

Effect of Sticky Rice, Jaggery, Sugar, And Additional Lime on the Fresh, Flexural, and Moisture-Related Properties of Lime Mortar

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Abstract

Background: Lime mortars are compatible with breathable masonry but often exhibit limited early bending resistance and high moisture uptake. **Purpose:** This study compares the fresh-state, flexural and pore-related performance of a control lime mortar and mortars modified with jaggery, sticky rice, sugar and additional lime at 3%, 6%, 9%, 12% and 15% by lime mass. **Methods:** The base proportion was lime: sand: water = 1:2.5:0.45. Workability, water absorption, apparent porosity and flexural strength at 7 and 28 days were evaluated using The control recorded 16.1 mm workability, 14.4% absorption, 58.9% porosity and flexural strengths of 0.04 and 0.08 MPa at 7 and 28 days. Jaggery at 6% produced the highest workability, 17.9 mm. Sticky rice at 9% gave the lowest absorption and porosity, 12.5% and 55.4%, and the highest flexural strengths, 0.14 and 0.25 MPa. Additional lime at 9% ranked second in durability and 28-day flexure, with 12.9% absorption, 56.3% porosity and 0.24 MPa. Sugar was dosage-sensitive and its 15% mix reached 14.9% absorption, 59.0% porosity and only 0.09 MPa at 28 days. **Conclusion:** A moderate additive content improves cohesion and pore continuity, whereas excessive dosage reverses these benefits; 9% sticky rice is the optimum composition for balanced fresh, flexural and moisture-related performance.

Keywords—*lime mortar, sticky rice, jaggery, workability, water absorption, porosity, flexural strength.*

1. Introduction

Lime mortar remains important in heritage conservation, masonry jointing and repair because it is comparatively deformable, vapour-permeable and compatible with porous masonry units. Its practical limitation is the combination of slow hardening, modest early mechanical resistance and a connected pore system that can admit liquid water. A modifier intended for lime mortar must therefore improve handling and crack resistance without creating an excessively dense or brittle repair material.

Fresh-state behaviour and hardened durability are coupled. Adequate workability supports uniform placement and compaction, while poor consistency may trap air or create discontinuous interfaces. After hardening, connected pores govern capillary water uptake, and the same pore network influences the effective area available to transmit flexural stress. A mix that is easy to place but remains highly absorbent is not necessarily durable; conversely, a very stiff mix may compact poorly and retain defects that lower bending resistance. The programme examined a control mortar and percentage-wise material series using jaggery, sticky rice, sugar and additional lime. Dosages of 3%, 6%, 9%, 12% and 15% were compared. Sticky rice represents a starch-rich modifier, jaggery a less-refined sugar with minor minerals, sugar a refined sucrose source, and the lime series an increase in lime content relative to the reference composition. Their responses were compared using workability, water absorption, porosity and flexural strength at 7 and 28 days. The objective of this paper is to identify the composition that provides the most balanced combination of placement quality, reduced moisture ingress, refined pore structure and resistance to bending. The analysis uses only the final result tables and experimental photographs embedded in the uploaded report. Where earlier narrative values differ from Chapter 5 tables, the Chapter 5 tables are treated as the controlling dataset so that every comparison remains internally consistent.

2. Related Work

Hanley and Pavia linked fresh workability to later strength in lime mortars and emphasized control of water and aggregate packing [1]. Veiga showed that conservation mortars must balance deformability, moisture transport and strength rather than maximize a single property [2]. Yang et al. attributed the performance of sticky-rice lime mortar to organic–inorganic interaction and modified calcium-carbonate growth [3], while Zhao et al. demonstrated that organic admixtures can alter binder mineralogy and pore arrangement [4]. Glenn et al. showed that starch-based aquagels can retain water and modify the internal void system of cementitious materials [5]. Kang et al. related

carbonation uptake to mechanical development in air-lime materials [6]. Zhang et al. reported improved resistance of sticky-rice mortars during cyclic wetting, drying and dilute sulfate exposure [7]. Qureshi et al. found that controlled jaggery addition can improve workability and strength, although their binder system was concrete rather than pure lime mortar [8]. Collectively, these studies support simultaneous assessment of flow, pore connectivity, water ingress and bending resistance. They also justify reporting the control alongside every dosage so that optimum selection remains traceable and transparent.

