a cost-efficient, non-toxic, and natural process that enhances the properties of bio-additives from the experimental analysis that gives strength and durability properties to the lime mortar [58];
• The laboratory exposure conditions have less carbon dioxide present in the atmosphere; exposing these specimens to polluted areas will make them gain more strength since the rate of carbonation is higher with higher carbon dioxide presence;
• The use of these lime mortars in plastering works will be the initial step toward the use of sustainable construction materials, bringing in a vast scope for researchers to improve the setting time properties of lime for further use in the construction works and in the preservation of ancient constructions as a compatible repair material [66].
• The research results also encourage people to do extensive research on utilizing naturally available bio-additives and less processed materials, bringing in the best properties of locally available materials for an environmentally friendly and healthy lifestyle.

Author Contributions: Conceptualization, A.M.; Data curation, A.M.; Funding acquisition, A.M.; Investigation, A.M.; Methodology, A.M.; Resources, A.M.; Supervision, C.U.; Validation, C.U.; Writing—original draft, A.M.; Writing—review & editing, A.M. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by UGC-OBC, grant number 201819-NFO-2018-19-OBC-TAM-70033.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data required to reproduce these findings, as well as the processed data required to reproduce these findings, are available within the paper.

Acknowledgments: The authors would like to thank Raghavan HR and CE Tamil Nadu for the study on-site of renovation works in ancient temples and the Hindu Religious and Charitable Endowments Tamil Nadu, the lab technician Pazhani and Chemistry Department and the concrete laboratory of structures division, and the SEM lab of Mechanical Department of College of Engineering Guindy, Anna University Chennai. The authors also thank Subbulakshmi, lab technician from Tamil Nadu Test House Chennai.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References
1. De Almendra Freitas, J., Jr.; de Mello Maron, M.D.R.; Artigas, L.V.; Martins, L.; Sanquettta, C.R. Assessment of the impact of binders in the evolution of carbonation in mortars. Constr. Build. Mater. 2019, 225, 496–501. [CrossRef]
2. Chena, Y.; Huanga, B.; Huangb, M.; Lua, Q.; Huang, B. Sticky rice lime mortar-inspired in situ sustainable design of novel calcium-rich activated carbon monoliths for efficient SO2 Capture. J. Clean. Prod. 2018, 183, e449–e457. [CrossRef]
3. Carran, D.; Hughes, J.; Leslie, A.; Kennedy, C. A Short History of the Use of Lime as a Building Material—Beyond Europe and North America. Beyond Europe. Int. J. Archit. Herit. 2012, 6, 117–146. [CrossRef]
4. IS 712; Specification for Building Limes. Bureau of Indian Standards: New Delhi, India, 1984.
5. Santarelli, M.L.; Sbardella, F.; Zuena, M.; Tirillò, I.; Sarasini, F. Basalt fiber reinforced natural hydraulic lime mortars: A potential bio-based material for restoration. Mater. Des. 2014, 63, 398–406. [CrossRef]
6. Jayasingh, S.; Baby, J. Influence of organic addition on strength and durability of lime mortar prepared with clay aggregate. Mater. Today Proc. 2022. [CrossRef]
7. Zuixiong, L.; Linyi, Z.; Li, L.; Jinua, W. Zuixiongetal Research on the modification of two traditional building materials in ancient China. Herit. Sci. 2013, 1, 27. [CrossRef]
8. Rehan, R.; Nehdi, M. Carbon dioxide emissions and climate change: Policy implications for the cement industry. Environ. Sci. Policy 2005, 8, 105–114. [CrossRef]
9. Nie, S.; Zhoua, J.; Yanga, F.; Lanb, M.; Li, J.; Zhangd, Z.; Chenda, Z.; Xua, M.; Lia, H.; Sanjayan, J.G. Analysis of theoretical carbon dioxide emissions from cement production: Methodology and application Song. J. Clean. Prod. 2022, 334, 130270. [CrossRef]
10. Benhelal, E.; Shamsaei, E.; Rashid, M.I. Challenges against CO2 abatement strategies in cement industry: A review. J. Environ. Sci. 2021, 104, 84–101. [CrossRef]
11. Sun, G.; Li, X.; Wang, Y.; Chakraborty, A.; Wang, Z.; Wu, Y. Editorial Impacts of Climate Change on Biological Dynamics. Hindawi Publ. Corp. Discret. Dyn. Nat. Soc. 2016, 2016, 9046107. [CrossRef]
12. Bonneuila, C.; Choquetb, P.; Franta, B. Early warnings and emerging accountability: Total’s responses to global warming, 1971–2021. *Glob. Environ. Chang.* 2021, 71, 102386. [CrossRef]

