M.Tech (Structural Engineering) Monika Yadav 2023

# EXPERIMENTAL STUDY ON ADDITION OF ORGANIC ADDITIVES IN LIME MORTAR

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE
OF

MASTER OF TECHNOLOGY
IN
**STRUCTURAL ENGINEERING**


Submitted by:

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## CANDIDATE'S DECLARATION

I, **Monika Yadav**, Roll No. 2K21/STE/15, student of M. Tech (Structural Engineering), hereby declare that the project dissertation entitled "**Experimental Study on Addition of Organic Additives in Lime Mortar**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi (**MONIKA YADAV)**

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# CERTIFICATE

I hereby certify that the Project Dissertation entitled "**Experimental Study on Addition of Organic Additives in Lime Mortar**" which is submitted by Monika Yadav, Roll No. 2K21/STE/15, to Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the 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, 2023

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# ABSTRACT

Lime has been crucial part of early construction works, used for centuries. Old structures made with lime as mortar has shown exceptional performance in their lifetime, however despite these structures showing their exceptional behaviour in terms of durability and performance, these structures have also gone through many distresses, and some of them need repair and restoration. Durability is one of the most significant parameters of old masonry structures. It has been witnessed that organic additives present in the old mortars have enhanced the properties of these mortars. In India, historical structures have been built using animal and plant extracts as an additive.Therefore, understanding the behaviour of these additives and their impact on the durability of the mortar is required.

Unfortunately, the physical and mechanical properties of organic based lime mortar are not documented and need more research emphasis. The amount in which these organic additives are added to shows better result is yet to be determined. There is very less study on the bond strength of the organic additives-based lime mortar. Although lime has shown incredible behavior in terms of durability but there is few research related to the durability criteria of the lime mortar and organic additive-based lime mortar.

This study suggests the possible interaction of organics like jute, jaggery, and egg with lime, to simulate the mortar used in old structures. Jaggery has been added after its fermentation in 10%, 12.5%, and 15% percentages. Raw jute fibre has

been used after chopping and incorporated in three different percentages i.e., 1%, 1.5%, and 2%, and percentages for egg are as 4%, 6%, 8%. Physical properties of these mortars are evaluated using tests like water absorption, workability etc., while for mechanical properties compressive strength and split tensile testing has been performed. Results reveal that mortar with jaggery as additive performs better in compression, jute based mortar has the best tensile strength, and egg based mortar has the least water affinity. Optimum percentage of additive is evaluated here and then it is used to study other engineering properties like durability and bond strength.

To determine the durability properties of these organic-based lime mortars, carbonation depth test, acid attack, alkali attack, and wetting and drying tests have been performed. Further, the bond strength of these organic lime mortar in brick masonry has been examined by performing a triplet test. According to the sulphuric acid attack test, the lime mortar with jute as an additive has shown the best results with only a 5% loss in strength which is 23% in standard lime mortar. In the alkali resistance test also, jute has shown exceptional behaviour with a strength loss of 1.5% which is 22% in standard lime mortar. In the triplet test, the shear bond strength of jaggery-based mortar in brick masonry is 27.77% higher than the standard lime mortar, hence showing the best result in the shear bond test.

# ACKNOWLEDGEMENT

I, **MONIKA YADAV**, 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 Dr. Shilpa pal Associate professor, 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 can only inadequately 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 education.

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 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 Rekha Yadav, my father Santosh Singh Yadav, my grandparents and my sister 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.

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# CHAPTER 1

# INTRODUCTION

## 1.1. HISTORICAL BACKGROUND OF THE MORTAR

India has a diverse range of traditional mortars that have been used in construction practices across different regions. These mortars are an integral part of India's rich architectural heritage. Here are some examples of traditional mortars found in various parts of India:

**Lime Mortar:** Lime mortar, consisting of lime, sand, and water, is one of the oldest and most widely used traditional mortars in India. It is renowned for its workability, breathability, and durability, making it suitable for historic structures like temples, forts, and palaces.

**Mud Mortar:** Mud mortar, also known as clay or earthen mortar, is made from a mixture of clay, sand, and water. It has been extensively utilized in rural areas for constructing low-rise buildings such as houses, huts, and village structures.

**Surkhi Mortar:** Surkhi mortar combines lime with finely ground burnt brick powder called surkhi. Surkhi acts as a pozzolanic material, enhancing the strength and durability of the mortar. Surkhi mortar has been commonly employed in historical monuments and buildings throughout India.

**Gypsum Mortar:** Gypsum mortar is composed of gypsum, sand, and water. It has traditionally been used for plastering walls and ceilings, particularly in regions with abundant gypsum deposits. Gypsum mortar offers good fire resistance and is easy to work with.

**Stone Dust Mortar:** Stone dust mortar is created by mixing stone dust, lime, and water. It is commonly utilized in areas where stone dust is readily available. This type of mortar is known for its excellent strength and durability.

**Kankar Lime Mortar:** Kankar lime mortar is made by combining kankar lime, sand, and water. Kankar refers to an impure limestone found in specific regions of India. Kankar lime mortar has been traditionally used in the construction of structures where kankar is abundant.

These examples represent the diversity of traditional mortars used in different parts of India. The selection of mortar depends on factors such as local material availability, regional construction practices, and the specific requirements of the structure or building.

Lime has been an essential element in ancient constructions, resulting in magnificent heritage structures. Lime mortar has been a crucial component of ancient Indian structures. These structures hold significant historical importance and lime has been used as a binder until the early 1900s. Lime has several advantages, including the fact that it is burnt at a lower temperature than cement during the production process, making it environmentally friendly and cost-effective. Lime production emits 20% less carbon dioxide than cement production and when lime mortar sets, it re-absorbs carbon dioxide. Lime is soft and flexible, allowing the building to move without cracking, and it has been described as "self-healing" due to this characteristic. Lime also permits the building to "breathe," allowing water to escape by evaporation, unlike cement where water can only escape by being absorbed into the bricks, risking dampness and erosion of the building substrate. Finally, lime is biodegradable and recyclable.

Although the usage of lime in construction has decreased due to the popularity of cement, it was discovered in the late 20th century that improper use of cement mortars can lead to the degradation of masonry, which is not the case with lime mortar brickwork. Cement has several advantages that meet the demands of modern construction, but it also has some drawbacks that cannot be overlooked in an era where eco-friendliness and sustainability are essential. $CO_2$ emissions are a critical parameter in assessing the eco-friendliness of a component, and Portland cement emits approximately 5-8% of the world's $CO_2$ emissions [1]. Studies have demonstrated that cement is incompatible with old building components such as old mortar, it can cause rapid degradation in existing buildings, and it has a shorter lifespan than ancient structures built with lime.

## 1.2. HERITAGE CONSERVATION

Lime mortar, blended with organic additives, has been widely used in India for constructing ancient structures of significant heritage value, which have demonstrated excellent strength and durability. This has prompted a renewed interest in the study of lime, particularly in the context of conservation projects aimed at repairing and restoring old structures. However, despite their exceptional durability, these structures have also experienced various forms of distress, such as thermal, chemical, and physical attacks, interventions, and earthquakes, over the course of their long lifetimes, necessitating repairs and restoration in some cases.

The Indian government places great importance on the conservation of historic buildings, not only to maintain their cultural significance but also to attract more tourists. This is evident in the various conservation projects being carried out. The preservation of cultural heritage is also recognized by international organizations such as UNESCO, which has established ICOMOS (International Council on Monuments and Sites) to support these efforts. It is crucial to protect these structures while retaining their authenticity and heritage value[2].

Humayun’s tomb is an example where traditional lime plaster is preferred over cement plaster as the latter was found incompatible with the structure during earlier restoration attempts. Marble dust, egg white, and lime are used in the final layer of lime plaster. Pakistan's Hiran Minar has demonstrated the superiority of lime mortar as a waterproof material. Charminar in Hyderabad, built in 1591, also used lime with natural additives such as jaggery and egg white [3], while the Indo-Islamic style included jute and straw. These examples highlight the compatibility of lime with traditional building materials, making it suitable for restoring architectural heritage.

## 1.3. ORGANIC ADDITIVES

Additives are typically blended into the base material during manufacturing or added during application, depending on the specific application and desired outcomes. Rigorous formulation and testing ensure compatibility with the base material and facilitate the desired enhancements in performance. Ultimately, additives play a crucial role in augmenting the properties and performance of construction materials, enabling more efficient and effective construction practices. In India, plant and animal extracts were added in lime mortar to increase its strength and durability. Locally available plants and animal derivatives have been used as organic admixtures in traditional lime mortar. However, there is limited knowledge about the use of herbs and their significance in the construction industry. In ancient times, buildings were not only constructed to withstand external forces but also to ensure the well-being of their inhabitants. The ingredients used in plaster and mortars helped to create a healthy environment as the building functioned like an organism. In India, various plant extracts have been used as admixtures in lime mortar, although their exact role is not fully understood.

There are reports suggesting that organic substances such as egg white, milk of figs, blood, beer, vegetable juices, tannin, animal glue, urine, and other natural polymers were added to lime mortars and concrete in ancient times to improve their durability. Various historic buildings were found to contain a wide range of other additives, including casein, beer, and oil mastics. The use of additives like nopal, which can be used as either a powder or mucilage, proteins in the form of animal glue and casein, and fatty acids like olive oil, have been found to enhance mechanical properties, water resistance, carbonation speed, and texture. These additives are compatible with traditional building materials and can be used for restoring architectural heritage and modern architecture featuring natural stone.

## 1.4. OVERVIEW OF BRICK MASONRY

Even today, mortar and brick are fundamental components of buildings and play a vital role in their construction. The bond between the brick and mortar is crucial in masonry structures and has been emphasized by various researchers, especially when the structures are subjected to in-plane and out-of-plane loads. Therefore, it is important to have ways to assess the strength of masonry bond.

## 1.5. SCOPE OF THE WORK

The present investigation is performed on hydraulic lime mixed with different organic additives i.e., jaggery, jute and egg at varying proportions. Tests have been performed to find its physical, mechanical, and durability-related properties. Analysing the behaviour of lime mortar with organic additives used in historic buildings is crucial for conservation and repair purposes, as it provides valuable information to experts studying these structures and enables them to protect them from various environmental conditions.

## 1.6. OBJECTIVE OF THE STUDY

The primary aim of the study is to check the engineering properties that can be incorporated by adding organic additives in lime mortar. The following are the primary goals of this research:

To prepare the lime mortar with organic additives such as jute, jaggery and egg and do the comparative analysis of lime mortar with organic based lime mortar.

- To check the efficacy of organic addition on physical and mechanical properties of lime mortar.
- To check the enhancement in durability properties of the mortar after adding optimum percentages of organic additives
- To check the bond strength of organic lime mortar in brick masonry after mixing additives in optimum percentages.

## 1.7. OUTLINE OF THE THESIS

The present thesis is for M. Tech dissertation and consists of five chapters.

At the beginning of this thesis, a brief introduction about the lime in construction industry, ancient structures and the use of organic additives in the formation of stronger binder. Based on the need for appropriate inputs for conservation experts, objectives are framed to address the concerns.

Chapter 2 provides a review of previous research that examines the physical, mechanical, and durability properties of lime mortar with additives. The chapter also discusses the use of various organic additives used in heritage structures to enhance material quality and the study their properties.

Chapter 3 describes an experimental framework developed from the literature reviewed, and details the characteristics of raw materials, the mortar preparation process, and the testing methods.

Chapter 4 exhibits different phases of study following the experimental procedures to discuss the physical and mechanical and durability behaviour of the organic modified lime mortar respectively.

The end of this thesis in Chapter 5 includes the conclusion and further work.

# CHAPTER 2

# LITERATURE REVIEW

A comprehensive literature review has been conducted, encompassing a range of studies that have been analysed beforehand. Through this process, gaps in works and conclusions are drawn from the reviewed literature. The presented literature review serves as a vital background to enhance comprehension of this thesis and serves as a foundation for a better understanding.