Giridhar et al. identified sugar and jaggery as dosage-sensitive natural admixtures that may improve consistency but retard hardening at excessive levels [9]. Ahmad et al. confirmed that sugar dosage strongly affects setting, microstructure and strength [10]. Bende and Wagh reported an optimum jaggery range for fresh and hardened performance [11], and Kokila et al. observed altered water demand in palm-jaggery blended concrete [12]. Raju and Lakshmi extended natural-admixture concepts to cement and lime mortars, highlighting the need for controlled preparation and uniform dispersion [13]. Mydin examined sticky rice and jaggery additions over a comparable dosage sequence and found intermediate contents more effective than high contents [14]. Vandhiyan et al. further connected palm jaggery and traditional additions with improved lime-mortar workability, absorption and strength [15]. The reviewed work generally isolates one additive, one response or a narrow dosage range. The research gap is therefore a common experimental matrix that ranks several additives using fresh-state behaviour, water absorption, porosity and flexural strength together; the dataset addresses this gap across five dosage levels and four material series.

3. Research Method

3.1 Data Basis and Experimental Matrix

The final results matrix contains one separate control and four modified material series. Each modified series was evaluated at 3%, 6%, 9%, 12% and 15%, giving twenty modified conditions plus the control. Earlier methodology text in the report describes only three organic additives, but the final Chapter 5 tables also contain a complete additional-lime series; the present paper includes that series because it is part of the reported experimental results. The control value is repeated graphically across dosage positions only as a constant reference and is not treated as five separate control mixes.

Table 1. Material roles and reported characteristics

Material	Reported property or form	Functional role
Lime putty	Primary binder; $\text{Ca}(\text{OH})_2$; specific gravity 2.25–2.35	Carbonation, plasticity and binding
Fine sand	Clean graded sand; specific gravity 2.60–2.65; fineness modulus 2.60–2.80	Aggregate skeleton and packing
Sticky rice	Amylopectin-rich powder, paste or cooked slurry	Viscosity modification and pore refinement
Jaggery	Sucrose, reducing sugars and minerals; dissolved or crushed	Workability improvement and controlled retardation
Sugar	Refined sucrose in crystalline or solution form	Setting and workability modification
Additional lime	Percentage-wise lime series reported in Chapter 5	Adjustment of binder-rich composition
Water	Potable, near-neutral; 0.45 part by lime mass	Consistency and carbonation moisture

The material table shows that the variables differ chemically and physically. Sticky rice is starch-rich and can increase cohesion, jaggery combines sugars with minor constituents, refined sugar has the strongest retardation potential, and the additional-lime series changes the binder balance. Fine sand and water were kept constant so the observed differences could be linked primarily to modifier type and dosage.



Material sample: lime putty



Material sample: sticky rice



Material sample: jaggery



Material sample: sugar

Figure 1. Material samples

The photographs document the materials used or represented in the report. Uniform preparation is especially important for sticky rice and jaggery because lumps or uneven dissolution would produce local variations in water demand and setting. The images are included as source evidence only; no external experimental photograph has been added.

