MTech (Structural Engineering) Shreya Singh 2025

Influence of Sticky Rice and Modified Sticky Rice on the Properties of Lime Mortar

A Dissertation Submitted
in Partial Fulfillment of the Requirement for the Award of the Degree of

MASTER OF TECHNOLOGY

in

Structural Engineering

by

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(2K23/STE/16)

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CANDIDATE DECLARATION

I, **Shreya Singh**, M. Tech (Structural Engineering) student, having **Roll no: 2K23/STE/16**, hereby certify that the work which is being presented in the dissertation entitled "**Influence of Sticky Rice and Modified Sticky Rice on the Properties of Lime Mortar**" in the partial fulfilment of the requirements of the award of the Degree **Master of Technology in Structural Engineering**, submitted in the **Department of Civil Engineering, Delhi Technological University** is an authentic record of my work carried out under the supervision of Prof. Shilpa Pal, Department of Civil Engineering, Delhi Technological University, Delhi. The matter present in this dissertation has not been submitted by me for the award of any other degree of this or any other institute.

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CERTIFICATE

I hereby certify that the project Dissertation entitled "**Influence of Sticky Rice and Modified Sticky Rice on the Properties of Lime Mortar"** which is submitted by Shreya Singh, Roll No. 2K23/STE/16, to Department of Civil Engineering, Delhi Technological University in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of project work carried out by her under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi
Date: May 31, 2025

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ABSTRACT

Lime mortar is a traditional building component made from lime, sand, and water that is generally used in masonry construction. Unlike cement mortar, lime mortar hardens slowly by a process known as carbonation. Lime mortar also weathers over time with a gentle touch, as it integrates very well with old stone work. It has some disadvantages, however, including decreased initial strength and increased drying times, which can restrict its use in certain modern building applications. In spite of this, its performance in historical preservation and eco-friendly construction practices makes it a useful material in architecture. Natural additives enhance the workability, water retention, and bonding properties of the mortar without making it impermeable or incompatible with brickwork. For instance, sticky rice water, with its polysaccharides like amylopectin, acts as a natural binder, enhancing the cohesion and mechanical strength of lime mortar. Other organic additives, including molasses, oils, and cactus mucilage, have been found to avoid shrinkage, control setting time, and enhance durability. As interest in sustainable and historically accurate materials grows, use of organic compounds in lime mortar is being reassessed for restoration and for environmentally friendly construction methods A common traditional mortar used in many significant buildings is lime mortar mixed with sticky rice. However, there are variations in the amounts of water used to make mortar of lime to advance properties of sticky rice because of a lack of documentation. Additionally, not much research has been done on the proper amounts and functionality of starchy water in mortar of lime. Additionally, sticky rice can have a variety of ingredients added to improve its qualities. Cellulose is an example of such an addition. Therefore, the purpose of this learning is to test the strength due to compression, tensile strength, shear bond strength, water absorption, wetting & drying for lime mortar enhanced with sticky rice and sticky rice and cellulose. Compressive strength tests were performed for various percentages of sticky rice (3%, 5%, 7% & 9% by weight of water) with lime 1 unit and sand 3 units in order to optimize the process. The maximum increase in compressive strength observed at 5% which is 43.59% higher than that of lime mortar without additive. For this improved sticky rice ratio, cellulose was added in amounts of 2%, 4%, and 6% (by weight of sticky rice). The best results of compressive were achieved by combining 6% cellulose and 5% sticky rice in a lime mortar which is 67.90% greater than lime mortar without additive.

Other attributes were examined for these optimized ratios of cellulose and sticky ice

ratios. When cellulose is added to sticky rice, it significantly reduces its workability to 105% which increased maximum to about 7.3% when only sticky rice was added. Both sticky rice and sticky rice with cellulose demonstrated a significant increase in tensile strength. There was increase of about 36.36% when 5% sticky rice was added in lime mortar and further increases to about 65.50% when 6% cellulose was added in 5% sticky rice. Water absorption was about 14.85% on addition of sticky rice which is greater than reference mortar. For reference mortar it was 12.48% Water absorption decreased on addition of cellulose, it was only 6.53%. There was mass loss of 2.93% in lime mortar without additive. On addition of sticky rice it reduced to 1.74%. The best results came out when cellulose was added with sticky rice in lime mortar. The mass loss was only 1.176% Also, both sticky rice and modified sticky rice show higher resistance to acid and alkali attacks, with the latter being more robust. For reference mortar decrement in weight after 28 days of acid attack was 15.5%. For sticky rice mortar it came out to be 10% and for modified sticky rice it was only 7.2%. There was 35% decrement in compressive strength after 28 days of submergence in alkali solution in reference mortar, reduces to 11.96% in sticky rice mortar and 10.31% for modified sticky rice. Bond shear strength test shows best results with cellulose in sticky rice in lime mortar. There was increase of 18.18% in bond strength when sticky rice was added to lime mortar. Further on addition of cellulose it increased to 55.11%.

ACKNOWLEDGEMENT

I, **SHREYA SINGH**, would like to offer a special thanks to all those who have contributed to the successful completion of this thesis.

I express my deepest gratitude to my supervisor Prof. Shilpa Pal, Delhi Technological University. She introduced me to the world of research from scratch, my time with her has helped me to grow in many ways. Her comments at every stage of my writing and instances on perfection has helped this dissertation to come out in this sense. It is not only the careful supervision but also her personal affection that has given me lot of confidence to proceed smoothly with my work. Words cannot express my gratitude to my supervisor for patiently helping me to think clearly and consistently by discussing every point of this dissertation with me. It is my privilege to work with her in my post-graduation.

I am grateful to the faculty and staff of Delhi Technological University [DTU], especially the Civil Engineering Department, for providing a conducive academic environment and necessary resources for carrying out this research. The access to the laboratory facilities and library resources has greatly facilitated the experimental work and literature review.

I am also thankful to Mrs Khyati Saggu PhD scholar in DTU for imparting her knowledge and expertise in this subject as she has helped me in both practical and theoretical aspect.

I would also like to give special thanks to my mother Shilpa Singh, my father Deobhushan Singh and my friend Anchal Kaw for their continuous support and understanding while undertaking my research and writing my thesis. Your prayer and blessings have sustained me this far and will guide and encourage me in future also.

SHREYA SINGH

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ABBREVIATIONS AND ACROYNYMS

RM	Reference Mortar without any additive
S-3	Lime Mortar with 3% proportion of sticky rice by weight of water
S-5	Lime Mortar with 5% proportion of sticky rice by weight of water
S-7	Lime Mortar with 7% proportion of sticky rice by weight of water
S-9	Lime Mortar with 9% proportion of sticky rice by weight of water
S5C2	Lime Mortar with 5% sticky rice by weight of water and 2% cellulose by weight of sticky rice
S5C4	Lime Mortar with 5% sticky rice by weight of water and 4 % cellulose by weight of sticky rice
S5C6	Lime Mortar with 5% sticky rice by weight of water and 6 % cellulose by weight of sticky rice
XRD	X Ray Diffraction
PVC	Polyvinyl Chloride
LCA	Life Cycle Analysis

CHAPTER 1

INTRODUCTION

1.1 HISTORICAL BACKGROUND OF LIME MORTAR

Lime mortar has very long and distinguished history as one of the oldest and most widely used building materials in human civilization. It originated around 4000 BCE in Egypt. Egyptian temples and pyramids were made from lime mortar. The used to mix sand and water with lime to make bonding between the elements more stronger.This was the turning of era in construction industry as lime marked very crucial element in every aspect [1]. After Egypt, Greeks also enhanced the lime mortar by enhancing its properties [2] They used lime mortar both for strength and aesthetic purposes. However, it was Romans who made the use of lime mortar in many monuments, roads and massive public buildings. They are the one who gave new heights to the lime mortar. Romans also enhanced the mortar by mixing volcanic ash and they found that it enhanced [3]. Not, only in other countries in India also lime was traditional binder and used in many historical monuments. Even all the historical monuments that were constructed during ancient age, medieval or during British period were made of lime mortar [4].

Lime has been important binder since many years. Even its proportion is maximum in cement mortar. After introduction of cement the use of lime declined as cement sets quickly, imparts better strength. But the main problem with the cement is its compatibility with ancient structures. Also, it causes lot of pollution and not eco friendly. Lime mortar offers better durability than cement mortar. So, the demand of lime mortar is increasing day by day. Structures like the Taj Mahal and various South Indian temples demonstrate its long-standing use, often combined with natural additives such as jaggery, sticky rice water, or bael fruit to enhance strength and durability. Surkhi lime mortar, a blend of lime and brick dust, was commonly used in Mughal architecture.

Lime mortar offered excellent breathability, flexibility, and long-term durability—making it ideal for India's diverse climates. Its continued use in heritage conservation underscores its effectiveness and cultural relevance. In modern India, lime mortar is mainly applied in restoration work by organizations like the Archaeological Survey of India (ASI), as well as in eco-friendly construction. However, its usage is limited due to a general preference for Portland cement, which sets faster and is more readily available. Challenges such as lack of skilled labour, standard guidelines, and awareness have slowed its resurgence.

Nevertheless, there is a growing interest among conservationists, architects, and researchers in reviving lime mortar for its sustainability and compatibility with traditional Indian architecture. Lime is made from calcination of lime stone. Lime obtained from calcination of relatively pure lime stone is referred as quick lime. Quick lime has very high affinity for water hence reacts with it swells, cracks and fall out as powder and leads to the formation of Hydrated/ Slaked/ Milk of lime. Slaking is the process in which quick lime vigorously reacts with water and forms hydrated lime [5]. There are many different categories of lime mortar that are used in construction. Some of them are listed below-

1. **Fat lime mortar (Non – Hydraulic lime mortar)**- It is made by mixing pure lime with sand. It sets slowly by carbonation. It is useful for internal plastering and low moisture areas.
2. **Hydraulic lime mortar**- It contains high amount of reactive silica and alumina that helps it to set quickly. It can set in water also. Carbonation process is very fast in this mortar. It is suitable for damp and external environment.
3. **Dolomitic lime mortar-** It is made from dolomitic lime having very low percentage purity.
4. **Surkhi lime mortar-** Surkhi is burnt clay or brick dust. When lime is mixed with surkhi and water then this mortar is formed. It is very common in Indian historical conditions. It is used in domes and water retaining structures.
5. **Gauged lime mortar (Cement lime mortar)-** This is the best type of mortar. When cement is mixed lime it increases strength , rate of setting , durability etc. It is often used in repair works and non -load bearing walls.
6. **Lime sand mortar-** Lime-sand mortar is a traditional building material made by mixing lime (either fat lime or hydraulic lime) with sand and water. It has been used for centuries for masonry, plastering, and pointing due to its flexibility, breathability, and compatibility with historic structures [6]

1.2 ORGANIC ADDITIVES

Depending on the particular application and intended results, additives are usually added during application or blended into the base material during manufacture. Thorough formulation and testing guarantee base material compatibility and enable the intended performance improvements. Additives are essential for improving the qualities and functionality of building materials, which makes it possible for more effective and efficient building techniques. In India, lime mortar was strengthened and made more durable by adding plant and animal extracts.