## 2.1. ADDITION OF ADDITIVES

An additive refers to a substance that is introduced into another material or product with the intention of altering its properties or improving its performance. In the construction industry, additives are commonly utilized to modify the characteristics of construction materials like concrete, mortar, paints, coatings, and sealants. These additives have the capacity to enhance various properties, including workability, strength, durability, setting time, adhesion, water resistance, and more. Construction additives can be categorized into different types, such as admixtures, fibers, pozzolans, waterproofing agents, bonding agents, stabilizers, colorants, and others, each serving a specific purpose based on the desired effect and project requirements.

### 2.1.1. Review on Jaggery based lime mortar

**Jayasingh and Selvaraj (2020)** examined the interaction of organics, specifically kadukkai and jaggery, with inorganic lime mortar using chemical and analytical techniques such as XRD, FT-IR, TGA, and SEM. The addition of organic materials was found to enhance various properties of lime mortar, such as the carbonation process and durability. The addition of kadukkai and jaggery separately in the lime mortar increased the carbonation rate, while the hybridization of organics reduced the formation of calcium carbonate and increased the calcium oxalate. [4] The study demonstrated that the fermentation of carbohydrates in organic materials converts into carbon dioxide, which reacts with the lime mortar and precipitates calcium carbonate, enhancing the strength and durability of the structure.

**Thirumalini et. al. (2017)** investigated the physical and mechanical properties of lime mortar with the addition of organic materials. Specifically, the effect of kadukkai and jaggery on the lime mortar was analysed using different techniques such as compressive strength, water absorption, and porosity tests. [5] The results showed that the addition of organic materials in lime mortar increased its compressive strength, reduced water absorption, and decreased porosity. The study concluded that organic materials could be used as an alternative to traditional additives in lime mortar, resulting in better physical and mechanical properties.

### 2.1.2. Review on Organic Natural fibre based lime mortar

**Kesikidoua and Stefanidou (2019)** focused on investigating the behaviour of natural fibers, including jute, coconut, and kelp, in cement and lime mortars. The results showed that the addition of natural fibers in mortars increased their flexural strength and fracture energy, regardless of the fiber type, but dependent on the percentage added. Lime mortars showed a more significant increase in flexural strength, with jute-reinforced mortar being three times stronger than the reference mortar. However, the behavior of the mixtures under compression was different, with cement mortars having a decrease in strength, while lime-reinforced mortars presented an increase of 250% [6]. The addition of natural fibers in cement mortars led to an increase in shrinkage, while kelp fibers presented the lowest volume deformations in lime mortars. The study concluded that the use of natural fibers in mortars is beneficial for strength, durability, economic, and environmental reasons. Bio-fibers are recycled materials that could be promoted in the construction sector, but further investigation is needed to improve their behavior considering their shape, consistency, tensile strength, and adhesion to the mortar matrix.

**Tiwari et. al. (2020)** investigated the effect of adding jute fibers on the mechanical properties and durability of concrete. Different percentages of jute fibers were added to the concrete mix, and tests were conducted to determine the compressive strength, splitting tensile strength, flexural strength, water absorption, water penetration, and acid resistance. The results showed that the addition of jute fibers improved the concrete's mechanical properties and durability, with an optimum percentage of 1% for compressive strength and 1.5% for splitting tensile and flexural strength [7] .The authors attributed these improvements to the ability of jute fibers to form a protective layer around the concrete matrix. The study concluded that jute fiber can be an alternative to traditional steel reinforcement in concrete, but further research is needed to evaluate its long-term behaviour and performance under environmental factors.

### 2.1.3. Review on Egg based lime mortar

**Lu and Hall (2014)** investigated the effects of adding egg to lime mortar. The study includes laboratory experiments that analyse the physical, mechanical, and microstructural properties of the lime mortars with different percentages of egg. The results showed that the addition of egg to lime mortar can improve its workability, setting time, and mechanical properties, such as compressive strength and flexural strength. However, an excessive amount of egg can cause negative effects on the properties of the mortar. Microscopic analysis revealed that the addition of egg can lead to the formation of calcium carbonate crystals, which can enhance the durability of the mortar [8] .The study concluded that egg can be a useful organic additive for lime mortar, providing better performance and durability. However, further research is needed to investigate the long-term effects of egg on the properties of lime mortar.

**Md Azree (2017)** discussed the use of egg white as an additive in lime-based mortar. The study aimed to determine the effects of egg white on the compressive strength, water absorption, and setting time of the lime-based mortar. Three different mix proportions were tested, with varying percentages of egg white (2%, 4%, and 6%,8%,10%) added to the lime-based mortar [9]. The results showed that the addition of egg white improved the compressive strength and reduced the water absorption of the lime-based mortar. The setting time of the mortar was also found to be shorter with the addition of egg white.

## 2.2. HISTORICAL STRUCTURE AND MONUMENTS BUILT USING ORGANIC ADDITIVES IN LIME BASED MORTAR

**Moropoulou et. al. (2005)** evaluated the strength development and lime reaction of restoration mortars with similar chemical compositions to historic mortars. Several mixtures were tested in the laboratory for their chemical and mechanical properties up to 15 months of curing. The results indicated that most of the mortars had a slow rate of chemical and mechanical evolution, except for hydraulic lime mortar and mortar with lime putty-natural pozzolanic addition.

**Degloorkar et.al. (2020)** The study involved the collection of samples from various locations in the site and the use of different analytical techniques, such as X-ray diffraction, scanning electron microscopy, and energy-dispersive X-ray spectroscopy, to analyze the composition and microstructure of the mortar. The results of the study revealed that the ancient mortar was composed of lime, sand, and coarse aggregates, and that it exhibited good mechanical properties, such as high compressive strength and good adhesion to the masonry. The microstructural analysis also revealed the presence of various phases, such as calcium hydroxide, calcium carbonate, and silica, which contributed to the strength and durability of the mortar. Based on the results of the study, the authors concluded that the ancient mortar exhibited excellent properties and was an effective material for the construction of heritage structures.

**Pinteaa et. al. (2019)** discussed the use of natural polymers as additives to traditional mortars to improve their physico-mechanical properties. The authors conducted experiments to determine the optimal concentration of natural polymers and the effect of various factors, such as curing time and temperature, on the performance of the modified mortars. The results showed that the addition of natural polymers increased the compressive and flexural strength of the mortars, as well as their water absorption and resistance to freeze-thaw cycles. The study suggests that the modified mortars could be used in various construction applications, particularly in situations where high performance is required.

**Ventolà et. al. (2011)** found in their study various natural materials such as surkhi, batasha, urad ki dal, egg whites, malai, tambacoo sheera, jute, and belgiri were used as additives in mortars during the Mughal period in India. Jaggery was also mixed with lime, sand, and clay to make cement for stacking bricks. The use of additives such as sugar and jaggery in concrete can reduce segregation. The organic mortar used in Delhi's medieval buildings contained cow dung, schinduf, lentils, yogurt, and apple or bael pulp, allowing moisture to pass through the building [10]. The Rang Ghar, a two-story octagonal structure, was built with jaggery, black gram, elephant grass, limestone, glue removed from snails, lime powder, long fish bones, mustard oil, incense, bricks, and stones.

## 2.3. CARBONATION PROCESS IN LIME MORTAR

**Cizer and Bilir (2017)** investigated the effects of carbonation on the mechanical properties of lime mortar were investigated. Lime mortars with different proportions of sand were prepared and carbonated under controlled conditions for up to 180 days. The results showed that carbonation had a significant effect on the mechanical properties of lime mortar, including compressive and flexural strength, as well as modulus of elasticity. The degree of carbonation also influenced the mechanical properties of lime mortar, with higher degrees of carbonation resulting in increased strength. Additionally, the porosity and microstructure of the lime mortar were found to change as a result of carbonation [11]. Overall, the study provides insight into the long-term behavior of lime mortar in carbonated environments, which is important for the preservation of historic masonry structures.

**De Silva and Thambiratnam (2006)** found that carbonation does occur in lime mortar and affects its compressive strength. The rate of carbonation was found to be dependent on the environmental conditions and the porosity of the mortar. The results also showed that lime mortars with higher porosity had lower compressive strength after carbonation [12]. The findings of this study have important implications for the conservation and restoration of historic masonry structures, as it highlights the need for careful consideration of the properties of the mortar used in repairs to ensure long-term durability and stability of the structures.

**Oh and Kim (2013)** discussed a non-destructive method for determining the depth of carbonation in lime mortar used in historic buildings. The method is based on pH measurement and was tested on lime mortar samples prepared under controlled laboratory conditions as well as on actual historic buildings. The results showed that the method was effective in measuring the depth of carbonation, and that the depth of carbonation increased with exposure time [13]. The authors conclude that the pH measurement method is a useful tool for evaluating the condition of lime mortar in historic buildings, and can provide valuable information for the planning of restoration and conservation activities.

## 2.4. CURING PROCESS FOR LIME MORTAR

**Made and Dubey (2020)** investigated the effect of curing temperature on the properties of lime-based mortars was investigated. Four different curing temperatures, ranging from 5°C to 40°C, were used to cure the mortars for 28 days. The mechanical properties, water absorption, and microstructure of the mortars were evaluated. The results showed that increasing the curing temperature significantly increased the compressive strength of the mortars, with the highest strength obtained at a curing temperature of 40°C [14]. However, the water absorption of the mortars decreased as the curing temperature increased. The microstructural analysis revealed that the porosity of the mortars decreased with an increase in curing temperature.

## 2.5. SHEAR BOND STRENGTH OF BRICK MASONRY

**Lourenço et. al. (2002)** the authors investigate the shear bond strength of lime mortar in ancient masonry structures using a triplet test. The study involved testing samples of different types of masonry with different surface treatments and joint geometries, and comparing the results with those of existing tests. The results showed that the shear bond strength of lime mortar in ancient masonry structures is affected by the type of masonry, joint geometry, and surface treatment [15]. The authors also discuss the limitations of the triplet test and suggest further research to improve its accuracy. The study provides valuable information for the preservation and restoration of historical masonry structures.

**Hernandez et al. (2018)** investigated the effect of mix design on the shear bond strength of lime mortars used in historic masonry structures. Different mixtures of lime mortars with varying binder content, water/binder ratio, and aggregate gradation were prepared and tested using a triple-lap direct shear bond test [16]. The results indicated that the mix design significantly influenced the shear bond strength of lime mortars. Increasing the binder content and decreasing the water/binder ratio improved the shear bond strength, while increasing the aggregate gradation decreased the shear bond strength. The study suggests that selecting an appropriate mix design is crucial for achieving sufficient shear bond strength in historic masonry structures.

**De Oliveira et. al. (2021)** evaluated the shear bond strength of lime mortars in brick masonry using the triplet test. The study involved the preparation of two types of lime mortars and their application to brick masonry specimens, followed by the determination of their shear bond strength using the triplet test. The results showed that the shear bond strength of the lime mortars was influenced by the type of mortar, with the hydraulic lime mortar having a higher shear bond strength than the non-hydraulic lime mortar [17]. The study concludes that the triplet test can be a reliable method for evaluating the shear bond strength of lime mortars in brick masonry structures.

## 2.6. SPLIT TENSILE STRENGTH

**Kumar and Kumar (2017)** investigated the influence of different organic additives on the split tensile strength of hydraulic lime mortar. The study includes the preparation of four different types of mortar mixes with varying proportions of additives such as wheat straw ash, rice husk ash, and sawdust ash. The split tensile strength test was conducted on the mortar specimens after curing for 28 days, and the results were analyzed [18]. The study found that the addition of wheat straw ash and rice husk ash in the mortar mix resulted in an increase in the split tensile strength, while the addition of sawdust ash resulted in a decrease in the strength. The research suggests that the use of organic additives can enhance the mechanical properties of hydraulic lime mortar and can be a sustainable option for the construction industry.

**Singh and Jha (2018)** investigated the effect of coconut fiber on the split tensile strength of lime mortar was investigated. Different proportions of coconut fiber, ranging from 0.25% to 1.5%, were added to the lime mortar mix, and the split tensile strength was measured using a standard testing procedure. The results indicated that the addition of coconut fiber to the lime mortar mix improved the split tensile strength of the resulting composite material. The highest improvement in split tensile strength was observed for the mortar mix containing 1% coconut fiber. However, it was found that the split tensile strength decreased with the addition of higher proportions of coconut fiber, i.e., 1.25% and 1.5% [19]. The study concludes that the addition of coconut fiber to lime mortar can improve its mechanical properties, and the optimum proportion of coconut fiber in lime mortar mix is around 1%.