13. Haneefa, K.M.; Rani, S.D.; Ramasamy, R.; Santhanam, M. Microstructure and geochemistry of lime plaster mortar from a heritage structure. *Constr. Build. Mater.* 2019, 225, 536–554. [CrossRef]

14. Thirumalini, P.; Ravi, R.; Sekar, S.K.; Nambrirajan, M. Study on the performance enhancement of lime mortar used in ancient temples and monuments in India. *Indian J. Sci. Technol.* 2011, 4, 1484–1487. [CrossRef]

15. Jayasingh, S.; Selvaraj, T. Effect of Natural Herbs on Hydrated Phases of Lime Mortar. *J. Archit. Eng.* 2020, 26, 04020021. [CrossRef]

16. Shivakumar, M.; Selvaraj, T.; Dhassaih, M.P. Preparation and characterization of the ancient recipe of organic Lime Putty—Evaluation for its suitability in restoration of Padmanabhapuram Palace, India. *Sci. Rep.* 2021, 11, 13261. [CrossRef]

17. Arizzia, A.; Vilesb, H.; Cultrone, G. Experimental testing of the durability of lime-based mortars used for rendering historic buildings. *Constr. Build. Mater.* 2012, 28, 807–818. [CrossRef]

18. Lanas, J.; Alvarez, J.I. Masonry repair lime-based mortars: Factors affecting the mechanical behavior. *Cem. Concr. Res.* 2003, 33, 1867–1876. [CrossRef]

19. Ventolà, L.; Vendrell, M.; Giraldez, P.; Merino, L. Traditional organic additives improve lime mortars: New old materials for restoration and building natural stone. *Constr. Build. Mater.* 2011, 25, 3313–3318. [CrossRef]

20. Lanas, J.; Bernal, J.L.P.; Bello, M.A.; Alvarez, J.I. Mechanical properties of natural hydraulic lime-based mortars. *Cem. Concr. Res.* 2004, 34, 2191–2201. [CrossRef]

21. Frankeová, D.; Koudelková, V. Influence of ageing conditions on the mineralogical micro-character of natural hydraulic lime mortars. *Constr. Build. Mater.* 2020, 264, 120205. [CrossRef]

22. IS 2386; Methods of Test for Aggregates for Concrete (Part I). Bureau of Indian Standards: New Delhi, India, 1963.

23. IS 383; Specification for Coarse and Fine Aggregates from Natural Sources for Concrete. Bureau of Indian Standards: New Delhi, India, 1970.

24. IS 2386; Methods of Test for Aggregates for Concrete (Part III). Bureau of Indian Standards: New Delhi, India, 1963.

25. Eckel, E.C. *Cements, Limes and Plasters*; Taylor & Francis: Abingdon, UK, 2005; Volume 1.

26. Taylor, H. *Cement Chemistry*; Thomas Telford: London, UK, 1997.

27. Oliveira, A.; Pereira, A.S.; Lemos, P.C.; Guerra, J.P.; Silva, V.; Faria, P. Effect of innovative products in air lime mortars. *J. Build. Eng.* 2021, 35, 101985. [CrossRef]

28. Shanmugavel, D.; Dubey, R.; Ramadoss, R. Use of natural polymer from the plant as an admixture in hydraulic lime mortar masonry. *J. Build. Eng.* 2020, 30, 101252. [CrossRef]

29. Hwanga, H.-Y.; Kwna, Y.-H.; Hongb, S.-G.; Kang, S.-H. Comparative study of effects of natural organic additives and cellulose ether on properties of lime-clay mortars. *J. Build. Eng.* 2022, 48, 103972. [CrossRef]

30. IS: 2250-1981; Code of Practice for Preparation and Use of Masonry Mortars. Indian standard: New Delhi, India, 1981.

31. IS: 4031 (Part 8); Methods of Physical Tests for Hydraulic Cement. Indian standard: New Delhi, India, 1988.

32. IS 2541-1991; Preparation and Use of Lime Concrete-Code of Practice (Second Revision). Indian standard: New Delhi, India, 1991.

33. IS 10078-1982; Specification for Jolting Apparatus Used for Testing Cement. Indian standard: New Delhi, India, 1982.

34. IS:6932; Methods of Tests for Building Limes, Determination of Unhydrated Oxide (Part V). Bureau of Indian Standards: New Delhi, India, 1973.