Traditional lime mortar has employed organic admixtures made from locally accessible plants and animal derivatives. On the other hand, little is identified about the application of herbs and their importance in the building sector. In the past, structures were built for the welfare of their occupants as well as to endure outside influences. Although their precise function is unclear, a variety of plant extracts have been added to lime mortar in India.

According to sources, organic compounds such as egg white, fig milk, blood, beer, vegetable juices, tannin, animal glue, urine, and other natural polymers were used to strengthen the durability of lime mortars and concrete in ancient times. Other additives discovered in historic houses were casein, beer, and oil mastics. The addition of ingredients like as nopal and casein, as well as fatty acids like olive oil, has been shown to improve mechanical characteristics, water resistance, carbonation speed, and texture. These additives are compatible with traditional building materials and can be used to restore architectural history and modern architecture that incorporates natural stone. Despite many natural calamities historical buildings are still in good condition. Another notable natural additive is sticky rice. It is also known as glutinous rice. Rice is a main crop in South Asian countries. The Great Wall of China was built with pig blood and sticky rice. The Great Wall of China has weathered several disasters, including earthquakes, but it remains unbroken. Sticky rice contains a starch component known as amylopectin, which lends it adhesive properties. Apart from used in kitchen sticky rice has also been used in construction of tombs and pagodas. Sticky rice is obtained by boiling the rice and separating the water from rice, leaving water for sometimes makes it sticky. The sticky characteristics of water make it suitable to be used in lime mortar for improving the strength due to compression, binding properties, and durability.

Apart from historical significance, sticky rice has also emerged as a sustainable additive for modern day construction, still limited studies have been carried out on its proportions and performance with lime mortar.

Through different literatures it has been found that cement and other additives like slag can also be added in lime mortar to enhance its properties. It has been found that workability of natural lime came out to be higher than that of cement and slag based lime mortar. Environmental resistance of slag based lime mortar observed to be highest. Carbonation rate was faster in case of hydraulic lime as compared to other mortars with additives[7]. Jaggery, Jute and egg were added separately in lime mortar and different properties were tested. Jaggery showed the best bond and compressive strength, and Jute showed better tensile strength[8].

In India, lime mortar mixed with organic additives has been utilized extensively to build historic buildings with high heritage value that have shown to be incredibly strong and resilient. As a result, there is now more interest in studying lime, especially when it comes to conservation initiatives that fix and restore historic buildings. Over the course of their lengthy lifespans, ancient structures have, however, also undergone a variety of distress events, including physical, chemical, and thermal attacks, interventions, and earthquakes, which has occasionally required repairs and restoration despite their remarkable resilience.

The preservation of ancient structures is a top priority for the Indian government, both to preserve their cultural value and to draw in more tourists. The numerous conservation initiatives underway are clear examples of this. International institutions like UNESCO, which created ICOMOS (International Council on Monuments and Sites) to assist in these efforts, also acknowledge the need of preserving cultural heritage. Preserving the authenticity and heritage value of these structures is essential [9]. Since cement plaster was determined to be incompatible with the building during previous repair attempts, traditional lime plaster is favored in places like Humayun's tomb. The last layer of lime plaster is made of marble dust, egg white, and lime. The excellence of lime mortar as a waterproof material has been proven by Pakistan's Hiran Minar. While the Indo-Islamic style used jute and straw, the 1591 Charminar in Hyderabad also used lime with natural ingredients like jaggery and egg white [10].

For restoration purpose cement had been found to be incompatible with historical monuments. For this,the usage of lime mortar increases, as in older days cement was not present and ancient structures were made with lime with organic additives.

Manufacturing of Renderings and plaster is done with lime mortar these days. Aggregates impacts the structure and properties of lime mortar directly as observed that coarse aggregates reduces capillary pores and led to volume stability. Low binder and aggregate ratio is favourable as it shows low porosity [11] .

Blood is also an organic additive that was used in many Chinese structures. Animal blood was used in Great wall of China. Now a days for restoration purpose the concept of using blood became prevalent in China. It has been found that mortar containing blood shows better binding strength, low water absorption and high durability. Curing time for blood based mortar is comparatively than that of natural lime mortar[12] .

Lime based mortar structures is not only found in Asian countries but also in eastern Roman provinces. Through investigation in Turkey the structures that were made during Roman Provinces contains lime sand mortar mixed with pozzolana[13] .

Cement mixed with lime mortar is prevalent now a days as restoration of older structures become necessary. Only cement mortar is not compatible with historical structures, for this purpose cement is mixed with lime mortar which increases its durability and compatibility[14] .

1.3 OBJECTIVE OF THE STUDY

The fundamental goal of the research is to the investigate of lime mortar augmented with sticky rice and modified sticky rice. The objectives of the project are described below:

1. To determine optimal percentage of sticky rice water that maximizes strength and durability
2. To assess the properties of lime mortar mixed with traditional sticky rice
3. To find the optimum percentage of additive(cellulose) to be used with sticky rice in lime mortar
4. To determine the properties of lime mortar enhanced with modified sticky rice.

1.4 OUTLINE OF THE THESIS

The present work comprises of 5 chapters. This thesis begins with a brief introduction to lime in the construction industry, ancient structures, and the usage of organic additions to form stronger binder. To address the concerns, objectives are developed based on the need for suitable inputs from conservation experts. Chapter 2 summarizes prior studies on the physical, mechanical, and durability aspects of lime mortar with additions. The chapter also covers the usage of various organic compounds in heritage constructions to improve material quality and investigates their qualities. Chapter 3 covers an experimental framework based on the literature study, as well as the raw material properties, mortar preparation procedure, and testing methodologies. Chapter 4 depicts many phases of study that follow the experimental protocols to describe the physical, mechanical, and durability behaviours of the organic modified lime mortar. Chapter 5 concludes this thesis and discusses future work.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

This section provides a complete evaluation of the literature related to the topic. It begins by describing historical structures built with lime mortar and organic additions, illustrating the long-term usefulness of such materials. Following that, investigations concentrating on the inclusion of sticky rice and cellulose into lime mortar are investigated to better understand their impact on the material's engineering qualities. Finally, a critical analysis of the examined literature identifies existing research gaps, demonstrating the necessity and direction for the current study.

2.2 HISTORICAL MONUMENTS BUILT WITH ORGANIC ADDITIVES IN LIME MORTAR

Pradeep et al. (2022) Mortars with chemical compositions identical to antique mortars were evaluated in terms of strength development and lime reaction. Several mixes were evaluated in the lab for chemical and mechanical Except for hydraulic lime mortar and mortar with lime putty-natural pozzolanic addition, the results revealed that the majority of mortars evolved slowly in terms of chemical and mechanical properties. [15]

M Singh et al (2021) The investigation involves collecting samples from several areas on the site and using various analytical techniques, such as X-ray diffraction, scanning electron microscopy, and energy-dispersive X-ray spectroscopy, to investigate the mortar's composition and microstructure. The use of organic additives in lime mortar has been an integral part of traditional construction practices, both in India and globally. [16]

A. Acharya et al. (2017) In India, structures like the Padmanabhapuram Palace in Tamil Nadu utilized fermented extracts of *kadukkai* (Terminalia chebula), *neelamari* (Indigofera tinctoria), hibiscus, palm jaggery, and aloe vera to enhance the mechanical strength, carbonation, and durability of lime mortars. [10]

B. Dighe et al (2021) The Solapur Fort in Maharashtra incorporated bamboo foliage, flax fiber, and millet grains, which reduced shrinkage and improved environmental resistance.[17]

S. Pradeep et al. (2019) In Auroville, Puducherry, fermented *kadukkai* and jaggery were used in sacred grove construction, where natural CO_2 generation enhanced lime setting and strength.[18] These methods reflect India's rich heritage of sustainable construction.

T. Dettmering et al. (2022) Internationally, one of the most remarkable examples is the Great Wall of China, where sticky rice was mixed with slaked lime to form a highly durable and water-resistant mortar that has withstood centuries of weathering. The Xiangji Temple Stone Tower and the Wugang City Wall in China also employed sticky rice-lime mortar, contributing to structural longevity and environmental resistance. In Roman architecture, pozzolanic materials were combined with lime to build iconic structures like aqueducts and temples, demonstrating exceptional durability, especially in marine environments. These examples from both India and abroad showcase how ancient builders used locally available organic materials to enhance lime mortar, achieving remarkable strength, resilience, and sustainability that modern materials often struggle to match. The Great Wall of China, built during the Ming Dynasty, utilized an innovative organic additive in its construction: a mixture of sticky rice and slaked lime.[19] This sticky rice-lime mortar offered exceptional strength and remarkable water resistance, which significantly contributed to the Wall's durability and longevity, allowing it to withstand the test of time for centuries.

R. Ravi et al. (2018) The analysis of Charminar which is present is Hyderabad, India had been carried out to find out the internal structural materials. XRD, TGA with DTA , SEM etc testing were carried out. It was observed that the structure was composed of lime and sand with ratio 1:2.75-1:3.43 . Organic additives jaggery , kadukkai and egg white was also present which make it sound and durable[20]

2.3 STICKY RICE AND CELLULOSE WITH LIME MORTAR

F. Yang et al. (2010) Lime mortar, while widely used in traditional and sustainable construction due to its breathability and environmental benefits, often suffers from certain limitations such as low compressive strength, poor water resistance, and susceptibility to cracking over time. These weaknesses can reduce the durability and longevity of structures built with lime mortar. To address these challenges, researchers have explored the incorporation of natural additives like sticky rice, also known as glutinous rice. [21]

S. Thirumalini et al. (2017) Sticky Rice enhanced ancient lime mortar in East Asia had been witnessed increasing its strength and endurance, as demonstrated by buildings like the Great Wall of China. According to many studies, the mechanical properties of the mortar are greatly improved by adding organics to the lime matrix because it strengthens the bond between the mortar's two successive lime particles[22]

M. A. O. Mydin et al. (2022) In the study, different proportions of jaggery and sticky rice were added to lime mortar, and the properties of the mortar were tested. It has been found that sticky rice water is a better additive than jaggery[23].

K. Zhang et al (2021) Sticky rice mixed with lime mortar in different proportions increases compressive strength water retention capacity and slows down carbonation as hydration proceeds. It prolongs setting time[24]**.**

Y. Xiao et al. (2017) The urgent restoration of the Wugang Ming dynasty city wall necessitated analysis of mortar qualities. To determine the characteristics of lime mortar, samples were collected and diffraction methods were applied. The inorganic-organic hybrid bonding substance used in the Wugang city wall's mortars is mostly made of calcium carbonate and about 3% sticky rice [25].