## 2.7. WETTING AND DRYING PROCESS

**Arizzi et. al. (2007**) investigated the drying and wetting behavior of traditional and industrial lime-based mortars. The authors use different techniques, including thermogravimetric analysis, mercury intrusion porosimetry, and scanning electron microscopy, to analyze the physical and microstructural changes of the mortars after drying and wetting cycles. The results suggest that traditional lime-based mortars have better resistance to water than industrial mortars, with less deformation and cracking [20]. Additionally, the authors find that the presence of a small amount of Portland cement in the industrial mortar improves its resistance to water, but also increases the risk of cracking due to shrinkage. Overall, the study highlights the importance of understanding the behavior of different types of lime-based mortars under various environmental conditions to ensure their long-term durability in historic masonry structures.

**Desideri and Goffredo (2015)** conducted an experimental study to investigate the effect of wetting and drying cycles on the mechanical properties of lime-based mortars. The researchers evaluated the compressive strength, flexural strength, and tensile strength of the mortars after subjecting them to different numbers of wetting and drying cycles [21]. The results showed that the mechanical properties of the lime-based mortars decreased with an increasing number of wetting and drying cycles. The authors concluded that the durability of lime-based mortars may be compromised when exposed to a high number of wetting and drying cycles.

## 2.8. ALKALINE AND ACIDIC EXPOSURE CONDITION

**Sivakumar et. al. (2012)** investigated the effect of alkali exposure on the strength properties of lime mortar. The authors conducted an experiment where lime mortar cubes were exposed to different concentrations of sodium hydroxide and potassium hydroxide solutions for different durations. The study found that exposure to alkali solutions significantly affected the strength properties of lime mortar. The compressive and flexural strengths of the lime mortar cubes decreased with increasing concentrations of alkali solution and longer exposure durations. The researchers also observed the formation of secondary phases in the lime mortar samples exposed to alkali, which contributed to the deterioration of the material [22]. The study suggests that exposure to alkali environments should be considered when using lime mortar in construction applications, and appropriate measures should be taken to mitigate the detrimental effects of alkali exposure.

**Bangash et. al. (2016)** aimed to assess the durability of lime mortars subjected to alkaline and acidic environments. Lime mortar specimens were prepared and exposed to alkaline (NaOH) and acidic ($H_2SO4$) solutions. The specimens were tested for their compressive strength, water absorption, and visual appearance before and after exposure to the solutions. The results showed that the compressive strength of the lime mortars decreased after exposure to both alkaline and acidic environments. The specimens subjected to alkaline solution showed a higher decrease in strength compared to those subjected to acidic solution. The water absorption of the specimens also increased after exposure to the solutions [23]. The visual appearance of the specimens showed noticeable changes, including colour changes and surface erosion. The study concluded that the durability of lime mortars is affected by exposure to both alkaline and acidic environments, and further research is required to improve the durability of lime mortars in these conditions.

## 2.9. GAP IN THE STUDY

The study of ancient mortar has gained prominence as a result of the increase in attempts to preserve heritage buildings. As lime mortar is widely used in India along with organic additives, the characteristics of lime have been greatly improved.

- Unfortunately, the physical and mechanical properties of organic based lime mortar are not documented and need more research emphasis.
- The amount in which these organic additives are added to shows better result is yet to be determined.
- There is very less study on the bond strength of the organic additives-based lime mortar.

- Although lime has shown incredible behavior in terms of durability but There is few research related to the durability criteria of the lime mortar and organic additive-based lime mortar.

# CHAPTER 3

# EXPERIMENTAL PROGRAMME

The experimental program was undertaken to fulfil the objectives of the study. The procedure followed a step-by-step approach, starting from the procurement of raw materials to the evaluation of their fundamental properties. Subsequently, the specimens were prepared and a series of tests were conducted. A detailed account of each stage is provided in this section, outlining the comprehensive process involved in the experimental program.

Firstly, the additives were chosen from the literature review and were procured from the local dealer. Mortar mix was prepared as prescribed in the literature and cast in the desired moulds. The aim was to obtain the optimum percentage of additive required to enhance the engineering property. After finding the optimum percentage of the additive the alkali attack, acid attack and shear bond strength was performed on the specimens prepared from the optimum percentage of the additives.

Materials are procured from the local dealer in Delhi, India. In the present study lime is taken as the binder, natural river sand as the fine aggregate, bricks as basic building block, jaggery, jute, egg as the organic additives. On these raw materials some tests were performed to get the basic material properties of all raw materials. After that lime and sand were mixed in definite proportions. This mix was cast in the desired moulds i.e., cubes, cylinders and triplets. On the specimens different tests was performed to analyse the various engineering properties that depicts the physical, mechanical and durability related properties. Fig.3.1 depicts the step wise procedure that is adopted in this project work.

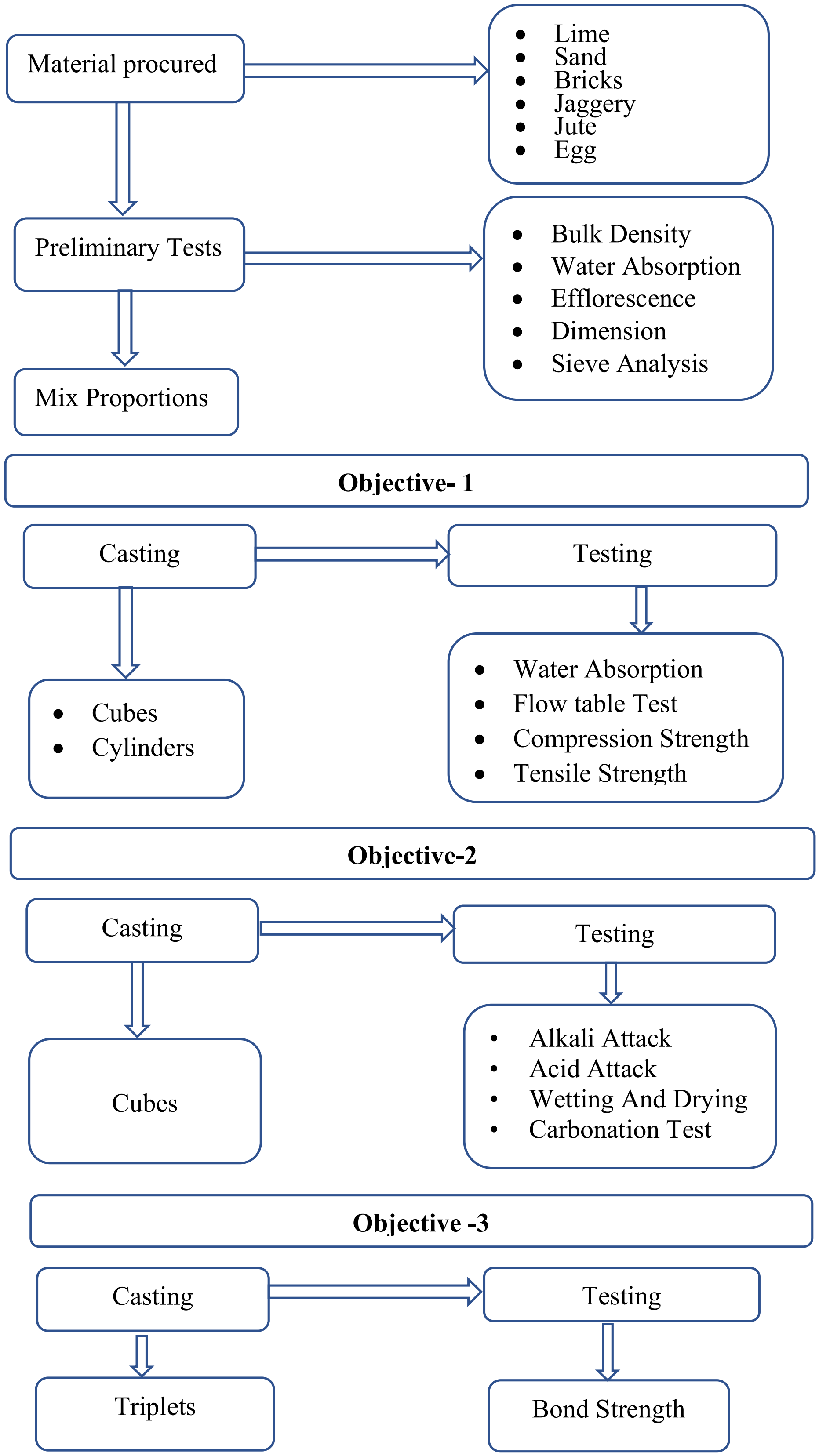


**Figure 3.1. Flow chart of the methodology**

## 3.1. MATERIALS

### 3.1.1. Lime

Lime is commonly used as a binder in various construction applications. It acts as a binding agent that helps hold together the particles of aggregate, such as sand or stone, in mortar. When mixed with water, lime undergoes a chemical reaction called hydration, which results in the formation of calcium hydroxide. This hydrated lime reacts with carbon dioxide from the air and gradually hardens, providing strength and durability to the construction material.

In this study Natural Hydraulic Lime Class, A, which appears white upon visual inspection is used. The bulk density of the lime is calculated that came out to be 874.63 Kg/$m^3$. Table 3.1 represents the properties of the binder i.e., lime as provided by the dealer.

**Table 3.1. Properties of Lime**

| Properties | Hydraulic lime |
|---|---|
| *Chemical Composition (%)* | |
| $Sio_2$ | 12.3 |
| $Al_2O_3$ | 0.6 |
| $Fe_2O_3$ | 2.7 |
| Cao | 66.4 |
| Mgo | 0.6 |
| $K_2O$ | 0.1 |
| Loi | 17.1 |
| *Physical Properties* | |
| Specific Gravity | 2.7 |
| Fineness($cm^2$/gm) | 3800 |
| Colour | White |

### 3.1.2. Sand

Sand is a crucial component of mortar, a substance used with binder material to bind bricks, stones, or other building materials together in masonry construction. The strength, workability, and durability of the finished product are greatly influenced by the quality of the sand used in the mortar. Here are some essential details regarding using sand in mortar:

Sand particle size and gradation have an impact on the mortar's capacity to be worked and its strength. Better packing and fewer voids are made possible by well-graded sand with a variety of particle sizes, creating a stronger mortar.

Workability: The amount of sand in a mortar batch will determine how readily it can be mixed, applied, and finished. Greater workability is provided by coarser sands, but finer sands could need more water to get the necessary consistency.

Durability: The completed structure's durability is influenced by the quality of the sand used in the mortar. The mortar might get weaker and function less effectively over time if the sand contains impurities like organic matter or large amounts of silt or clay.

In this study the natural sand is procured from a local supplier. To analyse its characteristics, the sand underwent a sieve analysis following the guidelines of IS 2116-1980 [24] to assess its particle size distribution. The sand's bulk density is determined to be 1750 kg/m$^3$ through calculations. These measurements yield significant insights into the sand's appropriateness for construction purposes.

### 3.1.3. Water

For the study, water was taken in accordance with IS 456-2000 [25], which specifies a minimum pH value of 6. Generally, drinkable water is deemed acceptable to be used for the mixing process of mortar.

### 3.1.4. Bricks

Bricks are considered the basic building block of the construction industry and was in use for many decades. Bricks are produced by shaping and firing clay in a kiln to achieve hardening. The quality of bricks is related to both the clay's quality and the temperature at which they are manufactured. They are available in diverse shapes, sizes, and colours, serving various construction purposes such as walls, pavements, arches, and columns. Conducting brick testing helps ascertain their strength, durability, and ability to endure the stresses and loads they will encounter during construction, ensuring their suitability for the intended use. Burnt clay bricks of class A were taken for the study, that are checked with basic properties like dimension, efflorescence, water absorption test. Its bulk density is determined to be 1890 kg/m$^3$ through calculations.