3.2 Editable Methodology Flowchart

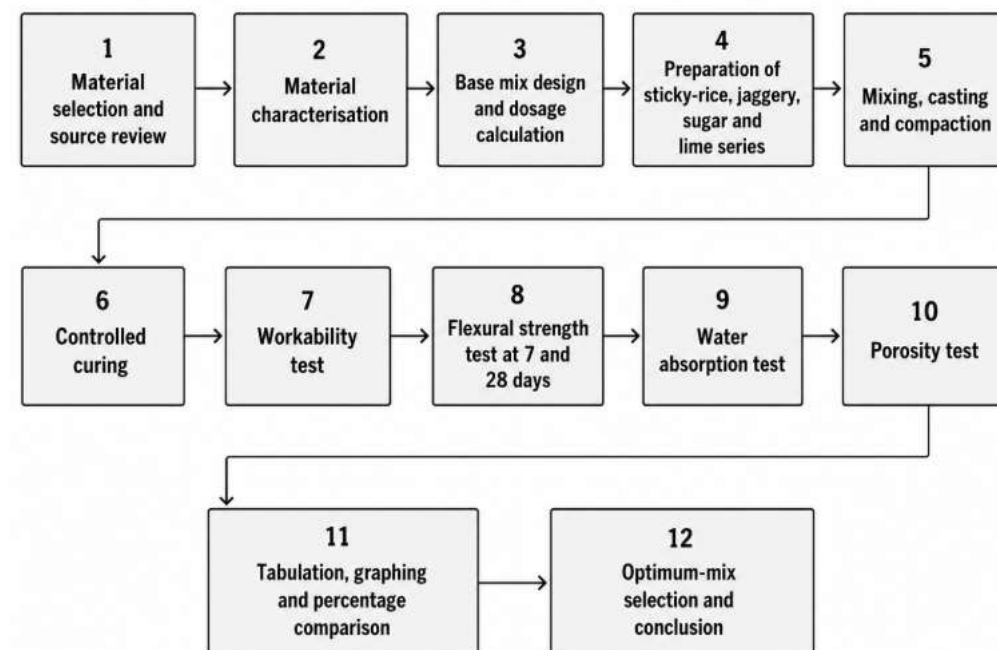


Figure 2. Editable experimental sequence used for Paper 1

4. Experimental Work

4.1 Mix Proportioning and Specimens

Table 2. Base batch and additive quantities

Mix level	Dosage (%)	Lime (kg)	Sand (kg)	Water (kg)	Modifier (kg)	Total (kg)
Control	0	6.00	15.00	2.70	0.00	23.70
3% series	3	6.00	15.00	2.70	0.18	23.88
6% series	6	6.00	15.00	2.70	0.36	24.06
9% series	9	6.00	15.00	2.70	0.54	24.24
12% series	12	6.00	15.00	2.70	0.72	24.42
15% series	15	6.00	15.00	2.70	0.90	24.60

The base proportion was 1:2.5:0.45 by lime mass. Each modifier quantity was calculated from the 6.00 kg lime content, while sand and water remained 15.00 and 2.70 kg. This fixed basis isolates dosage effects and avoids attributing changes to uncontrolled variation in aggregate or mixing water.

Table 3. Reported specimen and test information

Item	Specimen/report status	Procedure	Age/stage
Workability	Fresh mortar	Flow/spread measurement	Fresh stage
Water absorption	Hardened specimen; dimensions not stated for this test	Oven-dry and immersion mass change	Hardened stage
Porosity	Hardened specimen; dimensions not stated for this test	Vacuum/saturation-based measurement	void Hardened stage
Flexural strength	Prism, 100 × 100 × 500 mm	Bending until cracking and failure	7 and 28 days

The source provides sufficient information to identify the test types and prism dimensions, but it does not state the number of replicate specimens, the exact curing temperature and humidity, or whether the flexural load was centre-point or third-point. These omissions are retained transparently rather than filled with assumed values.

4.2 Mixing, Casting, Curing and Test Procedures

Lime putty and clean fine sand were brought to a uniform condition. Sticky rice was prepared as a paste or slurry, jaggery and sugar were dissolved or finely dispersed, and the additional-lime series was batched at the specified percentage. Materials were mixed until a homogeneous consistency was obtained, placed in moulds in layers, compacted consistently, finished, labelled and cured under the common regime described in the report. Saccharide effects were interpreted with reference to binder–sugar interaction [16], while the importance of controlled lime-mortar curing follows Grilo et al. [17]. The general relation among pores, water transport and mechanical resistance is consistent with Neville [18] and Mehta and Monteiro [19].



Mixing and Filling



Casting Specimen



Curing Specimens



Flexural Testing

Figure 3. Mixing, prism preparation and flexural testing photographs

Panel (a) shows manual mixing and placement, where uniform dispersion and controlled water addition are essential. Panels (b) and (c) show multiple cast and labelled specimens used for percentage-wise comparison. Panel (d) records the flexural testing arrangement, in which a prism was aligned under the loading frame and loaded until cracking. The photographs support specimen traceability and confirm that the reported values originated from physical laboratory work.