Shriram Nagorao Bengal et al. (2023) Some studies summarize the partial replacement of cement by sticky rice and jaggery. These eco-friendly construction materials are combined with cement and limestone to improve compressive strength and workability. Adding jaggery in cement concrete enhances various properties, including compressive, flexural, and split tensile strength. The sticky rice and sticky rice pulp enhance the compressive strength of concrete and are hence implemented in China on a large scale insights into the lime mortars mixed with sticky rice sol-gel or water [26]

R. Yang et al. (2016) Microstructural insights into the lime mortars mixed with sticky rice sol-gel or water are carried out. Compressive Strength, Tensile Strength and freezing and thawing cycles are much better than traditional lime mortar[27] **.**

J. Otero et al (2019) Many old Chinese structures that was made with organic additives are still alive without much deterioration. The long-term durability of adding glutinous rice water to standard mortar enhanced with traditional recipes is the main reason for exposure. The results from the research showed that using glutinous rice alone or in combination with nanolime gives a high value of consolidation than that attained by a simple nanolime consolidation[28]**.**

C. D'erme et al. 2022 Carbonation is one of the most important phenomena observed in mortar. Mortars without any additive shows more carbonation Also, it is observed that mortar having low binder to aggregate ratio undergoes rapid carbonation than those with high binder to aggregate. In order to reduce the CO2 emissions from the production of Portland cement, using nanocellulose in conventional lime-based mortars is a viable way to create green structures. Fibrillated cellulose (FC) was added to lime pastes and lime-based mortars at dosages of 0%, 0.1%, 0.2%, and 0.3 weight percent by binder weight in order to examine its effects. Thermal and nitrogen gas sorption examinations were performed on the lime pastes to determine whether FC had an impact on the volume and distribution of mesoporosities as well as the development of hydraulic compounds. Isothermal calorimetry was used to examine the mortars' setup and early hydration [29]

H. Liu et al 2016 Lime mortar has less compressive strength, high shrinkage and high porosity which make it less suitable to be used for construction. To overcome these drawbacks additives are used to enhance its properties. One such additive is carboxymethyl cellulose. By addition of CMC compressive strength increases and shrinkage and porosity decreases[30] .

Z. Lu et al 2023 Cellulose fibers can increase compressive and flexural strength, prevent fracture expansion, and lessen drying shrinkage during freeze-thaw cycles. However, adding fiber alone can delay carbonization and negatively impact frost resistance. A combination of fly ash and fiber prevents porosity and reduce adverse effects Thus leads to increase in durability**.**[31]

According to the Chinese patent**,**[32] the modified glutinous rice mortar can be further improved by adding cellulose fibers. The patent describes a preparation method where sticky rice slurry is mixed with lime and cellulose fibers to produce a mortar with enhanced strength and durability. The cellulose fibers reinforce the mortar by preventing cracking and improving toughness, while the sticky rice component enhances water resistance and binding properties. This patent validates that cellulose can be effectively incorporated into sticky rice-lime mortars, producing a composite material that leverages both chemical and mechanical enhancements to meet modern construction and restoration needs.

2.4 RESEARCH GAPS

Several research gaps have been identified while analysing the available literature, highlighting the necessity for additional research into the usage of organic ingredients such as sticky rice and cellulose in lime mortar. The gaps include:

1. There is disagreement over the ideal proportion of sticky rice and sticky rice with cellulose to offer the most strength and durability without compromising workability.
2. Lack of study on properties like strength and durability when organic additives like sticky rice and cellulose are added in lime mortar
3. Minimal research on compatibility of mortars with existing historic or modern building materials.
4. Inadequate evaluation of bonding strength with masonry units using triplet or flexural bond tests.

CHAPTER 3

METHODOLOGY AND EXPERIMENTAL WORK

3.1 GENERAL

In this section, lime mortar was enhanced by partially replacing mixing water with sticky rice water and modified sticky rice water to assess the effects on mortar qualities. The sticky rice extract was made by boiling glutinous rice, and the modified form was created by adding cellulose in various amounts. Mortar specimens were cast at a constant lime-to-sand ratio, with varying quantities of organic additions. The prepared specimens were evaluated for workability, compressive strength, tensile strength, water absorption, acid and alkali resistance, and durability throughout wetting and drying cycles. A control mix was also evaluated for comparison. The data were evaluated to determine the optimal percentage of sticky rice and modified sticky rice for improving lime mortar performance.

3.2 METHODOLOGY FLOW CHART

This investigation began with a raw material analysis, followed by the casting of lime mortar cubes without additives to serve as the reference mix. To maximize the quantity of sticky rice, cubes were made at four different percentages (3%, 5%, 7%, and 9%) based on the weight of mixing water and tested for compressive strength. The best percentage from this step was utilized to make and test cubes, cylinders, and brick triplets. The sticky rice mortar was then modified by adding cellulose at three different percentages (2%, 4%, and 6%) to the optimized sticky rice mix, and cubes were cast again for testing. Finally, a comparative analysis was carried out between the reference mortar, sticky rice mortar, and modified sticky rice mortar to assess improvements in workability, strength, water absorption, and resistance to acid, alkali, and wetting-drying conditions. This step-by-step methodology helped determine the most effective combination of natural additives for enhanced lime mortar performance.

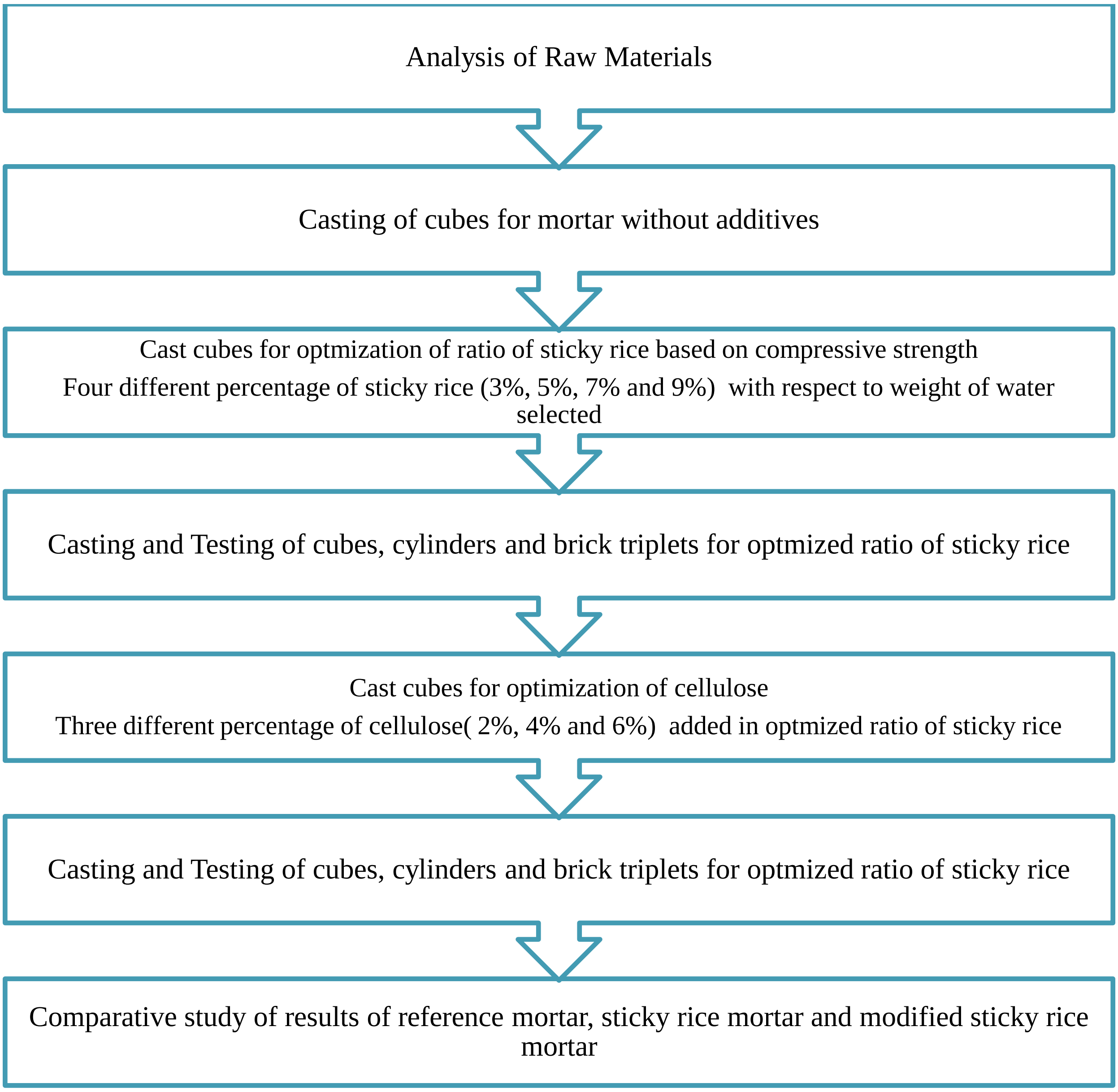

Figure 3. 1 Flow chart of methodology

3.3 RAW MATERIALS AND THEIR PRELIMINARY ANALYSIS

3.3.1 Lime

Lime is one of the oldest and most commonly used binders in building materials, particularly in traditional and heritage architecture. In this investigation, the predominant binding material is hydrated lime [$Ca(OH)_2$]. It is made by slaking quicklime (CaO) with water, producing a fine, white powder with excellent plasticity and workability. Lime hardens slowly through carbonation, where calcium hydroxide combines with carbon dioxide to generate calcium carbonate, providing strength to mortar over time. Lime mortar, unlike cement, is more flexible, breathable, and environmentally benign, making it ideal for restoration projects and low-strength applications. For the analysis Hydraulic Lime of Class A was obtained for the vendor. Hydraulic lime is a type of lime that sets and hardens through a chemical reaction with water, known as hydration, in addition to carbonation. Unlike non-hydraulic (or air) lime, which requires carbon dioxide from the air to set, hydraulic lime can set even in damp or underwater conditions. This property makes it especially useful in areas where moisture resistance and early strength gain are important. It is produced by calcining limestone that contains clay or other siliceous materials, which introduces reactive silica and alumina that contribute to its hydraulic behaviour. The properties of Hydraulic lime are as follows-

Table 3. 1 Properties of Lime

Properties	Values	Sources
Bulk Density	874.6 kg/m^3	Vendor
Specific Gravity	2.7	Vendor
Fineness	3800gm/cm^2	Vendor
Colour	White	Visual inspection

3.3.2 Sand

Sand is an essential component of lime mortar, acting as a fine aggregate that adds bulk, minimizes shrinkage, and enhances workability. This study used well-graded river sand that was devoid of organic contaminants, clay, and silt, which could impair the mortar's strength and bonding capabilities. The sand was sieved using a 4.75 mm IS sieve to ensure uniform particle size distribution. Its role is critical in producing correct particle packing, improving mechanical interlocking, and contributing to the mortar's overall strength. The amount of sand in the mix also influences the porosity and carbonation rate of lime mortar. The properties of sand are shown in Table 3.2. This table shows the bulk density, specific gravity, fineness modulus and compactness of the sand used for the study according to different IS codes.

Table 3. 2 Properties of Sand

Properties	Values	Sources
Bulk Density	1750kg/m3	IS2386(3):1963[33]
Specific Gravity	2.50	IS2386(3):1963[33]
Fineness Modulus	1.93	IS 1542:1992[34]
Compactness	64.30	IS2720(14):1983[35]

3.3.3 Water

For the project, the quality of water was taken in accordance with IS 456-2000[36] which specifies minimum pH value of 6.