### 3.1.5. Organic additives

Additives can be either synthetic or organic. Organic additives refers to the substance derived from natural sources like plants or animals and are incorporated into different materials or products to improve the desired properties and performance. In the construction industry, organic additives are commonly employed to alter the attributes of concrete, mortar, or other building materials. For the current study, organic additives taken are jaggery, jute and egg.

The basic properties of all the raw material and additives are presented in Table 3.2.

**Table 3.2. Properties of raw materials**

| Material | Calculated Density (Kg/m$^3$) | Properties |
|---|---|---|
| Lime | 874.63 | Hydraulic lime Class A |
| Natural sand | 1750 | Well graded |
| Stone dust | 1778.42 | - |
| Brick | 1890 | Class A |
| Jaggery | 1180 | - |
| Egg | 1025 | - |
| Jute | 1150 | Cellulose =72%, Lignin = 13%, Water absorption = 215.9%, Length (average) =10 mm |

## 3.2. INITIAL STUDIES ON THE RAW MATERIALS

The initial phase of the study, sample tests were conducted using both natural sand and stone dust. A comparison was made, and it was found that the average compressive value for stone dust and natural sand was 2.81 MPa and 3.06 MPa, respectively. As a result, natural sand was selected for further experimental work.

Attempt was made for accelerated curing of the samples cubes according to the IS:9013-1978 [26], but the cubes were boiled and deformed showing bulging effect.

Now using above as prerequisite, the cubes for reference mortar were prepared with natural sand as fine aggregate and air curing was performed on them.

To prepare the mortar with organic additives these organic materials were first processed to ensure optimal results. Jaggery was crushed into small pieces and mixed in the water to prepare the solution. This solution is then fermented for one-month before being added to the mortar. This fermentation process enhances the carbonation process in the mortar and results in better strength gain.

Similarly, the mortar mixture was prepared using various percentages of egg white. Only the egg white or albumen was used for this study. Approximately 30 grams of egg white is present in one egg, and it is the protein present in the organic materials that interacts with $Ca(OH)_2$, thereby increasing the hydrophobic nature of the mortar [5]. Egg white contains nearly 40 different proteins [9]. The process in which the egg is added is shown in Fig. 3.2.

**Figure 3.2. Process of making egg mortar**

Raw jute fibers collected from the manufacturer as sutli, then this sutli was separated in fibres and chopped to a length of 1 cm. This processed sutli is then added in three different percentages. Now since jute fibre absorbs the water this could have used the water requires in the mortar to get the required workability. The water absorption test was performed on the fibres, so that the jute do not absorbs the water from the mortar and is saturated beforehand. The water absorption value came out to be 215.9%. The step wise process to add the jute in mortar mix is represented in Fig. 3.3.


**Figure 3.3. (i)Preparation of jute fibre, (ii)Water absorption test, (iii) Before mixing, (iv)After mixing**

Since the organic additives are added in different percentages to get the optimum percentage of additive required to be added. The percentages of additive were taken as shown in the Table 3.3.

**Table 3.3 Percentages of additives taken in the study**

| Mortar | Ref. Mortar | Jaggery Mortar | | | Egg Mortar | | | Jute Mortar | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Percentage of additives | - | 10% | 12.5% | 15% | 4% | 6% | 8% | 1% | 1.5% | 2% |
| Nomenclature | RM | J10 | J12.5 | J15 | E4 | E6 | E8 | Ju1 | Ju1.5 | Ju2 |

## 3.3. PREPARATION OF SPECIMENS

All materials were mixed in precise proportions using lime to sand ratio as 1:3 as specified in IS 712-1984 [27] for mortar preparation. The lime to sand ratio is typically expressed in terms of by weight.

The mortar was prepared by maintaining the binder to aggregate ratio for lime mortar and by adding the organic additives one by one to lime and sand mixture. All the components are mixed thoroughly in dry state and then the water is mixed. On this fresh mortar tests were performed to get the workability of the mortar and to get the water to binder ratio.

Then the mortar was cast in the different types of moulds like cubes and cylinder based on the tests that are going to be performed on it. The number of specimens prepared are mentioned in Table 3.4. Cylinder specimens were prepared for the split tensile strength test. Cube specimens were cast in 70.7 x 70.7x 70.7 mm moulds. All specimens were kept at a temperature of 27±2 0C inside the laboratory. After three days, the moulds were removed, and the specimens were left to air cure for 25 days to achieve 28 days strength. These specimens were very fragile to handle as they had very less strength. Then after 28 days of casting these specimens were tested. The different set of tests performed on the specimens are listed in Table 3.5.

**Table 3.4 Specimen calculation**

| Tests | Ref. mortar | Egg mortar | | | Jute mortar | | | Jaggery mortar | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 4% | 6% | 8% | 1% | 1.5% | 2% | 10% | 12.5% | 15% | |
| Compressive Test | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 30 |
| Tensile Test | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 30 |
| Wetting and drying | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 30 |
| Sulphate attack | 3 | - | 3 | - | - | 3 | - | - | - | 3 | 12 |
| Alkali attack | 3 | - | 3 | - | - | 3 | - | - | - | 3 | 12 |
| Triplet Test | 3 | - | 3 | - | - | 3 | - | - | - | 3 | 12 |

**Table 3.5. Tests performed on specimens**

| Physical tests | Mechanical test | Durability test |
|---|---|---|
| • Flow table<br>• Bulk Density<br>• Water absorption | • Compressive strength<br>• Split tensile/Flexural test<br>• Triplet test | • Wetting and Drying test<br>• Carbonation test<br>• Acid attack test<br>• Alkali attack test |

## 3.4. INVESTIGATION ON FRESH PHASE OF MORTAR

### 3.4.1. Workability

Workability refers to the ability of mortar to be easily manipulated and flow smoothly during its application in construction projects. It is an important characteristic as it directly influences the ease of handling and placing mortar in various construction activities such as bricklaying, plastering, and masonry work. Flow table test as per IS:2250-2000[28] was conducted to measure the flow, and the flow was kept between 90 mm and 130 mm as specified for workable mortar. Fig 3.4 represents flow table test conducted on egg, jute and jaggery mortar respectively.

**Figure 3.4. Flow table test on egg, jute and jaggery mortars**

## 3.5. INVESTIGATION ON HARDENED PHASE OF MORTAR

### 3.5.1. Water Absorption

Water absorption is measured as the percentage increase in mass to the dried mass of the specimen. Water absorption is the indirect indication of the porosity of the material, more will be the water absorption of the mortar more is the chances of the mortar to get damp and disintegrated. If the mortar is used in construction will be having more water absorption value than the brick in the corresponding brickwork then the water will get penetrated to the structure through this mortar. Hence the water absorption value of the mortar must be as low as possible or at least less than the brick with which they are used in construction. The weight of the mortar in dry state is denoted as $W_1$ and the weight after taking it out form submerged water is denoted as $W_2$, equation 3.1 is used to calculate the water absorption value.

$$\text{Water Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \qquad (3.1)$$

### 3.5.2. Compression Strength

A material's capacity to endure applied compressive stresses without experiencing considerable deformation or failure is referred to as its compressive strength. It is a crucial factor in determining the structural strength and stability of building materials. Compressive strength is crucial in the case of mortar since it indicates the material's capacity to bear compressive stresses and support the integrity of the entire structure. Bricks and mortar being the basic building blocks of the ancient structures the contribution of strength in compression of mortar is no less important than the compressive strength of brick.

Compressive strength test is conducted according to IS 2250-1981[28] on mortar cubes of 70.7 mm size. Three specimens of each category have been tested to get the average value. Fig 3.5 depicts the failure pattern on each additive.

**Figure 3.5. Failure of egg, jaggery, and jute mortar cubes, respectively**

### 3.5.3. Split Tensile Strength

The tensile strength of mortar plays significant role in several aspects of construction. Although mortar is mostly evaluated for its compressive strength, the tensile strength plays a crucial role in ensuring structural stability and preventing cracking or failure under tensile forces. Flexural strength, or mortar's capacity to withstand bending or stretching pressures, is influenced by tensile strength. Mortar with sufficient tensile strength helps distribute and resist these pressures efficiently in constructions exposed to bending or flexural stresses, such as beams or cantilevers.

The tensile strength of the mortar has been evaluated as per IS 10082-1981 [29]. All the specimens with different organic additives were tested for split tensile strength test in Brazilian testing machine. The progressive failure of the specimens can be seen in Fig. 3.6.

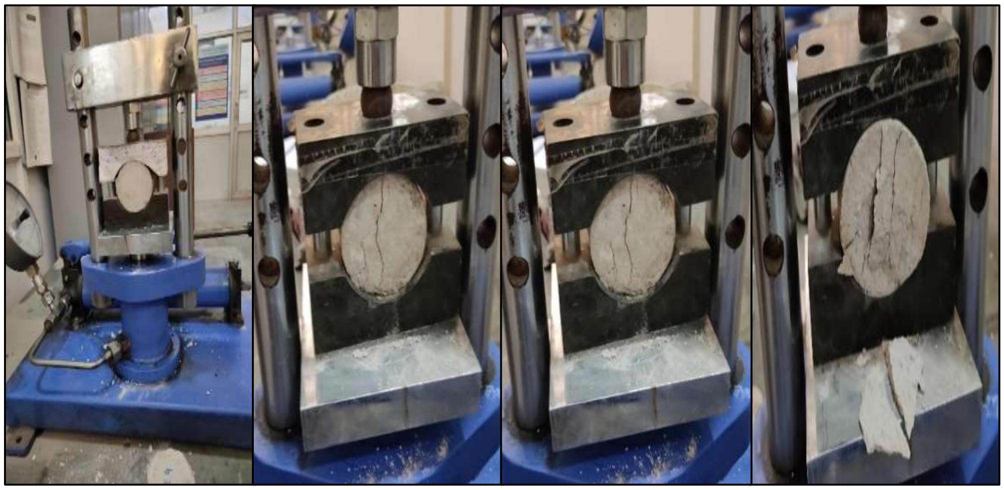

**Figure 3.6 Split tensile test: Progressive failure process**

## 3.6. INVESTIGATION OF DURABILITY PROPERTIES

### 3.6.1. Alkali attack

To evaluate the alkali resistance, 70.7 x 70.7 x 70.7 mm cubes were cast and air-cured for 28 days. The mortar cubes are then submerged in a 2% wt NaOH solution for 12 hours. After that, the samples were dried in an oven at $105^0$C for 4 hours according to the guidelines of GB/T 50082–2009 [30]. The compressive strength of the specimens before (C0) and after (C1) immersion in the NaOH solution was measured, and the strength loss was calculated using the equation (3.2) to determine the alkali resistance of the mortar. A greater strength loss indicates lower resistance to alkali, while a lower loss indicates greater resistance.

$$AR = (C0 - C1)/(C0) \times 100 \quad (3.2)$$

### 3.6.2. Acid attack

The objective of the acid attack test was to investigate the chemical deterioration that occurs when mortar specimens are exposed to dilute solutions of sulphuric acid, in order to simulate the damage that occurs to mortar structures under external exposure conditions. To evaluate the acid resistance of the mortar, the residual compressive strength was measured [31]. To conduct the acid resistance test, 70.7 x 70.7 x 70.7 mm cubes were cast and air-cured for 28 days. The initial weights of these specimens were recorded. A solution of sulphuric acid ($H_2SO_4$) with a volume concentration of 5% and a pH value of approximately two was prepared. The cubes were then submerged in this acid solution for 28 days. After 28 days, the surface of the cubes was examined, as shown in Fig 3.7. The reduction in compressive strength of the mortar specimens (AAR) was evaluated by measuring the compressive strength before (C0) and after (C1) immersion in the acid solution as shown in equation (3.3).

$$AAR = (C0 - C1)/(C0) \times 100 \quad (3.3)$$

**Figure 3.7. Cubes showing different type of failure after acid attack**

### 3.6.3. Carbonation

Carbonation test also known as the phenolphthalein test is the considered as the non-destructive test. This test was performed on all the mortars to check the depth of carbonation that has taken place in the mortars according to IS 516(Part 5/Sec 3) [32] .To determine the extent of carbonation, mortar cubes are tested using a 1% phenolphthalein solution. The solution is applied to the fresh fracture surface of the mortar cube and observed for 10 minutes to determine the depth of carbonation. In the present carbonation test was performed at two intervals i.e., 28 days and 90 days. Fig 3.8 shows the cubes on which carbonation test has been performed.