Workability was recorded as the spread diameter after lifting the mould. Water absorption was determined from dry and saturated masses using the method category referenced in BS 1881-122 [20]. Apparent porosity was obtained through a saturation-based mass/volume relation consistent with BS EN 993-1 [21]. Flexural strength was reported using a prism bending procedure and the corresponding bending-stress principle referenced by BS EN 1521 [22]. Because the exact load geometry was not stated, the source-safe general flexural equation is used rather than imposing an unreported coefficient.

$$D = \frac{(D_1 + D_2)}{2} \quad (1)$$

Where D is the mean spread diameter and D₁ and D₂ are perpendicular measurements.

$$\text{Water absorption, } W = \left[\frac{(M_s - M_d)}{M_d} \right] \times 100 \quad (2)$$

Where M_d is the oven-dry mass and M_s is the saturated mass.

$$\text{Apparent porosity, } n = \left[\frac{(M_s - M_d)}{(\rho_w V)} \right] \times 100 \quad (3)$$

Where ρ_w is water density and V is the bulk specimen volume.

$$\text{Flexural strength, } f_f = \frac{M_{\max}}{Z} \quad (4)$$

Where M_{max} is the maximum bending moment and Z is the section modulus for the reported loading arrangement.

5. Results and Discussion

5.1 Workability Test Results

Table 4. Workability of control and modified lime mortars (mm)

Dosage	Control	Jaggery	Sticky Rice	Sugar	Additional lime
3%	16.1	16.8	16.5	16.9	16.7
6%	16.1	17.9	16.9	17.5	17.1
9%	16.1	17.6	17.6	17.8	17.5
12%	16.1	17.2	16.7	17.1	17.0
15%	16.1	16.6	16.3	16.4	16.6

The control remained at 16.1 mm. Jaggery increased to 17.9 mm at 6%, the maximum recorded workability, and then declined to 16.6 mm at 15%. Sticky rice peaked at 17.6 mm at 9%; sugar reached 17.8 mm at 9% but its mechanically optimum dosage was 6%; additional lime reached 17.5 mm at 9%. The data show that maximum spread alone does not define the optimum because sugar at 9% had high workability but weaker durability and flexural results.

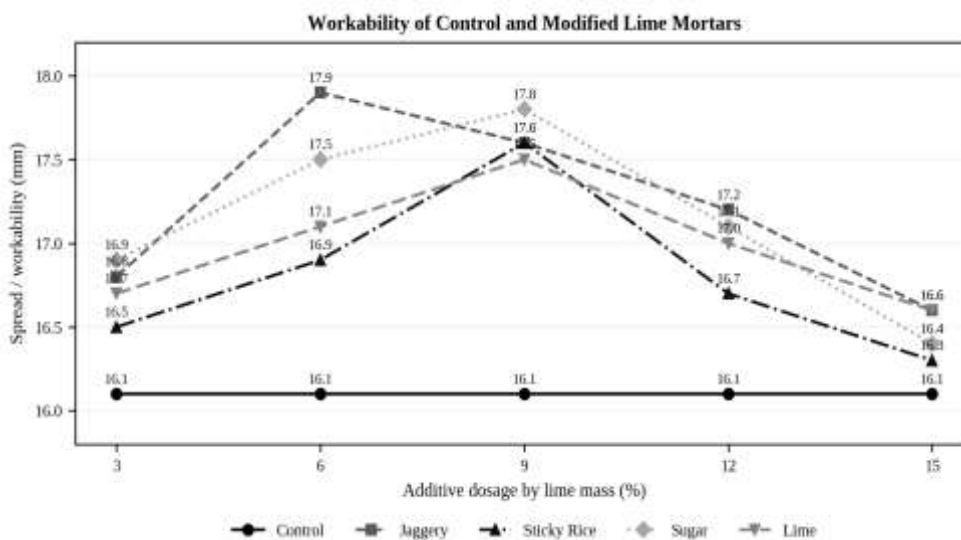


Figure 4. Percentage-wise workability trends

All modified series initially rose above the control, confirming improved lubrication and ease of placement at moderate dosage. Jaggery showed the strongest fresh-state effect, while sticky rice and additional lime produced more balanced peaks at 9%. The downward trend after the optimum indicates that excessive solids, gel formation or retardation can reduce effective flow and may increase stickiness rather than useful workability.