3.3.4 Bricks

Bricks are considered the most fundamental structure element in the construction business and have been used for many decades. Bricks are made by moulding clay and burning it in a kiln until it hardens. The quality of bricks is determined by the clay used and the temperature at which they are created. They come in a variety of shapes, sizes, and colors and can be used to build walls, pavements, arches, and columns. Brick testing determines its strength, durability, and ability to withstand the stresses and loads encountered during building, assuring their appropriateness for their intended application. The study used burnt clay bricks of class A, which were tested for fundamental qualities such as dimension, efflorescence, and water absorption. The bulk density is calculated to be 1890 kg/m^3

3.3.5 Sticky Rice

Sticky rice, also known as glutinous rice, is a variety of rice found primarily in Southeast and East Asia. It is distinguished by opaque grains and a sticky texture when cooked due to high amylopectin and low amylose levels. Unlike other rice varieties, sticky rice softens and clumps together, making it perfect for use in traditional foods like dumplings, rice cakes, and desserts. Aside from gastronomic applications, sticky rice has historical relevance in construction, particularly in ancient Chinese architecture, where its starchy water was combined with lime to create a stronger, more durable mortar. This traditional addition has been shown to improve the mechanical characteristics and durability of lime-based construction materials. The bulk density of sticky rice used in mortar came out to be 1150kg/m3 and color observed was off white. The procedure for preparation of sticky rice can be illustrated from Fig 3.2

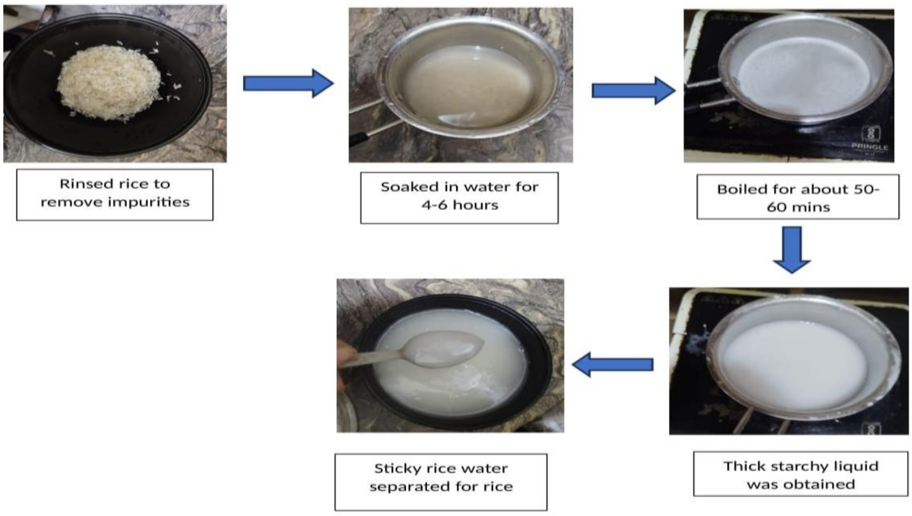

Figure 3. 2 Procedure for preparation of sticky rice

3.3.6 Cellulose

Cellulose, commonly added to lime mortar in the form of cellulose ethers like hydroxypropyl methylcellulose (HPMC), significantly improves the mortar's properties by increasing water retention, which enhances lime hydration and strength, and by improving workability and consistency, making the mortar easier to apply and more uniform. Additionally, cellulose reduces shrinkage and cracking by maintaining moisture and adding flexibility, while also extending the open time, allowing more time for application before the mortar sets. The pH of cellulose obtained from product specification was between 5 to 7.

3.4 PREPARATION OF SPECIMENS

All components were blended in precise amounts using a lime-to-sand ratio of 1:3 taken for mortar preparation. The lime-to-sand ratio is commonly represented in terms of weight. The mortar was made by keeping the binder to aggregate ratio of lime mortar and gradually adding the organic ingredients to the lime and sand mixture. All of the components are properly combined while dry, and then the water was added. Fresh mortar tests were performed to determine the mortar's workability and the water-to-binder ratio. The mortar was then cast in various moulds, like as cubes and cylinders, according to the tests that would be performed on it. The number of specimens prepared is shown in Table 3.3. and Table 3.4 Cylinder specimens were prepared for the split tensile strength test. Cube samples were made in moulds that measured 70.7 x 70.7 x 70.7 mm. Specimens were stored at a temperature of 27±2°C in the laboratory. After three days, the moulds were removed, and the specimens were air-cured for 25 days to obtain 28 days of strength. These specimens were extremely fragile due to their low strength. Following 28 days of casting, these specimens were tested.

Table 3. 3 Number of specimens for sticky rice mortar and reference mortar

Tests	Reference Mortar	Sticky rice mortar				Total
		3%	**5%**	**7%**	**9%**	
Compressive Test	3	3	3	3	3	15
Tensile Test	3	--	3	---	---	6
Carbonation test	3	--	3	---	---	6
Wetting and Drying test	3	--	3	---	---	6
Water Absorption test	3	--	3	---	---	6
Acid Attack	3	--	3	---	---	6
Alkali Attack	3	--	3	---	---	6
Bond Strength test	3	--	3	---	---	6

Total of 57 specimen including cubes , cylinders and bricks were used for the testing of properties of lime mortar without additive and lime mortar with sticky rice.

Table 3. 4 Number of specimens for modified sticky rice lime mortar

Tests	Cellulose with optimized ratio of sticky rice in mortar			Total
	2%	4%	6%	
Compressive Test	3	3	3	9
Tensile Test	---	--	3	3
Carbonation test	---	---	3	3
Wetting and Drying test	---	---	3	3
Water Absorption test	---	---	3	3
Acid Attack	---	---	3	3
Alkali Attack	---	---	3	3
Bond Strength test	---	---	3	3

3.5 DETERMINATION OF PHYSICAL PROPERTIES OF SPECIMENS

3.5.1 Workability

The flow table test was used to determine the workability of several lime mortar mixes, both with and without sticky rice and modified sticky rice. Workability is an important property that influences the ease of mixing, putting, and finishing mortar in construction applications. As per IS 5512[37] The testing technique began with installing the standard flow table on a clean and level surface. A conical mould was positioned in the center of the table and tightly fastened. The mould was then filled with the prepared mortar in two layers, each properly compacted with a tamping rod to remove air spaces and ensure consistent density. Once filled, the surplus mortar was removed, and the mould was carefully removed vertically to preserve the shape of the mortar cone. After that, flow table was dropped 25 times and diameter of spread was measured. According to IS 4031 1988 (part 7) [38] the average percentage flow for workable mortar should be between 105% to 115% of the original spread. To promote homogeneity and simplify comparison analysis, all mix types had a constant water-to-binder (w/b) ratio of 0.74. By holding the w/b ratio constant, the effect of sticky rice and its modified variation on lime mortar workability could be efficiently identified and evaluated.

3.5.2 Water Absorption

The water absorption test was used to determine the porosity and permeability of the mortar sample. This test offers information about mortar's ability to resist moisture penetration, which is important for the durability and long-term performance of construction materials. The operation was completed in accordance with the guidelines given in IS 3495 part 2:1992[39] Water absorption is defined as the percentage increase in a specimen's mass when submerged in water compared to its oven-dry mass. This feature is especially important in lime-based mortars, as excessive water absorption can indicate increased porosity and decreased durability, whilst low values indicate higher resistance to moisture infiltration. To start the test, typical mortar cube specimens were dried in a hot air oven at 105°C ± 5°C. The specimens were maintained in the oven until they reached a consistent mass, which ensured that all moisture was removed. The specimen's original dry weight, indicated as W_1, was determined by recording its constant mass. Following the drying procedure, the specimens were allowed to cool to room temperature before immersing in clean water at ambient temperature for 24 hours. After the immersion period, the specimens were taken from the water and any surface water was gently wiped off with a damp towel to prevent extra surface moisture from being absorbed. The saturated mass of each item was determined and recorded as W_2.

$$\text{Water absorption} = \frac{W2 - W1}{W1} * 100$$

W_1 = Preliminary dry weight of the specimen (grams).

W_2 = Concluding saturated weight of the specimen (grams)

3.6 DETERMINATION OF MECHANICAL PROPERTIES OF LIME MORTAR ENHANCED WITH STICKY RICE

3.6.1 Compressive Strength

In accordance with to IS 2250-1981 [40] compressive strength testing was performed on mortar cube specimens that measured 70.7 mm on each side.

This test was specifically designed to aid in the optimization of the mortar mixture. For this reason, three specimens were created for each varied percentage compositions under investigation. Throughout the test batches, the lime-to-sand mix ratio was kept constant at 1:3 by volume. The mortar was fully mixed before being placed into conventional cube moulds. Each mould was thoroughly filled and compressed to guarantee homogeneity and to remove any entrapped air that could influence the test findings. After casting, the specimens were left to set inside the moulds for three days. Following the initial setting phase, the cubes were demoulded and air-cured for 25 days. This resulted in a 28-day curing period, which is consistent with normal techniques for measuring mortar compressive strength. After the 28-day curing period, the mortar cubes were evaluated using a compression testing equipment. Each specimen was carefully placed inside the machine to ensure even loading. The specimen was then subjected to increasingly increasing compressive loads until it failed. The highest load at which each specimen failed was documented. This load was then utilized to determine the mortar's compressive strength for each % composition tested. The findings of this test were utilized to evaluate and compare the performance of various mortar compositions, resulting in the selection of the most appropriate mix. Figure. 3.3 shows the different specimen which were used for optimization of sticky rice proportion. Figure 3.4 shows the specimen for optimization of cellulose in ideal proportion of sticky rice

Figure 3. 3 Specimen for optimization of sticky rice

Figure 3. 4 Specimen for optimization of cellulose

3.6.2 Tensile Strength

The split tensile strength test evaluates mortar's tensile strength, which is an essential mechanical parameter that influences cracking behavior and overall structural integrity. Unlike direct tensile testing, which is difficult to accomplish due to gripping and alignment concerns, split tensile strength is measured indirectly by applying a compressive load along the vertical diameter of a cylindrical specimen. This causes uniform tensile stress along the cylinder's horizontal axis, eventually resulting in tension failure. Cylindrical specimens were produced for this test with a length-to-diameter (L/D) ratio of around 2, as is typical practice. The split tensile strength was only measured for the mortar mix containing the optimal percentage of sticky rice, which had previously performed well in the compressive strength test. The test was carried out in accordance with the approach specified in IS 5816:1999[41], which specifies how to determine the splitting tensile strength of concrete and is routinely used for mortar testing under comparable conditions. Due of the lack of typical cylindrical moulds, an unusual casting procedure was used. Polyvinyl chloride (PVC) pipes were utilized as moulds to create the cylindrical specimens. These pipes were cut to the required dimensions and firmly sealed at one end to keep the mortar mix in place during casting. The use of PVC pipes proved to be a feasible and cost-effective alternative, allowing for consistent specimen preparation while conforming to the geometrical constraints. Figure 3.5 illustrates the casting process using

PVC pipes. To maintain consistency, the specimens were cured under the same conditions utilized for compressive strength testing. After the curing period was completed, the specimens were carefully placed in the compression testing machine, with the stress applied along the vertical diameter. The load was gradually increased until the specimen failed due to tensile cracking across the horizontal axis.