**Figure 3.8. Carbonation after 28 days and 90 days, respectively**

### 3.6.4. Wetting and drying

Mortar cube specimens were subjected to alternate wetting and drying cycles to understand the thermal resistance of the mortar mixes. The test is conducted as per RILEM TC 25-PEM (1980) [33]. Here, mortar cube specimens of each category were immersed in water at a temperature of 20 ± 5ºC for 16 h. And then dried in an oven at 105ºC for 6 h. The mass of each specimen is measured before and after each thermal cycle, a maximum of 20 cycles is considered or until a complete mass loss or disintegration occurs, whichever condition occurs early.

## 3.7. INVESTIGATION OF BOND STRNGTH PROPERTIES

### 3.7.1. Shear Bond Strength

Shear bond strength is the ability of a material to resist shear forces at the interface between two bonded surfaces. Shear bond strength is particularly relevant for mortar as it determines the strength of the bond between mortar and other materials such as bricks, or any block. Shear bond strength also helps to prevent the formation and propagation of cracks within the bonded interface.

A common technique for assessing the shear bond strength of masonry units, such as bricks or blocks, is the triplet test. In the present study, this test was performed according to standards BS EN 1052-3:2002 [34]. Since the setup for the triplet test was not available in the lab for the research work, a temporary setup was made with the help of a hydraulic jack of capacity 50kN as shown in Fig 3.9.

Before using bricks to prepare triplet specimens, the bricks were soaked in water to prevent them from absorbing water from the mortar mix during the formation of the bond between the brick and mortar. For the shear bond test, identical triplets were formed, each containing three bricks, with lime mortar and lime mortar with organic additives used as the binder. Equation (3.4) was used to calculate the shear bond strength.

$$\text{Shear bond strength} = \frac{P}{2A} \quad (3.4)$$

Where-

P = Peak Load

A = Cross-section Area

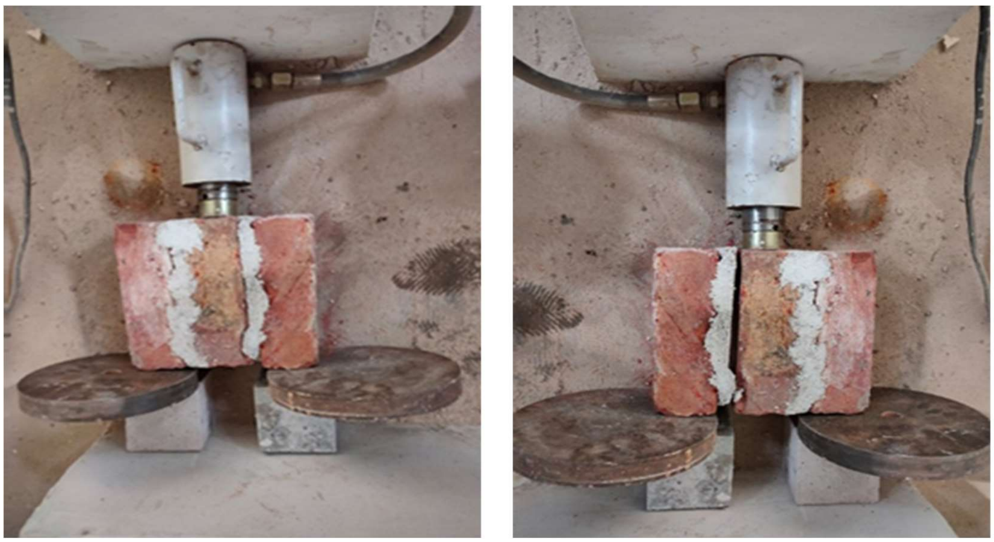

**Figure 3.9. Shear test setup & Failure between brick-and-mortar interface**

# CHAPTER 4

# RESULTS AND DISCUSSION

In this chapter the outcomes of the conducted experiments, which aimed to assess the various properties of lime mortar and additive based lime mortar is presented. The primary objective of this chapter is to offer a comprehensive analysis and interpretation of the data derived from the experiments. It is divided into sections that focus on particular property of these mortar. The presentation of results includes the use of tables and graphs, accompanied by descriptive statistics to facilitate a clear comprehension of the data. The results are critically analysed in the discussion.

## 4.1. TESTS ON BRICKS

Bricks are commonly used in the construction industry for building walls, pavements, and other structures. It is essential to determine their mechanical properties to ensure the quality and durability of the structures. Various tests are conducted to evaluate the different properties of bricks, including dimensions, water absorption, efflorescence, compressive strength, and shear strength. These tests help in assessing the performance of bricks and ensuring their suitability for specific construction applications. In this section, we will discuss the different tests conducted on bricks to determine their mechanical properties.

### 4.1.1. Dimensions Test

Bricks are typically rectangular in shape and have a variety of dimensions. (Length x depth x height). The dimensions of a brick can vary depending on the type of brick, the manufacturer, and the country in which it is made. However, it should be noted that not all of the bricks possess exact and precise measurements. The various brick samples are referred to as S1, S2, S3, S4, and S5. The measurements of these samples are shown in Table 4.1.

**Table 4.1. Dimensions Of Bricks**

| Specimen | Dimensions(mm) |
|---|---|
| S1 | 220*110*74 |
| S2 | 221*110*75 |
| S3 | 223*110*75 |
| S4 | 221*110*73 |
| S5 | 220*110*75 |

### 4.1.2. Water Absorption test on Bricks

The water absorption test is a common test performed on bricks to evaluate their porosity and the amount of water they can absorb. This test is important as it helps in assessing the durability and weather resistance of the bricks, which are crucial factors in their selection for construction purposes. The water absorption of the brick specimens was calculated using Equation (4.1).

$$\text{Water Absorption (\%)} = \frac{W_2 - W_1}{W_1} \times 100 \qquad (4.1)$$

**Table 4.2. Water Absorption Test Results**

| Specimens | Weight after oven-dry($M_1$) (Kg) | Weight after 24 hours in water($M_2$) (Kg) | Water absorption (%) | Avg. Water absorption (%) |
|---|---|---|---|---|
| S1 | 3.08 | 3.43 | 12.03 | |
| S2 | 3.02 | 3.37 | 11.59 | |
| S3 | 3.11 | 3.44 | 10.61 | 10.96 |
| S4 | 3.13 | 3.46 | 10.54 | |
| S5 | 2.99 | 3.29 | 10.03 | |

The results of the water absorption test for the brick specimens in this study are presented in Table 4.2. This table provides information on the water absorption characteristics of the different brick samples, which can be used to evaluate their suitability for specific applications.

After conducting the test on the specimens, the average water absorption was determined to be 10.96 %. According to Indian standards, when tested in the manner described, the average value should not surpass 20% by weight for Class 12.5, and 15% by weight for higher classes. This is because excessive water sorption can result in structural damage, including cracking, warping, and deterioration of the brick. Consequently, it is essential to monitor the characteristics of bricks and ensure they meet the appropriate standards for the specific class of brick being used.

### 4.1.3. Efflorescence Test on the Bricks

The efflorescence test was conducted on the bricks to determine the presence of soluble salt deposits. The results indicated that the efflorescence was below 4%, (Table 4.3) which is within the permissible limit set by IS 3495:1992 [35]. This standard specifies that for Class 12.5 bricks, the allowable efflorescence limit is less than or equal to 10%, while for higher classes, it should be less than or equal to 5%. Since the efflorescence of the bricks in this study falls well within the specified limits, it can be concluded that the bricks meet the required standards and are suitable for use in construction.

**Table 4.3. Efflorescence Test Result**

| Test | As per IS 3495:1992 | Experimental Result |
|---|---|---|
| Efflorescence | 10% or less for Class 12.5 bricks and 5% or less for Higher Classes of bricks | Below 4% |

## 4.2. TESTS FOR PHYSICAL AND MECHANICAL PROPERTIES OF MORTAR

### 4.2.1. Flow Table Test

Water requirement for each category of mortar is shown in Table 4.4 in the form of water to binder ratio. The water to binder ratio of the reference mortar is 0.72 comparing this to the mortar in which additives are added it is observed that the water to binder ratio has decreased in egg as the percentage of additives is increasing. As for lime with egg as additive the ratio is 0.70, 067 and 0.65 as the percentage of egg is increasing from 4% to 6% to 8%. The ratio is 0.58, 0.59 and 0.60 as the percentage of jaggery is increasing from 10% to 12.5% to 15% hence the water content is increasing as the percentage of jaggery is increasing in the mortar. In mortar with jute as additive the percentage of water is increasing as the percentage of jute in increasing in the mortar i.e., 1.04, 1.06, 1.08 with jute as 1%, 1.5% and 2% as an additive.

**Table 4.4 Water Requirement For Standard Workability**

| Mixture | RM | E4 | E6 | E8 | Ju1 | Ju1.5 | Ju2 | J10 | J12.5 | J15 |
|---|---|---|---|---|---|---|---|---|---|---|
| W/B | 0.72 | 0.70 | 0.67 | 0.65 | 1.04 | 1.06 | 1.08 | 0.58 | 0.59 | 0.60 |

Jute is a fibre that when mixed in mortar is decreasing the workability due to its texture and was interfering with the dispersion of mortar particles, causing clustering or agglomeration. Hence needed more water content then reference mortar.

The addition of egg in the mortar increased its workability as the egg albumen forms the bubbles that acts as the bearing to increase the workability of the mortar hence as the percentage of egg increases in the mortar the water requirement decreases.

Jaggery here acted as a natural lubricant in the mortar mix. It helps in reducing friction between mortar particles, allowing them to slide and flow more easily. This lubricating effect has improved the overall workability of the mortar. The water required in jaggery based lime mortar is very less as compared to the reference mortar.

### 4.2.2. Water Absorption Test

The water absorption test was conducted, and the result is shown in Fig. 4.1, its value for reference mortar is coming out to be 12.5%, for egg-based mortar this value is 10.20%, 9.01%, 10.40% for 4%, 6%, and 8% additive addition.

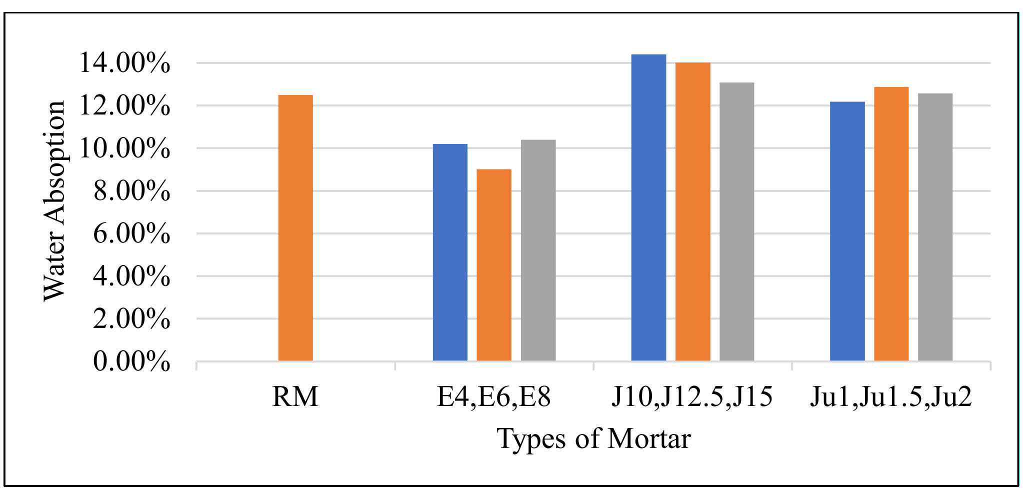


**Figure 4.1. Water absorption of specimens**

For jaggary the water absorption is coming out to be 14.41%, 14%, 13.08% for 10%, 12.5%, 15% additive addition. For jute the water absorption is coming out to be 12.19%,12.87%, 12.57% for 1%, 1.5% and 2% additive addition.