35. IS:6932; Methods of Tests for Building Limes—Determination of Compressive and Transverse Strengths (Part VII). Bureau of Indian Standards: New Delhi, India, 1973.

36. Singh, M.; Arbad, R.B. Characterization of traditional mud mortar of the decorated wall surfaces of Ellora caves. *Constr. Build. Mater.* 2014, 65, 384–395. [CrossRef]

37. Ravikumar, R.S.M.S.; Avudaiappan, S.; Amran, M.; Aepuru, R.; Vatin, N.; Fediuk, R. The Effect of Superabsorbent Polymer and Nano-Silica on the Properties of Blended Cement. *Crystals* 2021, 11, 1394.

38. Bokea, H.; Akkurt, S. Ettringite formation in historic bath brick–lime plasters. *Cem. Concr. Res.* 2003, 33, 1457–1464. [CrossRef]

39. Borgesa, C.; Silvab, A.S.; Veiga, R. Durability of ancient lime mortars in humid environment. *Constr. Build. Mater.* 2014, 66, 606–620. [CrossRef]

40. Kazea, C.R.; Adesinad, A.; Lecomte-Nanab, G.L.; Metekongc, J.V.S.; Samenc, L.v.K.; Kamseuc, E.; Melo, U.C. Synergetic effect of rice husk ash and quartz sand on microstructural and physical properties of laterite clay based geopolymer. *J. Build. Eng.* 2020, 65, 101234. [CrossRef]

41. Liu, H.; Zhao, Y.; Peng, C.; Song, S.; López–Valdivieso, A. Lime mortars—The role of carboxymethyl cellulose on the crystallization of calcium carbonate. *Constr. Build. Mater.* 2018, 168, 169–177. [CrossRef]

42. Enriqueza, E.; Torres-Carrasco, M.; Cabreraa, M.J.; Muñozoa, D.; Fernández, J.F. Towards more sustainable building based on modified Portland cements through partial substitution by engineered feldspars. *Constr. Build. Mater.* 2021, 269, 121334. [CrossRef]

43. Yao, G.; Wang, Z.; Yao, J.; Cong, X.; Anning, C.; Lyu, X. Pozzolanic activity and hydration properties of feldspar after mechanical activation. *Powder Technol.* 2021, 383, 167–174. [CrossRef]

44. Torres-Carrascoa, M.; Enriqueza, E.; Terrón-Menoyoaa, L.; Cabreraa, M.J.; Muñozoa, D.; Fernández, J.F. Improvement of thermal efficiency in cement mortars by using synthetic feldspars. *Constr. Build. Mater.* 2021, 269, 121279. [CrossRef]

45. IS 7219; Method for Determination of Protein in Foods and Feeds. Bureau of Indian Standards: New Delhi, India, 1973.
46. Romero-Hermida, M.I.; Borroto-Lopez, A.M.; Flores-Ales, V.; Alejandro, F.J.; Franco, J.M.; Santos, A.; Esquivias, L. Characterization and analysis of carbonation process of lime mortar obtained from Phosphogypsum waste. *Int. J. Environ. Res. Public Health* **2021**, *18*, 6664. [CrossRef]

47. Rana, A.; Negi, P.B.; Sahoo, N.G. Phytochemical screening and characterization of bioactive compounds from Juniperus Squamata root extract. *Mater. Today Proc.* **2022**, *48*, 672–675. [CrossRef]

48. Tiwari, P.; Khare, T.; Shriram, V.; Bae, H.; Kumar, V. Plant synthetic biology for producing potent Phyto-antimicrobials to combat antimicrobial resistance. *Biotechnol. Adv.* **2021**, *48*, 107729. [CrossRef]

49. Paul, D.; Das, G. Bio-inspired synthesis of flavonoids incorporated CaCO3: Influence on the composites’ phase, morphology, and mechanical strength. *Colloids Surf. A: Physicochem. Eng. Asp.* **2021**, *642*, 128720. [CrossRef]

50. Qiana, C.K.; Songa, Y.; Laia, J.; Qiana, X.; Zhang, Z.; Liang, Y.; Ruan, S. Characterization of historical mortar from ancient city walls of Xindeng in Fuyang. *Constr. Build. Mater.* **2022**, *315*, 125780. [CrossRef]

51. Takuli, N.P.; Khulbe, K.; Kumar, P.; Parki, A.; Syed, A.; Elgorban, A.M. Phytochemical profiling, antioxidant and antibacterial efficacy of a native Himalayan Fern: Woodwardia unigemmata (Makino). *Saudj J. Biol. Sci.* **2020**, *27*, 1961–1967. [CrossRef]