$T = 2P/\pi DL$

P= applied load observed at failure

L= length of cylindrical case

D= diameter of cylindrical case

Figure 3. 5 Cylindrical mould and specimen for tensile strength test

3.6.3 Bond Strength

The Double Shear Strength Test in accordance with the Japanese Society of Civil Engineers (JSCE) Standard SF6 is used to measure the bond shear strength of triplets of bricks. [42]In this procedure, a three-brick assemblage is used—one in the centre and two on either side, bonded with lime mortar. To begin the setup, the bricks are washed, and lime mortar (which may contain additives such as sticky rice water or modified glutinous rice water) is put between them to make a stack in the following order: [Brick-Mortar-Brick-Mortar-Brick]. This assembly is oriented either horizontally or vertically and then cured in moist conditions for at least 28 days to allow the lime mortar to properly set and carbonate. After curing, the specimen is placed in a universal testing machine

(UTM) using a double shear test setup. Figure 3.6 shows the specimen for Bond Shear Strength Test. Load was applied to the center brick, which causes shear stress at both mortar joints between the center and side bricks. The load is increased gradually until failure occurs. [43]The maximum load at failure is recorded, and the shear strength is calculated using the formula:

$$\text{Shear Strength} = \text{Pmax}/2\text{A}$$

P_{max} is maximum load at which specimen fails

A is shear area

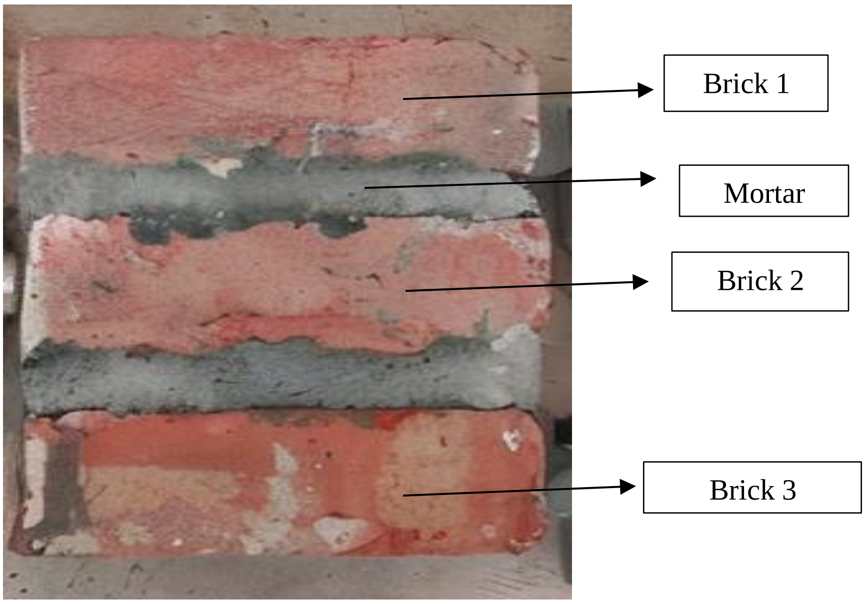

Figure 3. 6 Specimen for Bond shear strength test

3.7 DURABILITY TESTS ON SPECIMENS

3.7.1 Carbonation Depth Test

Carbonation occurs when carbon dioxide (CO_2) from the atmosphere penetrates the surface of mortar or concrete and combines with hydrated chemicals, especially calcium hydroxide, to generate calcium carbonate. This reaction reduces the alkalinity of the mortar, compromising its durability and protective characteristics, particularly in reinforced constructions. To determine the extent of carbonation in the mortar samples, a phenolphthalein indicator solution (1% concentration) was employed in accordance with IS 516 Part 5 Sec 3(2021)[44] This is a common method for assessing the depth of carbonation in hardened cementitious materials. Splitting the mortar sample revealed a new cross-sectional surface. The 1% phenolphthalein solution was then evenly sprayed onto the newly exposed surface. The indicator reacts with alkaline substances in uncarbonated environments, resulting in a distinctive pink coloring. In contrast, carbonated regions do not change color and stay colorless. After applying the indicator, the specimens were left alone for around 10 minutes to enable for clear observation and correct identification of the carbonation front. This test was carried out at three different curing ages to track the growth of carbonation over time. The ages chosen for testing were 28 days and 90 days. To ensure consistency and comparability of results, specimens were produced and examined at regular intervals using the same process. The depth of carbonation was measured from the surface downward to the point where the pink hue stopped, showing the boundary between carbonated and noncarbonated zones. These results gave vital insights on the mortar's durability qualities, specifically its resistance to ambient CO_2 over time. It has been found through different literatures that carbonation usually starts after 60 days in lime mortar. [45]

3.7.2 Wetting and Drying Test

The weathering resistance of mortar is an important factor in determining its long-term durability and capacity to endure environmental changes such as moisture and temperature. To assess this feature, a thermal cycling test was carried out using the procedure given in RILEM TC 25-PEM (1980)[8] . This method simulates natural weathering conditions and aids in determining mortar resistance to several wetting and drying cycles. For this test, typical mortar cube specimens were manufactured for each mix category being investigated. The specimens were subjected to numerous heat cycles that consisted of two major steps: wetting and drying. During the wetting phase, mortar cubes were totally immersed in water at 20 ± 5°C for 16 hours. This simulates the absorption of moisture during rainy or humid conditions.

Following the soaking phase, the specimens were moved to a hot air oven and dried at 105°C for 6 hours. This drying phase simulates exposure to high heat or intense sunshine in real-world settings. As a result, each temperature cycle replicated the natural environmental fluctuations the mortar encountered while in operation. Before beginning the test, each specimen's original mass was carefully documented. Following each cycle, the mass was measured again to monitor any changes caused by degradation, material loss, or moisture variation. Each specimen underwent a maximum of 25 wetting-drying cycles. The weathering resilience of mortar samples might be assessed by measuring mass loss as well as any obvious surface damage or cracking after multiple cycles. This test revealed crucial information on the long-term performance and stability of various mortar compositions under changing environmental conditions.

3.7.3 Acid Attack

The sulfate attack resistance test was used to assess mortar's durability when subjected to harsh sulfate environments, which are known to cause chemical deterioration and shorten the service life of cementitious materials. This test was carried out according to the standard protocol outlined in ASTM C267-20[46] At the commencement of the test, the weight of each cubical mortar specimen was carefully measured and recorded. The specimens were then totally immersed in a sulfuric acid solution with a normality of 0.612 N, or about 3% sulfuric acid by weight. This concentration was chosen to represent aggressive sulfate exposure circumstances. The mortar specimens were submerged in the acidic solution for 28 days, giving the sulfate ions enough time to react with the mortar components. Following the immersion period, the specimens were carefully removed from the solution and properly washed to remove any remaining acid. A visual inspection was performed to look for symptoms of surface deterioration, such as scaling, cracking, or material loss, all of which indicate sulfate attack damage. Each specimen's final weight was then precisely measured. The % weight loss for each specimen was determined by comparing the initial and end weights. This statistic quantified the mortar's resistance to sulfate attack; a smaller percentage weight loss indicated greater resistance. The findings of this test offered vital information about the chemical endurance of mortar mixes under harsh sulfate conditions. Figure 3.7 shows the surface deterioration of specimen due to sulphate attack

 

Figure 3. 7 Surface deterioration due to acid attack

3.7.4 Alkali Attack

The mortar's alkali resistance was tested using cubical specimens sized 70.7 mm × 70.7 mm × 70.7 mm. Each specimen was completely immersed in a 2% by weight sodium hydroxide (NaOH) solution for 12 hours. This concentration and exposure period were intended to represent the aggressive alkaline conditions that mortar may experience in specific settings. After the immersion period, the specimens were taken from the NaOH solution and dried in an oven at 105°C for 4 hours. This drying procedure was performed in accordance with the guidelines specified in GB/T 50082 2009[47] which details the standard method for assessing the durability of concrete and mortar under chemical attack. After drying, the compressive strength of the specimens was measured using a compression testing machine. This test provided critical information on how exposure to alkaline solutions affects the mechanical properties of the mortar, particularly its ability to maintain strength after chemical exposure.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

This chapter summarizes and examines the findings from the experimental studies undertaken during this project. The primary goal of the study was to determine the effects of sticky rice water and modified sticky rice water on the engineering qualities of lime mortar. The results are examined to assess the impacts of various addition proportions on mortar performance, with an emphasis on compressive strength, workability, and other pertinent physical and mechanical properties. The findings are examined in connection to the control mix and compared to previous research to corroborate identified patterns and anomalies. Statistical analysis and graphical depiction are utilized when needed to improve the interpretation of the results. This chapter not only discusses the substantial benefits or drawbacks of using organic additives, but it also provides explanations based on material behaviour and chemical interactions.
This chapter's sub-sections focus on various test results, such as compressive strength, setting time, and durability, and conclude with a comparative discussion. The goal is to determine the optimal content of sticky rice water and its modified form that results in improved lime mortar performance, in accordance with both traditional practices and modern technical standards.

4.2 TEST ON BRICKS

Bricks are widely utilized in the construction sector to create walls, pavements, and other constructions. It is critical to assess their mechanical qualities in order to assure the quality and durability of constructions. Brick qualities are evaluated including size and water absorption These tests aid in evaluating the performance of bricks and determining their suitability for various construction applications. In this section, we will go over the various tests performed on bricks to evaluate their mechanical qualities.

4.2.1 Dimension Test

Bricks are typically rectangular in shape and come in a range of dimensions. (length x depth x height). The dimensions of the bricks vary based on the type of brick, the maker, and the country in which it is created. However, not all bricks have exact and precise measurements. The different brick samples are known as B1, B2, B3, B4, and B5. Table 4.1 shows the measurements for these samples.

Table 4. 1 Dimensions of the Bricks

Specimen	Dimensions(mm)
B1	210*100*73
B2	212*100*75
B3	210*100*72
B4	210*100*75
B5	214*100*73

4.2.2 Water Absorption Test on Bricks

The water absorption test is a standard test used on bricks to determine their porosity and water absorption capacity. This test is significant because it aids in determining the durability and weather resistance of bricks, which are critical elements in their selection for construction applications. Table 4.2 shows the water absorption of bricks

Table 4. 2 Water absorption of bricks

Specimen	Weight after oven drying(M1) (kg)	Weight after 24 hours in water(M2) (kg)	Water absorption (%)
B1	3.12	3.55	13.78
B2	3.08	3.45	12.01
B3	3.13	3.55	13.42
B4	2.98	3.33	11.74
B5	3.20	3.61	12.81

After testing the specimens, the average water absorption was found to be 12.75% According to Indian standards, when tested as stated, the average value should not exceed 20% by weight for Class 12.5, and 15% by weight for higher classes. This is because excessive water sorption can cause structural damage such as cracking, bending, and degradation of the bricks. As a result, it is critical to monitor brick qualities and ensure they satisfy the appropriate specifications for the type of brick being used.