Water absorption in reference mortar is 12.5%, comparing this with other additives mortars, it is observed that mortar with egg 6% absorbs the least water. Egg proteins contain natural hydrophobic properties, hence have the ability to repel water. The proteins form a film around the lime particles, creating a barrier that limits the penetration of water into the mortar matrix. This film helps to reduce the mortar's porosity. In contrast, the values in jute and jaggery mortar are more or less comparable to reference mortar. Table 4.5,4.6, 4.7and 4.8 represents the average value of water absorption in all types of mortar. The water absorption shall not be more than 20%, and it is seen that no mortar category is crossing this limit. Hence by using any of these mortars, one can avoid damage in masonry units due to moisture, thereby avoiding failure of masonry structures.

**Table 4.5. Water Absorption Of Reference Mortars**

| Reference Mortar | Wt. of the dry cube (W1) (Kg) | Wt. of the cube after 24hr of absorption (W2) (Kg) | Water absorbed (%) |
|---|---|---|---|
| 1 | 0.655 | 0.736 | 12.5% |
| 2 | 0.652 | 0.732 | 12.2% |
| 3 | 0.649 | 0.732 | 12.9% |
| **Avg. value of water absorption =12.5%** | | | |

**Table 4.6. Water Absorption Of Jute Mortars**

| Mortar (%) / Specimens | | Wt. Of the Dry Cube (W1) (Kg) | Wt. of the Cube After 24hr of Absorption(W2) (Kg) | Water Absorbed (%) |
|---|---|---|---|---|
| Jute (1%) | 1 | 0.640 | 0.720 | 12.500 |
| | 2 | 0.651 | 0.730 | 12.135 |
| | 3 | 0.677 | 0.758 | 11.935 |
| **Avg. Value of Water Absorption = 12.19%** | | | | |

| | | | | |
|---|---|---|---|---|
| Jute (1.5%) | 1 | 0.637 | 0.719 | 12.50 |
| | 2 | 0.640 | 0.722 | 12.90 |
| | 3 | 0.688 | 0.779 | 13.21 |
| **Avg. Value of Water Absorption = 12.87%** | | | | |
| Jute (2%) | 1 | 0.636 | 0.716 | 12.50 |
| | 2 | 0.620 | 0.699 | 12.80 |
| | 3 | 0.653 | 0.734 | 12.41 |
| **Avg. Value of Water Absorption = 12.57%** | | | | |

**Table 4.7. Water Absorption Of Jaggery Mortars**

| Mortar (%) / Specimens | | Wt. of the Dry Cube (W1) (Kg) | Wt. of the Cube After 24hr Of Absorption(W2) (Kg) | Water Absorbed (%) |
|---|---|---|---|---|
| Jaggery (10%) | 1 | 0.718 | 0.818 | 14.00 |
| | 2 | 0.724 | 0.829 | 14.61 |
| | 3 | 0.739 | 0.847 | 14.62 |
| **Avg. Value of Water Absorption = 14.41%** | | | | |
| Jaggery (12.5%) | 1 | 0.720 | 0.822 | 14.28 |
| | 2 | 0.731 | 0.832 | 13.89 |
| | 3 | 0.753 | 0.857 | 13.83 |
| **Avg. Value of Water Absorption = 14.00%** | | | | |
| Jaggery (15%) | 1 | 0.728 | 0.823 | 13.18 |
| | 2 | 0.738 | 0.833 | 12.98 |
| | 3 | 0.746 | 0.843 | 13.08 |
| **Avg. Value of Water Absorption = 13.08%** | | | | |

**Table 4.8. Water Absorption of Egg Mortars**

| Mortar (%) / Specimens | | Wt. of the Dry Cube (W1) (Kg) | Wt. of the Cube After 24hr of Absorption(W2) (Kg) | Water Absorbed (%) |
|---|---|---|---|---|
| Egg (4%) | 1 | 0.605 | 0.665 | 09.96 |
| | 2 | 0.671 | 0.742 | 10.54 |
| | 3 | 0.635 | 0.699 | 10.10 |
| **Avg. Value of Water Absorption = 10.20%** | | | | |

| | | | | |
|---|---|---|---|---|
| Egg (6%) | 1 | 0.576 | 0.627 | 8.93 |
| | 2 | 0.598 | 0.652 | 9.14 |
| | 3 | 0.550 | 0.599 | 8.96 |
| **Avg. Value of Water Absorption = 9.01%** | | | | |
| Egg (8%) | 1 | 0.586 | 0.646 | 10.38 |
| | 2 | 0.591 | 0.652 | 10.45 |
| | 3 | 0.573 | 0.522 | 10.37 |
| **Avg. Value of Water Absorption = 10.40%** | | | | |

### 4.2.3. COMPRESSIVE STRENGTH TEST

To analyse the compressive strength of the mortar the cubes were tested in CTM (compression testing machine). The compressive strength of reference mortar is coming out to be 3.9 MPa. For egg-based mortar this value is 3.54 MPa, 4.1 MPa, 3.7 MPa, for 4%, 6%, and 8% additive addition. For jaggary the compressive value is coming out to be 5.1MPa, 5.3 MPa, 5.63 MPa for 10%, 12.5%, 15% additive addition. For jute the water absorption is coming out to be 3.81 MPa ,4.5 MPa, 4.18 MPa for 1%, 1.5% and 2% additive addition.

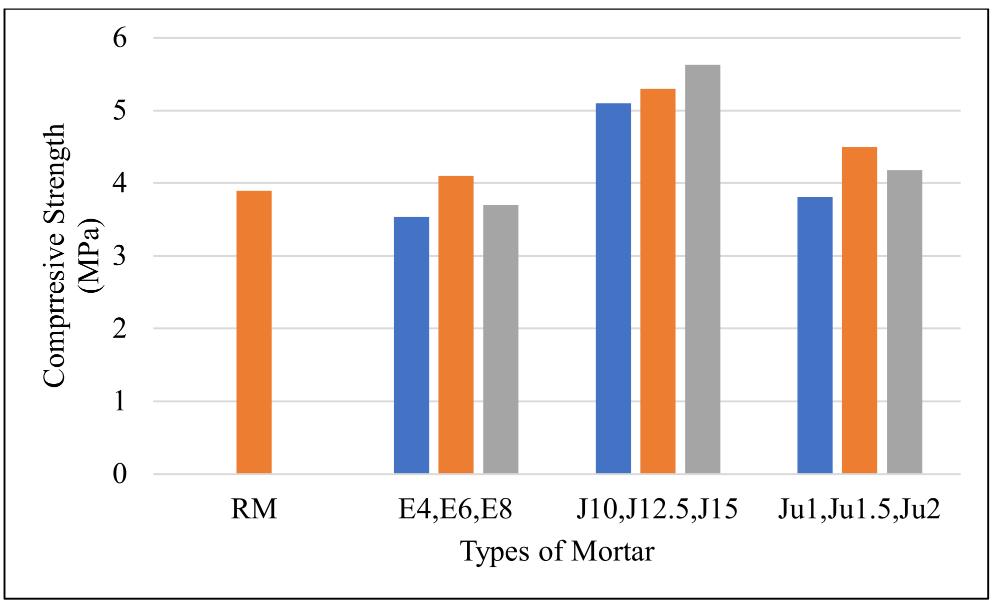


**Figure 4.2. Compressive strength of specimens**

Table 4.9,4.10, 4.11, and 4.12 are the tables which consists the compressive values of reference mortar, jute mortar, jaggery mortar and egg mortar.

**Table 4.9. Compressive Strength of Reference Mortars**

| Reference Mortar | Avg. Peak load (P) (kN) | Compressive Strength (MPa) |
|---|---|---|
| 1 | 26.40 | 4.09 |
| 2 | 19.60 | 4.00 |
| 3 | 17.69 | 3.61 |
| **Average value = 3.9 MPa** | | |

**Table 4.10. Compressive Strength of Jute Mortars**

| Mortar (%) / Specimens | | Avg. Peak load (P) (kN) | Compressive Strength (MPa) |
|---|---|---|---|
| Jute (1%) | 1 | 19.0 | 3.88 |
| | 2 | 19.1 | 3.90 |
| | 3 | 18.0 | 3.66 |
| **Average value = 3.81 MPa** | | | |
| Jute (1.5%) | 1 | 21.50 | 4.38 |
| | 2 | 23.66 | 4.83 |
| | 3 | 20.70 | 4.29 |
| **Average value = 4.50 MPa** | | | |
| Jute (2%) | 1 | 17.29 | 3.53 |
| | 2 | 22.00 | 4.48 |
| | 3 | 22.20 | 4.53 |
| **Average value = 4.18 MPa** | | | |

**Table 4.11. Compressive Strength of Jaggery Mortars**

| Mortar (%) / Specimens | | Avg. Peak load (P) (kN) | Compressive Strength (MPa) |
|---|---|---|---|
| Jaggery (10%) | 1 | 23.50 | 4.796 |
| | 2 | 24.00 | 4.9 |
| | 3 | 27.59 | 5.631 |
| **Average value = 5.10 MPa** | | | |
| Jaggery (12.5%) | 1 | 30.30 | 6.186 |
| | 2 | 23.10 | 4.714 |
| | 3 | 24.50 | 5.000 |
| **Average value = 5.3 MPa** | | | |
| Jaggery (15%) | 1 | 30.49 | 6.224 |
| | 2 | 23.50 | 4.796 |
| | 3 | 28.80 | 5.870 |
| **Average value = 5.63 MPa** | | | |

**Table 4.12. Compressive Strength of Egg Mortars**

| Mortar (%) / Specimens | | Avg. Peak load (P) (kN) | Compressive Strength (MPa) |
|---|---|---|---|
| Egg (4%) | 1 | 16.61 | 3.39 |
| | 2 | 18.20 | 3.71 |
| | 3 | 17.20 | 3.52 |
| **Average value = 3.54 MPa** | | | |
| Egg (6%) | 1 | 19.94 | 4.07 |
| | 2 | 19.50 | 3.98 |
| | 3 | 20.80 | 4.25 |
| **Average value = 4.10 MPa** | | | |
| Egg (8%) | 1 | 17.70 | 3.62 |
| | 2 | 17.50 | 3.67 |
| | 3 | 18.66 | 3.81 |
| **Average value = 3.70 MPa** | | | |

From Fig. 4.2, it can be concluded that the compressive values of jaggery is the highest in all the additives. The maximum value for jute additive in compression is achieved with jute additive at 1.5%. In case of egg mortar, the optimization is coming at 6%. Figure 4.2 depicts the comparative compressive values of all these mortars. Jaggery, acts as a natural adhesive as well has increased the workability at lower water content hence it promotes better bonding between mortar components and improve the adhesion with substrates contributing to the overall strength gain of the mortar.

## 4.2.4. SPLIT TENSILE STRENGTH TEST

To analyse the values of tensile strength of the mortar the split tensile test was performed. here the cylinders were tested in Brazilian machine. The split tensile strength of reference mortar is coming out to be 1.2 MPa. For egg-based mortar this value is 0.95 MPa, 1.2 MPa, 1.01 MPa, for 4%, 6%, and 8% additive addition. For jaggary the compressive value is coming out to be 1.9 MPa, 2 MPa, 2.2 MPa for 10%, 12.5%, 15% additive addition. For jute the split tensile strength is coming out to be 3.1 MPa ,5.3 MPa, 4.2 MPa for 1%, 1.5% and 2% additive addition. Looking at Fig 4.3 it can be absorbed that the tensile strength of the mortar with jaggery and jute as additives is more than the reference mortar. Whereas mortar with egg as additive has not shown any appreciable increase. The tensile test has shown excellent results for jute additive at jute with 1.5% used as additive. For J1.5 the tensile strength is 3.4

times more strength than reference mortar. Table 4.13 ,4.14, 4.15, and 4.16 are the tables which consists the tensile values of reference mortar, jute mortar, jaggery mortar and egg mortar.