52. Ding, Q.; Zhuang, T.; Fu, P.; Zhou, Q.; Luo, L.; Dong, Z.; Li, H.; Tang, S. Alpha-terpineol grafted acetylated lentinan as an anti-bacterial adhesion agent. *Carbohydr. Polym.* **2022**, *277*, 118825. [CrossRef]

53. Yamamoto, T.; Ujihara, H.; Watanabe, S.; Harada, M.; Matsuda, H.; Hagiwara, T. Synthesis and od of optically active trans-2,2,6-trimethyl cyclohexyl methyl ketones and their related compounds. *Tetrahedron* **2003**, *59*, 517–524. [CrossRef]

54. Suresh, A.; Praveenkumar, R.; Thangaraj, R.; Oscar, F.L.; Baldev, E.; Dhanasekaran, D.; Thajuddin, N. Microalgal fatty acid methyl ester a new source of bioactive compounds with antimicrobial. *Asian Pac. J. Trop. Dis.* **2014**, *4*, 5979–5984. [CrossRef]

55. Abraham, T.W.; Höfer, R. Lipid-Based Polymer Building Blocks and Polymers. In *Polymer Science: A Comprehensive Reference*; Volume Set; Elsevier: Amsterdam, The Netherland, 2012.

56. Al-Salman, H.N.K. Antimicrobial activity of the compound 2-Piperindinone,N-[4-Bromo-n-butyl]-Extracted from pomegranate peels. *Asian J. Pharm.* **2019**, *13*, 46–53.

57. Ridaoui, K.; Guenaoui, I.; Taouam, I.; Cherki, M.; Bourhim, N.; Elamrani, A.; Kabine, M. Comparative study of the antioxidant activity of the essential oils of five plants against the H2O2 induced stress in Saccharomyces cerevisiae. *Saudj J. Biol. Sci.* **2022**, *29*, 1842–1852. [CrossRef] [PubMed]

58. Pradeep, S.; Gummadi, S.; Selvaraj, T. Living mortars-simulation study on organic lime mortar used in heritage structures. *Eur. Phys. J. Plus* **2022**, *137*, 499. [CrossRef]

59. Ishikawa, M.; Nonoshita, K.; Ogino, Y.; Nagae, Y.; Tsukahara, D.; Hosaka, H.; Maruki, H.; Ohyama, S.; Yoshimoto, R. Discovery of novel 2-(pyridine-2-yl)-1H-benzimidazole derivatives as potent glucokinase activators. *Bioorganic Med. Chem. Lett.* **2009**, *19*, 4450–4454. [CrossRef]

60. Greco-Coppi, M.; Hofmann, C.; Ströhle, J.; Walter, D.; Epple, B. Efficient CO2 capture from lime production by an indirectly heated carbonate looping process. *Int. J. Greenh. Gas Control* **2021**, *112*, 103430. [CrossRef]

61. Glozzo, E.; Pizzo, A.; La Russa, M.F. Mortars, plasters and pigments—Research questions and sampling criteria. *Archaeol. Anthropol. Sci.* **2021**, *13*, 193. [CrossRef]

62. Shanmugavel, D.; Kumar, Y.P.; Khadimallah, M.A.; Ramadoss, R. Experimental analysis on the performance of egg albumen as a sustainable bio admixture in natural hydraulic lime mortars. *J. Clean. Prod.* **2021**, *320*, 128736. [CrossRef]

63. Ravi, R.; Thirumalini, S.; Taher, N. Analysis of ancient lime plasters—Reason behind longevity of the Monument Charminar, India a study. *J. Build. Eng.* **2018**, *30*, 30–41. [CrossRef]

64. Pintea, A.; Manea, D. New types of mortars obtained by aditiving traditional mortars with natural polymers to increase physicomechanical performances. *Procedia Manuf.* **2019**, *32*, 201–207. [CrossRef]

65. Shasavandi, A.; Salavessa, E.; Torgal, F.P.; Jalali, S. Air Lime Mortars with Vegetable Fat Addition: Characteristics and Research Needs. In *Proceedings of the 2nd Historic Mortars Conference HMC2010 and RILEM TC 203-RHM Final Workshop*, Prague, Czech Republic, 22–24 September 2010.

66. Manoharan, A.; Umarani, C. Review Lime Mortar, a Boon to the Environment: Characterization Case Study and Overview. *Sustainability* **2022**, *14*, 6481. [CrossRef]