4.3 TEST ON FRESH CONCRETE

4.3.1 Workability

The workability of the mortar was assessed using the flow table test, in accordance with standard procedures. This test provides a quantitative measure of the ease with which a mortar can be mixed, placed, and finished. It was observed that the mortar mixtures incorporating sticky rice exhibited greater workability compared to the reference mortar. The workability increases maximum to about 7.3% when sticky rice is added to the lime mortar. This improvement in workability can be attributed to the presence of amylopectin, a highly branched carbohydrate found abundantly in sticky rice. Amylopectin acts similarly to a natural plasticizer, enhancing the smoothness and internal cohesion of the mix. As a result, mortars containing sticky rice flowed more readily and exhibited a more uniform and workable consistency. However, the inclusion of cellulose into the sticky rice–lime mortar system had the opposite effect. The workability significantly decreases to 105 flow percentage with increasing cellulose content. This reduction is primarily due to the hygroscopic nature of cellulose, which absorbs free water in the mix, thereby reducing the amount of water available for lubrication. Additionally, cellulose increases internal friction within the mix, resulting in a stiffer, thicker, and drier consistency. This increased resistance to flow makes the mortar more difficult to handle and apply, thereby lowering its overall workability.

Table 4. 3 Workability for different mortar sample

Type of Mortar	Initial Diameter(mm)	Average Final Diameter (mm)	Flow (in percentage)(IS 4031 (Part 7) 1988)[38]
RM	100	106.00	106
S-3	100	110.20	110.20
S-5	100	113.75	113.75
S-7	100	112.32	112.32
S-9	100	113.00	113.00
S5C2	100	109.54	109.54
S5C4	100	110.12	110.12
S5C6	100	105.00	105.00

4.4 OPTIMIZATION

4.4.1 Optimization of Lime Mortar Enhanced with Sticky Rice

Initially, various compositions of sticky rice were selected for investigation, with compressive strength chosen as the primary parameter for optimizing the mortar mix. Four different proportions of sticky rice were added in 1:3 lime mortar (3%, 5%, 7% and 9 %). Mortar cubes were cast in standardized moulds and allowed to set undisturbed for a period of 3 days. After this initial curing phase, the cubes were carefully demoulded and subjected to air curing for an additional 25 days, resulting in a total curing period of 28 days. The compressive strength tests were performed at the end of this curing period using a Compression Testing Machine (CTM), following the standard procedure. Figure 4.3 illustrates the typical failure pattern observed in the cubical specimens when subjected to compressive loading. The failure mode is characterized by visible cracks and fragmentation indicative of the load-bearing capacity of the mortar. Table 4.4 depicts the compressive strength of different mortar samples when subjected to compressive load. The test results, summarized in Table 4.6 reveal that the maximum percentage increase in compressive load capacity compared to the reference mortar was achieved with a 5% addition of sticky rice. There was increase of about 43.59% at 5% addition of sticky rice. This significant improvement confirms that a 5% sticky rice composition is the optimized mix proportion for enhancing compressive strength. Having established the optimized composition, subsequent tests were conducted to evaluate other important engineering properties of the mortar at this specific percentage.

Table 4. 4 Values of compressive strength for different mortar samples

Reference Mortar	Value of compressive strength (MPa)
1	1.58
2	1.50
3	1.60
	Average= 1.56 MPa
S-3 Mortar	
1	1.85
2	1.92
3	1.93
	Average=1.90 MPa
S-5 Mortar	
1	2.12
2	2.04
3	2.56
	Average= 2.24 MPa
S-7 Mortar	
1	1.98
2	2.09
3	1.93
	Average=2.00 MPa
S-9 Mortar	
1	1.95
2	1.82
3	1.81
	Average=1.86 MPa

Table 4. 5 Percentage increase in compressive for different sticky rice lime mortar with respect to Reference mortar

Type of mortar	Value of strength due to compression MPa	Percentage increase in strength wrt RM
RM	1.56	----
S-3	1.90	21.79%
S-5	**2.24**	**43.59%**
S-7	2.00	28.20%
S-9	1.86	19.23%

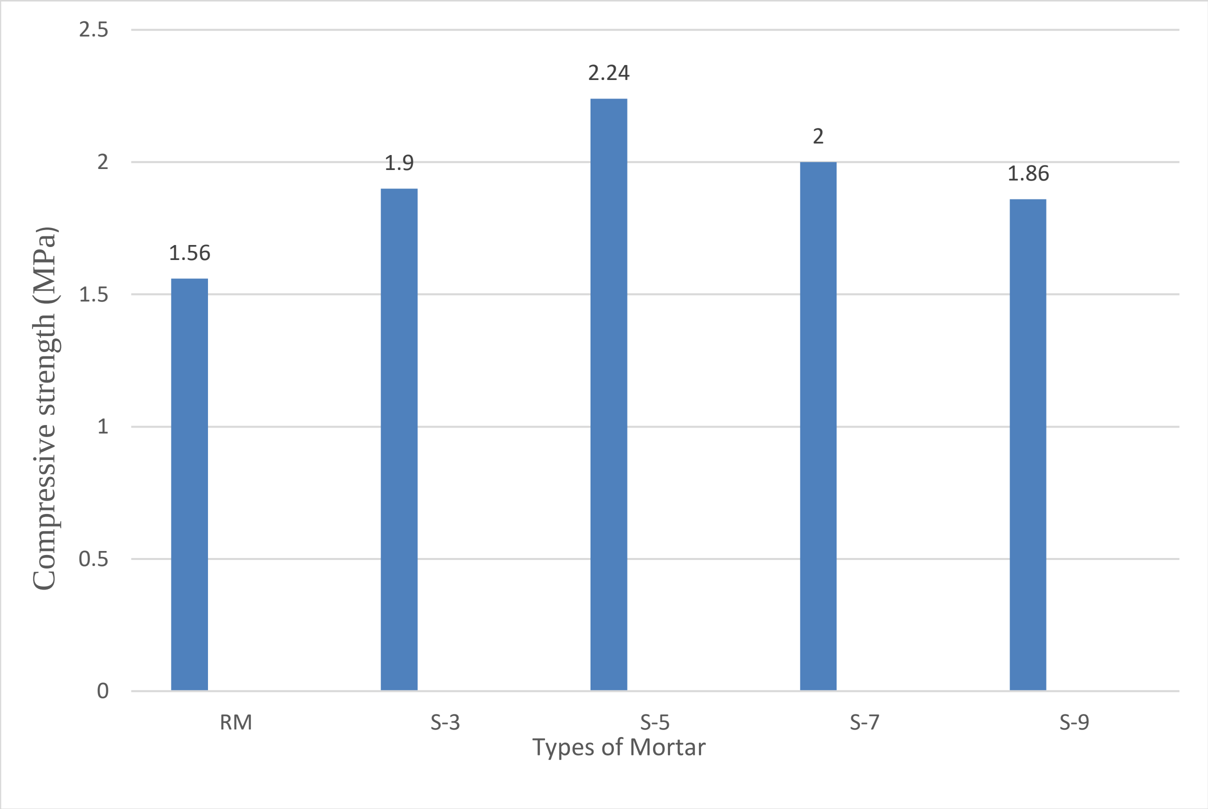

Figure 4. 1 Graphical representation of compressive strength of sticky rice lime mortar and reference mortar

4.4.2 Optimization of ratio of cellulose with ideal proportion of sticky rice in lime mortar

As previously indicated, the ideal percentage of sticky rice created was 5%, therefore cellulose was optimized using 5% sticky rice and a lime-to-sand ratio of 1:3. Compressive strength of different modified sticky rice mortar samples can be seen from table 4.6. A variable quantity of cellulose (2%, 4%, and 6%)

was added to the sticky rice lime mortar. The table 4.7 shows that the largest percentage gain in compressive strength for modified sticky rice is at 6% cellulose which 67.90%. So, 6% cellulose and 5% sticky rice is an optimal amount. Figure 4.2 shows the graphical variation of percentage increase in compressive strength.

Table 4. 6 Compressive strength of different modified sticky rice samples

S5C2 Mortar	**Value of compressive strength (MPa)**
1	2.10
2	2.05
3	1.94
	Average=2.03 MPa
S5C6 Mortar	
1	2.60
2	2.63
3	2.63
	Average= 2.48 MPa
S5C6 Mortar	
1	2.60
2	2.63
3	2.63
	Average= 2.62 MPa

Table 4. 7 Percentage increase in compressive strength for sticky rice and modified sticky rice lime mortar

Type of mortar	**Value of strength due to compression MPa**	**Percentage increase in strength wrt RM**
RM	1.56	----
S5C2	2.03	30.12%
S5C4	2.48	58.90%
S5C6	**2.62**	**67.90%**

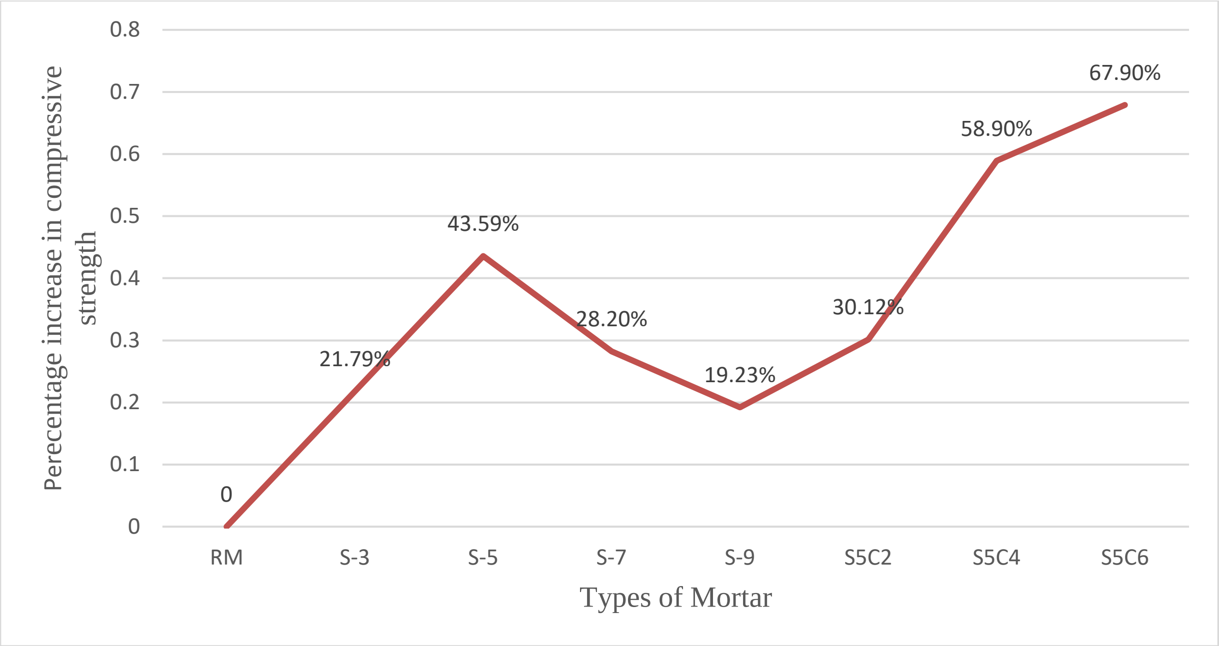

Figure 4. 2 Graphical representation of percentage increase in compressive strength with respect to RM