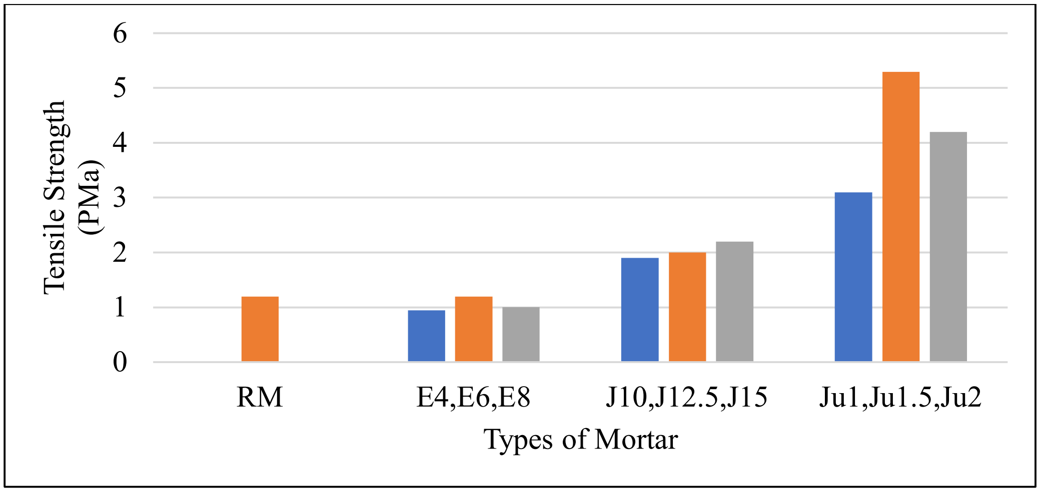


**Figure 4.3. Split tensile strength of specimens**

**Table 4.13. Tensile Strength of Reference Mortars**

| Reference Mortar | Tensile strength (MPa) |
|---|---|
| Specimen 1 | 1.21 |
| Specimen 2 | 1.26 |
| Specimen 3 | 1.13 |
| **Average value = 1.2 MPa** | |

**Table 4.14. Tensile Strength of Jute Mortars**

| Mortar (%) | Specimens No. | Tensile strength (MPa) |
|---|---|---|
| Jute (1%) | Specimen 1 | 3.09 |
| | Specimen 2 | 2.99 |
| | Specimen 3 | 3.22 |
| **Average value = 3.1 MPa** | | |
| Jute (1.5%) | Specimen 1 | 5.10 |
| | Specimen 2 | 5.22 |
| | Specimen 3 | 5.58 |
| **Average value = 5.3 MPa** | | |
| Jute (2%) | Specimen 1 | 4.53 |
| | Specimen 2 | 4.01 |
| | Specimen 3 | 4.06 |
| **Average value = 4.2 MPa** | | |

**Table 4.15. Tensile Strength of Jaggery Mortars**

| Mortar (%) | Specimens No. | Tensile strength (MPa) |
|---|---|---|
| Jaggery (10%) | Specimen 1 | 1.88 |
| | Specimen 2 | 1.94 |
| | Specimen 3 | 1.88 |
| **Average value = 1.9 MPa** | | |
| Jaggery (12.5%) | Specimen 1 | 2.23 |
| | Specimen 2 | 2.01 |
| | Specimen 3 | 1.76 |
| **Average value = 2.0 MPa** | | |
| Jaggery (15%) | Specimen 1 | 2.19 |
| | Specimen 2 | 2.09 |
| | Specimen 3 | 2.32 |
| **Average value = 2.2 MPa** | | |

**Table 4.16. Tensile Strength of Egg Mortars**

| Mortar (%) | Specimens No. | Tensile strength (MPa) |
|---|---|---|
| Egg (4%) | Specimen 1 | 0.89 |
| | Specimen 2 | 0.97 |
| | Specimen 3 | 0.99 |
| **Average value = 0.95 MPa** | | |
| Egg (6%) | Specimen 1 | 1.28 |
| | Specimen 2 | 1.15 |
| | Specimen 3 | 1.17 |
| **Average value = 1.2 MPa** | | |
| Egg (8%) | Specimen 1 | 1.000 |
| | Specimen 2 | 0.989 |
| | Specimen 3 | 1.041 |
| **Average value = 1.01 MPa** | | |

On adding jute fibers in lime mortar there is enhancement in its tensile properties as it provides additional reinforcement to the mortar.

Jute fibers have inherent tensile strength due to their fibrous nature. When incorporated into lime mortar, these fibers create a good connectivity within the matrix, distributing the tensile forces more effectively. Hence adding jute fibres in lime mortar will helps to resist cracking and improve the overall tensile strength of the mortar.

**Concluding remark**

After performing the tests explained above the optimum percentage of additives that is required to fulfil the desired property is evaluated. After these testing the casting and testing are only performed on the mortar that is prepared by adding the optimum percentage of additive.

## 4.3. TESTS FOR DURABILITY PROPERTIES OF MORTAR

### 4.3.1. ACID ATTACK TEST

Acid test was performed on the mortars cubes made of the optimum percentage of additives. The compressive strength of the mortar without applying the acidic expose condition was noted. Now the acidic exposure condition with 5% sulphuric acid solution was created. After 28 days the test was performed to see the strength loss of the mortar against this exposure condition. The reduction in compressive strength of reference mortar is 23%, egg-based lime mortar is 10%, jaggery-based lime mortar is 16 % and jute-based lime mortar is 5 % as shown in Table 4.17 and 4.18. Jute-based lime mortar shows the best results among all the mortars against acid attack as it can be concluded from Fig 4.4.

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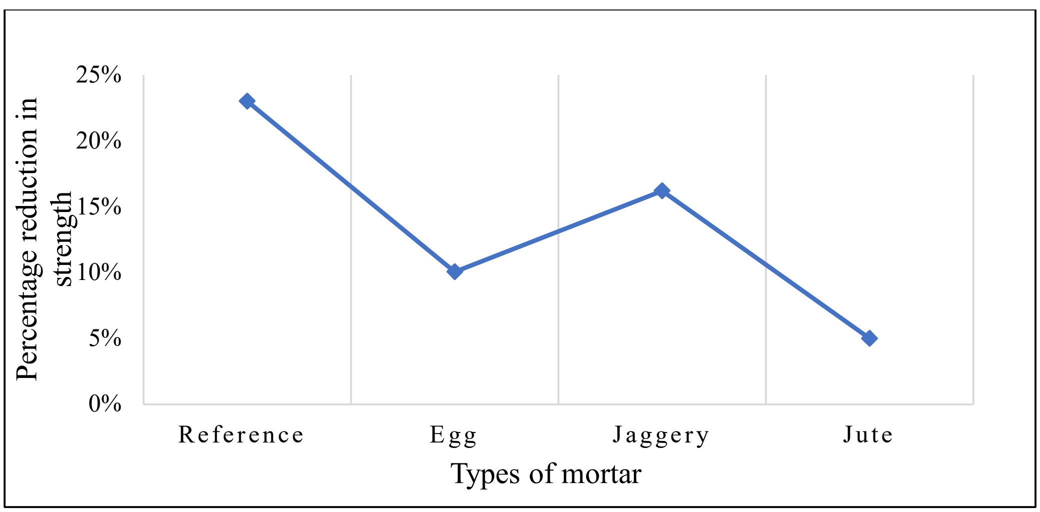


**Figure 4.4. Strength loss in acid attack**

**Table 4.17. Percentage reduction in strength of Reference Mortar (acid attack)**

| Mortar | Compressive value before submerging cubes in acid (C0) (MPa) | Compressive value after submerging cubes in acid(C1) (MPa) | Percentage reduction (%) |
|---|---|---|---|
| Reference | 3.9 | 3.01 | 23.00 |
| | | 2.99 | 23.20 |
| | | 3.00 | 22.90 |
| **Avg. value = 23.01%** | | | |

**Table 4.18. Percentage Reduction in Strength of Organic Mortar (acid attack)**

| Mortar | Compressive value before submerging cubes in acid (C0) (MPa) | Compressive value after submerging cubes in acid(C1) (MPa) | Percentage reduction (%) |
|---|---|---|---|
| Jaggery | 5.63 | 4.72 | 16.16 |
| | | 4.71 | 16.34 |
| | | 4.75 | 15.50 |
| **Avg. value = 16%** | | | |
| Jute | 4.5 | 4.25 | 5.50 |
| | | 4.28 | 4.80 |
| | | 4.29 | 4.70 |
| **Avg. value = 5%** | | | |
| Egg | 4.1 | 3.65 | 10.90 |
| | | 3.69 | 9.86 |
| | | 3.71 | 9.51 |
| **Avg. value = 10.09%** | | | |

## 4.3.2. ALKALI ATTACK TEST

Alkali test was performed on the mortars cubes made of the optimum percentage of additives. The compressive strength of the mortar without applying the alkaline expose condition was noted. Now the alkaline exposure condition with 2% NaOH solution was created. After 28 days the test was performed to see the strength loss of the mortar against this exposure condition. The reduction in compressive strength of reference mortar is 22%, egg-based lime mortar is 7%, jaggery-based lime mortar is 6.6% and jute-based lime mortar is 1.5% as shown in Table 4.19 and 4.20. The jute-based lime mortar shows the best results among all the mortars against alkali attacks as it can be concluded from Fig 4.5.

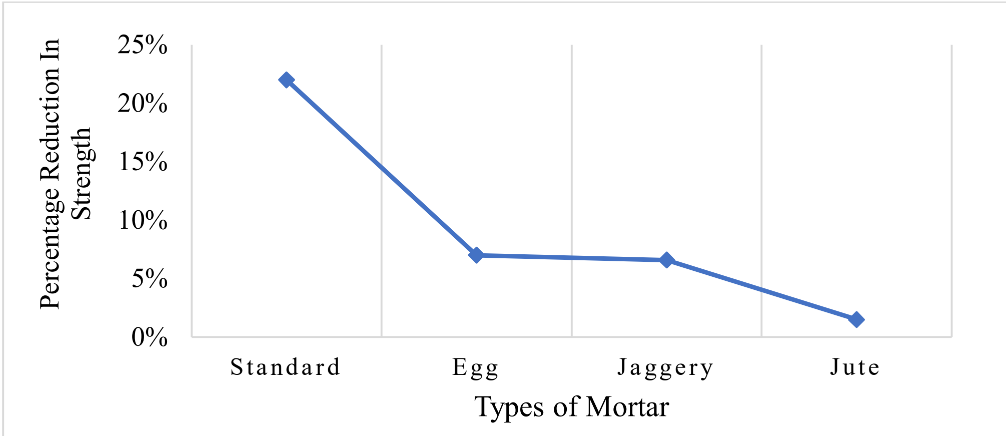


**Figure 4.5. Strength loss in alkali attack**

**Table 4.19. Percentage reduction in strength of Reference Mortar(alkali attack)**

| Mortar | Compressive value before submerging cubes in acid (C0) (MPa) | Compressive value after submerging cubes in alkali(C1) (MPa) | Percentage reduction (%) |
|---|---|---|---|
| Reference | 3.9 | 3.08 | 21.0 |
| | | 3.04 | 22.1 |
| | | 3.02 | 22.5 |
| Avg. value = 22% | | | |

**Table 4.20. Percentage Reduction in Strength of Organic Mortar(alkali attack)**

| Mortar | Compressive value before submerging cubes in acid (C0) (MPa) | Compressive value after submerging cubes in acid(C1) (MPa) | Percentage reduction (%) |
|---|---|---|---|
| Jaggery | 5.63 | 5.26 | 6.57 |
| | | 5.28 | 6.25 |
| | | 5.23 | 6.98 |
| **Avg. value = 6.60%** | | | |
| Jute | 4.50 | 4.432 | 1.01 |
| | | 4.456 | 0.98 |
| | | 4.380 | 2.51 |
| **Avg. value = 1.5%** | | | |
| Egg | 4.10 | 3.813 | 7.07% |
| | | 3.820 | 6.85% |
| | | 3.800 | 7.08% |
| **Avg. value = 7%** | | | |

### 4.3.3. CARBONATION DEPTH TEST

The test was performed after 28 days it was found that the surface was mostly covered by the pink tinge as the carbonation process taken place till now is very less. But after 90 days, mortar with jaggery shows the highest carbonation process among all the mortars. The result shows that adding jaggery to the lime mortar increases the carbonation rate, ultimately leading to higher and early strength gain. Table 4.21 shows the results of the carbonation of all mortars after 90 days.