Figure 4. 3 Failure of cube due to compressive loading

4.5 PHYSICAL PROPERTIES OF LIME MORTAR

4.5.1 Water Absorption

Water absorption test was carried to find out the how porous the mortar was. For good mortar, the water absorption should be less than that of bricks. Due to presence of amylopectin in high amount in sticky rice it forms gelatinous network enhanced water absorption. Sticky rice lime mortar's water absorption is comparatively more than that of reference mortar without additive. The values of water absorption can be observed from Table 4.8. The average value of water absorption for RM was 12.48% and for S-5 it was 14.86% which is greater than previous one. So, we can say that water absorbed by S-5 mortar is comparatively more. This problem was overruled by adding cellulose with sticky rice in lime mortar. Cellulose considerably decreased the water absorption. Water absorption for S5C6 came out to be 6.53% which makes it suitable to be added in lime mortar. Table 4.8 below show the water absorption for different mortar specimen. Figure 4.4 shows the graphical variation of water absorption for different specimen

Table 4. 8 Water absorption for different mortar samples

Reference Mortar	Values of water absorption (%)
1	12.20
2	12.45
3	12.80
	Average= 12.48%
S5 Mortar	
1	16.95
2	13.33
3	14.28
	Average= 14.85%
S5C6 Mortar	
1	5.88
2	7.25
3	6.47
	Average=6.53%

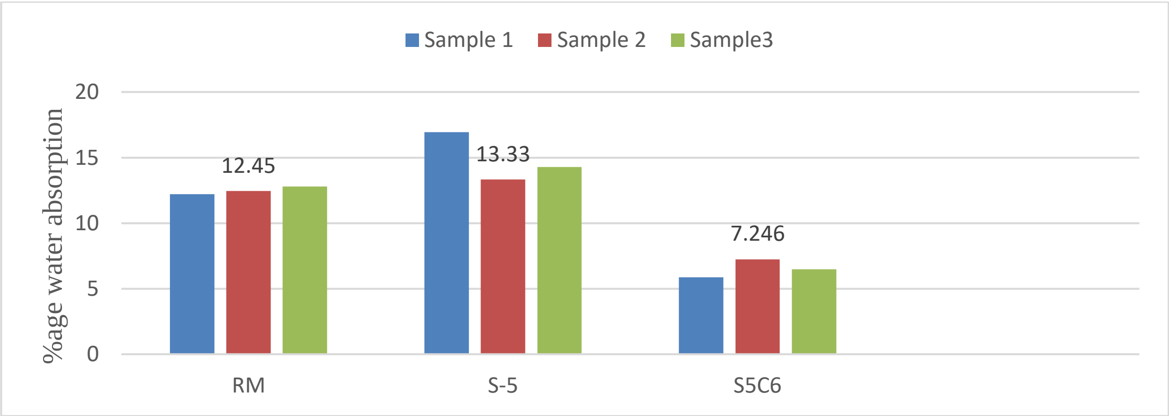

Figure 4. 4 Graphical variation of water absorption

4.6 MECHANICAL PROPERTIES OF LIME MORTAR

4.6.1 Tensile Strength

Cylindrical sample with diameter 65mm and length 130mm was utilized for checking tensile strength. Mortar was filled in mould and kept for 3 days. After 3 days specimen was removed from mould and left for air curing for 25 days to get 28 days strength. After 28 days specimen was subjected to compressive load using Brazilian testing machine. Figure 4.6 depicts the failure pattern of cylindrical specimen. It has been observed that there was considerable increase in tensile strength when optimized proportion of sticky rice was added to lime mortar. From Table 4.10 average percentage increase in tensile strength was 36.36% After addition of cellulose tensile strength increased by 65.50%.

Table 4. 9 Values of Tensile Strength

Reference Mortar	Values of tensile strength (MPa)
1	0.52
2	0.58
3	0.55
	Average= 0.55 MPa
S-5 Mortar	
1	0.70
2	0.78
3	0.76
	Average= 0.75 MPa
S5C6 Mortar	
1	0.98
2	0.93
3	0.99
	Average=0.96 MPa

Table 4. 10 Percentage increase in tensile strength with respect to reference mortar

Type of Mortar	Average Tensile Strength (MPa)	Percentage increase in tensile strength with respect to RM
RM	0.55	---
S-5	0.75	36.36%
S5C6	0.96	65.50%

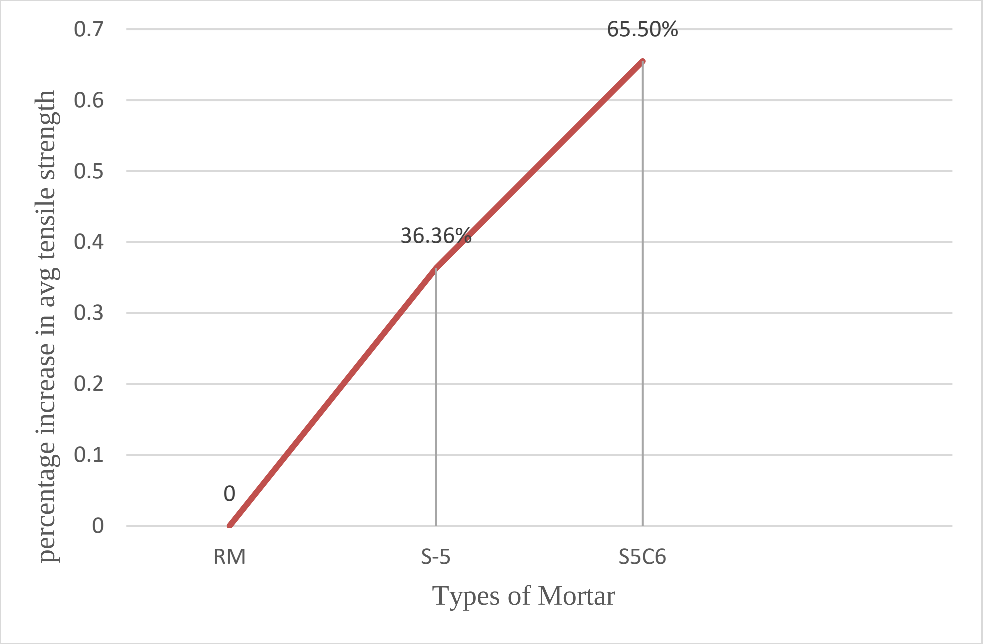

Figure 4. 5 Average percentage increase in tensile strength with respect to RM

Figure 4. 6 Failure of cylindrical specimen

4.6.2 Shear Bond Strength

This test was designed to assess the shear bond strength of various mortar specimens. The procedure involves the use of brick triplets that were built and then subjected to axial compression loading with a universal test equipment. The goal was to assess the bond performance between bricks and mortar under shear stress conditions. The test setup allowed for an exact assessment of each triplet assembly's peak load before failure. The observed peak load values and the known bonded area between the bricks were used to compute the related shear bond strength. The Table 4.11 summarizes the results, which include the peak load and calculated shear bond strength for various mortar mixtures. It has been found from table below that average percentage increase in strength of S-5 with respect to RM is 18.18% and that of S5C6 is 55.11%. For reference mortar the average value of bond strength came out to be 0.176 MPa and for S-5 it was 0.208 MPa and in addition of 6% cellulose it increases to 0.273 MPa. The failure of specimen can be seen from Figure 4.7.

Table 4. 11 Bond Strength values

Reference Mortar	Peak Load (KN)	Area of interface (mm^2)	Shear Bond Strength (MPa)
1	7.50	210*100	0.178
2	7.35	212*100	0.173
3	7.47	210*100	0.177
			Average=0.176MPa
S-5			
1	8.90	214*100	0.208
2	8.87	210*100	0.211
3	8.75	212*100	0.206
			Average=0.208MPa
S5C6			
1	11.50	212*100	0.271
2	11.35	210*100	0.270
3	11.59	212*100	0.273
			Average=0.273MPa

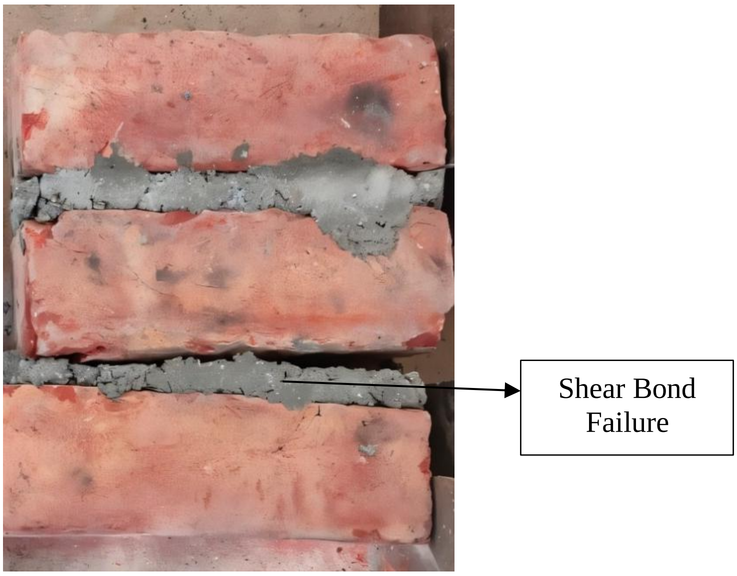

Figure 4. 7 Shear failure of specimen

4.7 DURABILITY TEST ON LIME MORTAR

4.7.1 Carbonation Depth

Carbonation is the reactivity tendency of lime with atmospheric CO_2 to form calcium carbonate. It can affect both strength and durability. This test was done by applying 1% phenolphthalein solution on mortar cubes after 28 days and after 90days of casting. From Fig. 4.3. it is observed that at the age of 28 days almost no carbonation was observed. The depth of carbonation increased after 90days is illustrated in Table 4.12 Carbonation depth increased after 90days but depth of carbonation for S-5 is still lower than that of RM. The carbonation depth of RM come out to be 2.30cm and for S-5 it was 2.17cm. After addition of cellulose with sticky rice in lime mortar there was increase in carbonation depth at the age of 90 days. For S5C6 carbonation depth was 3.80cm.

Figure 4. 8 Carbonation at the age of 28 days and 90 days

Table 4. 12 Average carbonation depth at the age of 90 days

Type of Mortar	Carbonation depth(cm)
RM	2.30
S-5	2.17
S5C6	3.80

4.7.2 Wetting and Drying Test

The wetting and drying test was performed to determine the weathering resistance of lime mortar specimens. This test replicates the natural climatic conditions in which mortar is subjected to alternate cycles of wetting and drying, which can have a substantial impact on its durability over time. Each specimen underwent 25 cycles, with the major measure being the % loss in mass, which reflects the degree of material degradation caused by weathering.

According to the findings in Table 4.13, the reference mortar (RM), which was made without any organic additions, had a mass loss of 2.93% after 25 cycles. In comparison, the mortar sample with 5% sticky rice addition (S-5) had a much-reduced mass loss of 1.74%, or approximately 40.6% less than the reference mortar. This finding demonstrates the beneficial effect of sticky rice in improving the durability of lime mortar.

When cellulose was added to the modified sticky rice mixture, the results improved much further. The modified sticky rice mortar lost significantly less mass (1.176%) and shown improved weathering durability. This demonstrates that adding sticky rice and cellulose as organic additives in lime mortar improves its performance under harsh environmental conditions. The synergistic action of these organic components improves internal bonding and decreases microcracking after repeated moisture exposure. Such enhancements are critical for constructions subjected to alternating wet and dry conditions. Overall, the study found that adding cellulose to sticky rice-enhanced mortar provided the best resistance to wetting and drying cycles. Figure 4.9 depicts the percentage loss in mass for several mortar samples, visually demonstrating the efficacy of utilizing organic additives to increase the long-term durability of lime mortar.

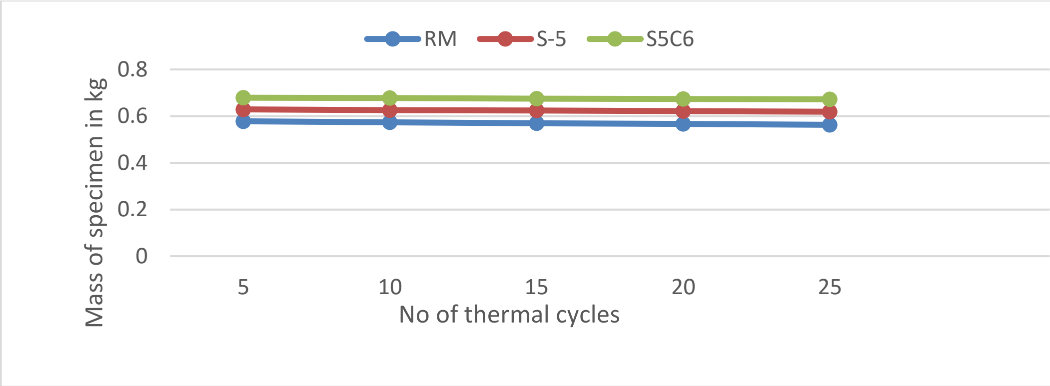

Figure 4. 9 Graphical variation of percentage loss in mass due to different cycle

Table 4. 13 Loss in mass due to wetting and drying

Type of Mortar	Number of cycles	Mass (kg)
RM	0	0.58
	5	0.578
	10	0.574
	15	0.569
	20	0.567
	25	0.563
S-5	0	0.630
	5	0.629
	10	0.626
	15	0.624
	20	0.621
	25	0.619
S5C6	0	0.680
	5	0.679
	10	0.678
	15	0.675
	20	0.674
	25	0.672

% age loss in mass for RM=2.93%

%age loss in mass for S-5= 1.74%

%age loss in mass for S5C6= 1.176%

4.7.3 Acid Attack

Acid attack test was done to investigate the resistance of mortar against acid attack. Moreover, it also analyses resistance against sulphate attack as the acid used in sulfuric acid. The percentage decrease in weight was observed after 28 days of submergence in acid. Decrease in weight for RM came out to be 15.5% for S-5 was 10% and for S5C6 it was 7.2%. This shows that S5C6 is performing better under acidic environment. Tables below show the decrease in weight of different mortar samples.

4.7.4 Alkali Attack

This test was done to determine the resistance of various mortar compositions to alkali attack. The major goal was to determine how sticky rice water and the inclusion of cellulose affected the durability of lime mortar when exposed to alkaline environments. The alkali assault significantly reduced the compressive strength of the specimens. The reference mortar (RM), which had no additives, showed a considerable decline in compressive strength following exposure to alkali, with a percentage fall of around 35%. In comparison, the sample labelled S-5, which contained 5% sticky rice water, showed improved alkali resistance, with only an 11.96% drop in compressive strength. This suggests that the use of sticky rice increases the durability of lime mortar in alkaline settings. Furthermore, adding cellulose to the adjusted sticky rice mixture resulted in even greater improvement. The sample that had both 5% sticky rice water and cellulose showed the least decline in strength, with a decrease of only 10.31%. This shows that cellulose works synergistically to improve the mortar's alkali resistance. Table 4.15 shows the compressive strength values before and after alkali exposure, as well as the calculated percentage strength drop for each sample.

Table 4. 14 Decrement in compressive strength due to alkali attack

Reference Mortar	Initial compressive strength (MPa)	Final compressive strength (MPa) after 28 days
1	1.580	1.030
2	1.500	1.012
3	1.600	1.000
		Avg decrease= 35%
S-5		
1	2.12	1.978
2	2.04	1.953
3	2.56	1.985
		Avg decrease= 11.96%
S5C6		
1	2.60	2.32
2	2.63	2.36
3	2.63	2.37
		Avg decrease=10.31%

CHAPTER 5

SUMMARY, CONCLUSIONS AND FUTURE SCOPE

5.1 GENERAL

This chapter presents a detailed review of the research conducted to investigate the impact of sticky rice water and modified sticky rice water on the engineering qualities of limestone mortar. It revisits the study's basic aims, describes the experimental approach used, and highlights the important findings from the numerous tests done. The study sought to investigate the possibility of traditional organic additives for improving lime mortar performance, with a particular emphasis on compressive strength, workability, and overall durability. The study used systematic testing to determine the ideal percentage of sticky rice-based additives that resulted in better mortar performance than the control mix. The conclusions reached in this chapter are based on a rigorous study of the test results and their comparison to existing literature, providing scientific validity for traditional construction procedures. This chapter summarizes the findings while also highlighting the study's shortcomings and proposing possibilities for future research. This includes recommendations for long-term durability testing, microstructural research, and practical applications of the modified lime mortar in restoration and sustainable construction techniques. Overall, the chapter strives to integrate research findings while paving the road for future innovation and progress in the use of bio-based materials in building.

5.2 SUMMARY

This study focuses on increasing the engineering qualities of lime mortar by incorporating sticky rice water and its modified form with cellulose. Lime mortar, which is historically significant and commonly employed in heritage projects, is prized for its flexibility, breathability, and compatibility with old materials. However, its limitations, like as low early strength and excessive porosity, render it unsuitable for modern construction without modification. Drawing inspiration from historical traditions such as those utilized in the Great

Wall of China and different Indian structures, organic additions such as sticky rice have demonstrated the capacity to improve strength and durability. The experimental work in this study looked at the effect of sticky rice water applied in different quantities (3%, 5%, 7%, and 9% by weight of lime) to determine the best amount for compressive strength. The best results were obtained with 5% sticky rice. Following that, cellulose was added in quantities of 2%, 4%, and 6% to the optimized 5% sticky rice-lime mortar to increase mechanical and durability features. Compressive strength, tensile strength, water absorption, shear bond strength, acid and alkali resistance, and weathering resistance were all tested in the lab using wetting and drying cycles. Workability and carbonation depth were also evaluated. The results consistently showed that sticky rice and its cellulose modification improved performance significantly when compared to the reference mortar. While sticky rice alone increased strength and bonding, the inclusion of cellulose greatly improved water resistance and reduced porosity, making the modified mortar more resistant to harsh environmental conditions. The findings encourage the use of old materials and modern technology to create sustainable, eco-friendly alternatives suited for both historical restoration and new construction.

5.3 CONCLUSIONS

The purpose of this study was to assess the impact of sticky rice water and its modified form (including cellulose) on the physical, mechanical, and durability qualities of lime mortar. According to a thorough experimental examination, the following findings can be drawn:

1. The lime mortar without any additive had an average compressive strength of 1.56 MPa. Adding 5% sticky rice water boosted the strength to 2.24 MPa, representing a 43.59% improvement. With the addition of 6% cellulose to the 5% sticky rice mix, the strength increased to 2.62 MPa, for a total increase of 67.90% above the reference mix.
2. Tensile strength for the lime mortar without additive was 0.55 MPa. It rose to 0.75 MPa with 5% addition of sticky rice (36.36% increase) and 0.96 MPa when 6% cellulose was added in 5% sticky rice (65.50% increase), demonstrating improved resistance to cracking and tensile failure.

3. 5% addition of sticky rice to lime mortar improved bond strength from 0.176 MPa to 0.208 MPa (18.18% increase). Further on addition of 6% cellulose to 5% sticky rice bond strength increased bond strength of 0.273 MPa, which was 55.11% greater than the reference mortar, showing improved mortar-brick adhesion.
4. The water absorption of the lime mortar without additive was 12.48%. With 5% addition of sticky rice, it increased to 14.85%, due to the gelatinous nature of amylopectin in rice water. However, when 6% cellulose was added to 5% sticky rice in lime mortar, water absorption dropped drastically to 6.53%, showing a 47.67% reduction compared to RM and making it more water-resistant.
5. After 25 cycles, the lime mortar without additive had 2.93% mass loss, whereas the sticky rice mortar had 1.74% (a 40.6% improvement). The modified sticky rice mortar demonstrated just a 1.176% loss, representing a 59.87% improvement over the reference.
6. The average weight loss of lime mortar without additive after acid was 15.5%, sticky rice mortar lost 10%, and modified sticky rice mortar lost only 7.2%.
7. There was decrease of about 35% in lime mortar without additive, after addition of 5% sticky rice it dropped to 11.96% Further, it decreased to 10.31% on addition of 6% cellulose in 5% sticky rice.
8. The carbonation depth was 2.30 cm for RM, 2.17 cm for sticky rice mortar (lower carbonation), and 3.80 cm for modified sticky rice, indicating increased reactivity in long-term exposure while maintaining strength.
9. Thus, modified sticky rice lime mortar with 5% sticky rice and 6% cellulose with 1:3 lime sand mortar is a sustainable, long-lasting, and effective solution for both heritage restoration and current eco-friendly construction.

5.4 FUTURE SCOPE

The findings of this study clearly demonstrate the potential of sticky rice and modified sticky rice (with cellulose) as long-lasting and performance-enhancing additives in lime mortar. However, this study suggests various directions for future investigation. To begin, the modified mortar's long-term durability under natural environmental circumstances must be evaluated over longer periods of time (6 months to several years) in order to establish its effectiveness in real-world scenarios. Second, large-scale field trials should be done, particularly in historic restoration initiatives, to validate laboratory results under real-world conditions. Furthermore, compatibility tests between modified lime mortar and numerous ancient masonry materials, such as sandstone, marble, and clay bricks, will be critical for conservation efforts. Microstructural investigation, such as XRD, SEM-EDS, and FTIR, can help understand internal changes and bonding mechanisms at the microscopic level. Furthermore, features such as thermal insulation, sound absorption, and fire resistance can be assessed to determine its suitability for environmentally friendly and energy-efficient building. Future research can look into the usage of additional locally available natural additions such jaggery, neem, cactus mucilage, or bael fruit to identify more sustainable options. A full life cycle analysis (LCA) can be performed to compare the environmental impact of this material to traditional cement mortar. Finally, based on ongoing research, standardized standards and requirements can be produced to encourage the practical use of organic-modified lime mortars in both restoration and current construction sectors.

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[1] Singh, S., Pal, S., and Saggu, K. (2025), "Influence of Sticky Rice and Modified Sticky Rice on the properties of Lime Mortar" 16th International Conference on Recent Engineering & Technology held on 16th & 17 th May 2025 at East West College of Engineering, Bangalore, India.


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