**Table 4.21. Carbonation depth for different mortar**

| Mortar Type | Carbonation Depth After 90 Days (Avg. Value) (cm) |
|---|---|
| Reference mortar | 1.15 |
| Egg mortar | 1.09 |
| Jute mortar | 1.01 |
| Jaggery mortar | 2.00 |

### 4.3.4. WETTING AND DRYING TEST

This test was performed on the cube specimens. The initial weight of the cube was noted after 28 days. then these cubes were put under wetting and drying condition. this was done by keeping these mortar cube sin water and oven as specified in Indian standard code.

The weight of the cubes was taken after every five cycles as shown in Table 4.22. The weight loss is calculated to see the effect of thermal stresses that are developed in these cubes. It is noticed that even after 20 cycles, the mortar cubes did not show any cracking, flaking, or disintegration and mass loss is also negligible, as shown in Fig 4.6. Therefore, it is clear that lime-based mortars have greater thermal stress resistance. Hence posses more durability in any wheather condition.

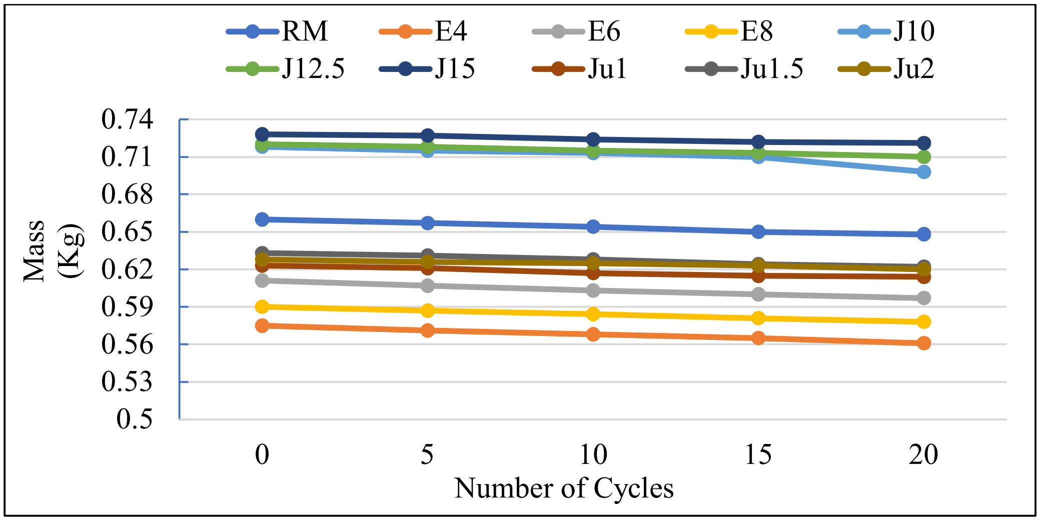


**Figure 4.6. Wetting and drying cycles on mortars**

**Table 4.22. Mass loss in different mortar due to Thermal Stresses**

| Mortar Type | RM | E4 | E6 | E8 | J10 | J12.5 | J15 | Ju1 | Ju1.5 | Ju2 |
|---|---|---|---|---|---|---|---|---|---|---|
| Wt. of mortar cube at 0 cycles (Kg) | 0.660 | 0.575 | 0.611 | 0.590 | 0.718 | 0.720 | 0.728 | 0.623 | 0.633 | 0.628 |
| Wt. of mortar cube at 5 cycles (Kg) | 0.657 | 0.571 | 0.607 | 0.587 | 0.715 | 0.718 | 0.727 | 0.621 | 0.631 | 0.626 |
| Wt. of mortar cube at 10 cycles (Kg) | 0.654 | 0.568 | 0.603 | 0.584 | 0.713 | 0.715 | 0.724 | 0.617 | 0.628 | 0.625 |
| Wt. of mortar cube at 15 cycles (Kg) | 0.650 | 0.565 | 0.600 | 0.581 | 0.710 | 0.713 | 0.722 | 0.615 | 0.624 | 0.623 |
| Wt. of mortar cube at 20 cycles (Kg) | 0.648 | 0.561 | 0.597 | 0.578 | 0.698 | 0.710 | 0.721 | 0.614 | 0.622 | 0.620 |

## 4.4. TESTS FOR SHEAR BOND STRENGTH OF MORTAR

The comparative study of the shear bond strength of all organic mortar with reference mortar is depicted in Fig. 4.7. The shear bond strength of reference, egg, jaggery, and jute-based lime mortar are 0.18 MPa, 0.175 MPa, 0.23 MPa, and 0.198 MPa respectively.

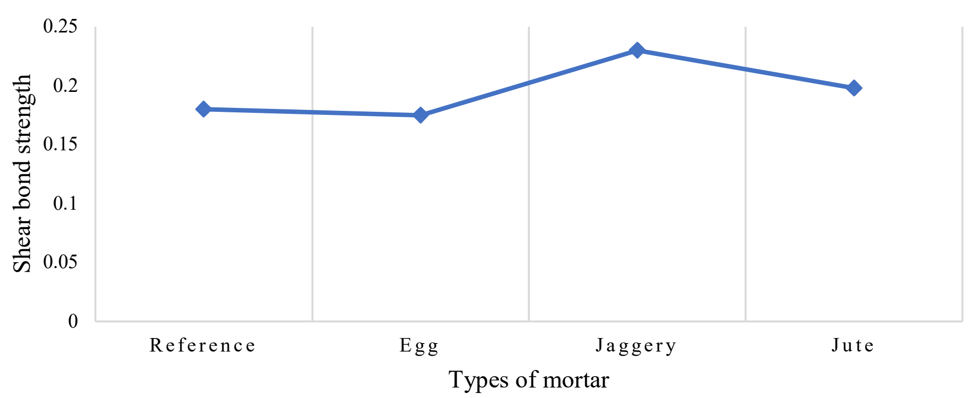


**Figure 4.7. Shear strength of different mortar bonds**

Here the shear strength of the jaggery and jute mortar is increasing with respect to the reference mortar. But egg-based mortar has this strength less than the reference mortar as depicted in Table 4.23. It can be observed that jaggery-based lime mortar shows the best results among all the mortars in shear bond strength with increment of about 27.7%.

**Table 4.23. Shear Strength Values**

| Mortar | Avg. peak load(P) (kN) | Area of interface($mm^2$) | Shear strength (MPa) |
|---|---|---|---|
| Reference | 8.700 | 220*110 | 0.180 |
| Jaggery | 11.132 | 220*110 | 0.230 |
| Jute | 9.583 | 220*110 | 0.198 |
| Egg | 8.470 | 220*110 | 0.175 |

# CHAPTER 5

# SUMMARY AND CONCLUSION & FUTURE SCOPE

## 5.1. SUMMARY

In this investigation the attempt has been done to prepare the mortar used in old structures. The engineering properties of the organic additive-based lime mortar used in brick masonry has been evaluated.

Tests were performed on raw materials like bulk density test, water absorption test for jute and sieve analysis for sand to get the basic properties.

Accelerated curing was performed on the cubes which failed showing bulging effects.

The mortar has been prepared using lime to sand ratio as 1:3 and jaggery, egg and jute was taken as the additives.

Flow table test was performed on the mortar in fresh phase and other tests were done on its hardened phase.

Compression test and tensile test were performed to check the mechanical properties of the mortars. The optimum percentage of additives were found on the basis of the mechanical tests.

Then carbonation test, alkali attack test, acid attack test and wetting and drying test were done to evaluate the durability properties of these mortars whereas triplet test was done to check the bond strength of the mortar with brick in masonry. These tests are done on the mortar with optimum percentages as found earlier.

## 5.2. CONCLUSION

The investigation was carried out to evaluate various engineering properties of organic additive-based lime mortar. Different percentages of additives were taken to find the optimum percentage of additive that can give best results, and to check engineering properties that can be enhanced using these additives.

- Jaggery mortar has shown the best results in compression test and has 44.35% greater strength than reference mortar at 15% additive addition. Jaggery, acts as a natural adhesive due to presence of sucrose hence it promotes better bonding between mortar components and improve the adhesion with substrates contributing to the overall strength gain of the mortar. Adding jaggery to the mortar has also increased the rate of carbonation by 1.74 times as compared to reference mortar. Hence for early strengthening requirements, jaggery can be used as an additive.
- Jute mortar has demonstrated exceptional results in split tensile strength with 341% greater strength than reference mortar at 1.5% of its addition. But further increasing the percentage of jute to 2% has reduced this strength. Hence 1.5% is the optimum percentage of jute as an additive. These fibers create a good connectivity within the matrix, distributing the tensile forces more effectively. Hence adding jute fibres in lime mortar will helps to resist cracking and improve the overall tensile strength of the mortar.
- Egg mortar has shown least water affinity in the water absorption test, with 6% egg albumen showing optimum results. Egg proteins contain natural hydrophobic properties, hence have the ability to repel water. The proteins form a film around the lime particles, creating a barrier that limits the penetration of water into the mortar matrix. This film helps to reduce the mortar's porosity. Hence this property of egg mortar will save the structure by absorbing moisture from the external environment.
- Lime mortar with all the additives has shown good resistance against wetting and drying test and hence has better resistance to thermal stresses. As lime has is known for its flexibility in breathing. This indicates better durability characteristics of lime mortars.
- According to the sulphuric acid attack test carried out, the lime mortar with jute as an additive has shown the best results with only a 5% loss in strength, whereas the reference lime mortar had a strength loss of 23%.

- In the alkali resistance test, jute mortar showed exceptional behaviour with a strength loss of only 1.5%, whereas the reference mortar had a strength loss of 22%. Hence jute mortar is showing best results in alkali and acid exposure conditions.
- In the triplet test, the shear bond strength of jaggery-based mortar in brick masonry is 27.77% higher than the reference mortar. The bond is stronger with jaggery as additive as it has adhesive nature due to the presence of sucrose, hence making good bond between mortar and brick, showing the best result in the shear bond test.

Hence addition of different organics in lime mortar can enhance its various properties. These additives shall be added in optimum percentage to obtain best results.

## 5.3. FUTURE SCOPE

To perform the characterisation tests on all mortars to find its chemical composition. The chemical composition of mortar through techniques like X-ray diffraction (XRD) or scanning electron microscopy (SEM) can provide insights into the types and proportions of ingredients used. This helps in quality control, identifying any variations or impurities that may affect the mortar's performance and can be compared with the mortar extracted from the old structure. This will yield the similarities and resemblance with the old mortar.

Environmental impact assessment: Conduct a comprehensive assessment of the environmental impact of lime mortar with organic additives compared to conventional mortar. This can include analyzing factors such as carbon footprint, energy consumption, and waste generation during the production and application of lime mortar with organic additives.

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UKIERI Concrete Congress
Sustainable Concrete Infrastructure
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Dr B R Ambedkar National Institute of Technology
Jalandhar – 144 027 (Punjab) India

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**Presented the Paper Titled**

*Experimental study to check the efficacy of adding organic additives on engineering properties of lime mortar*
Monika Yadav, Shilpa Pal
in

**International UKIERI Concrete Congress**

**Sustainable Concrete Infrastructure**

**held on**

**14 - 17 March 2023 (Virtual Mode)**

**Hosted by**

**Dr B R Ambedkar National Institute of Technology**
Jalandhar, India

**Guru Nanak Dev Engineering College**
Ludhiana, India

**Dr Navdeep Singh**
**[Congress Secretary]**

2. Monika Yadav, Shilpa Pal (2023), "The durability of organic blended lime mortar and the shear bond of blended mortar in brick masonry" 3rd International conference on "Advances in Materials, Mechanics, Mechatronics and Manufacturing" (IC4M 2023), April 15-16,2023.