5.2 Water Absorption Test Results

Table 5. Water absorption of control and modified lime mortars (%)

Dosage	Control	Jaggery	Sticky Rice	Sugar	Additional lime
3%	14.4	14.1	13.7	14.0	13.9
6%	14.4	13.2	13.1	13.6	13.4
9%	14.4	13.5	12.5	13.8	12.9
12%	14.4	13.8	13.3	14.3	13.5
15%	14.4	14.2	13.6	14.9	14.0

The control absorption was 14.4%. Sticky rice produced the lowest value, 12.5% at 9%, followed by additional lime at 12.9% at 9% and jaggery at 13.2% at 6%. Sugar reached 13.6% at 6% but increased to 14.9% at 15%, exceeding

the control. Thus, moderate dosage reduced capillary water entry, whereas excessive sugar produced the least favourable moisture response.

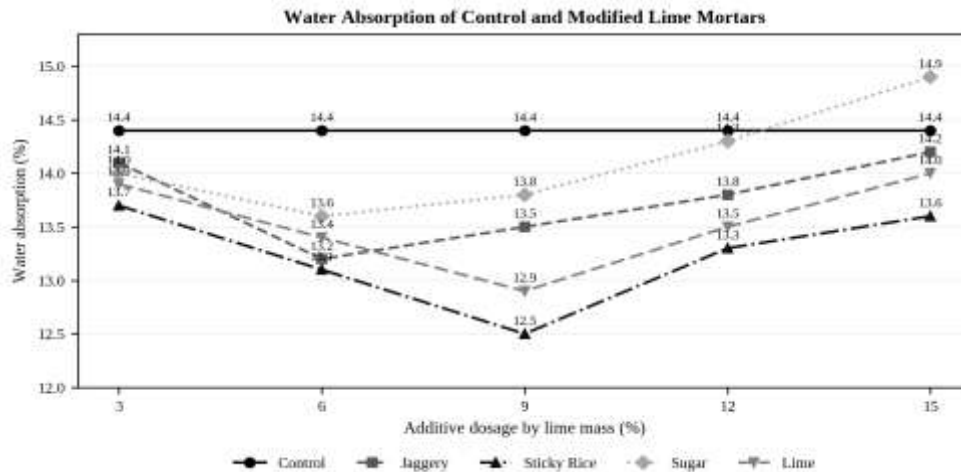


Figure 5. Percentage-wise water-absorption trends

The U-shaped trends identify a clear optimum range. Sticky rice maintains the lowest curve between 6% and 12%, with the minimum at 9%, suggesting better continuity of the lime–sand matrix and fewer harmful connected capillaries. The sharp increase in the high-sugar mixes indicates that excessive sucrose interfered with hardening and left a more permeable structure.

5.3 Porosity Test Results

Table 6. Apparent porosity of control and modified lime mortars (%)

Dosage	Control	Jaggery	Sticky Rice	Sugar	Additional lime
3%	58.9	57.3	56.7	57.8	57.8
6%	58.9	56.8	56.1	57.2	57.1
9%	58.9	57.1	55.4	57.4	56.3
12%	58.9	57.7	55.9	58.1	57.0
15%	58.9	58.2	56.6	59.0	57.9

The control porosity was 58.9%. Sticky rice reduced it to 55.4% at 9%, the minimum of the complete dataset. Additional lime reached 56.3% at 9% and jaggery reached 56.8% at 6%. Sugar achieved only a modest minimum of 57.2% at 6% and rose to 59.0% at 15%. The ranking closely mirrors water absorption, confirming that connected void structure controlled liquid-water uptake.

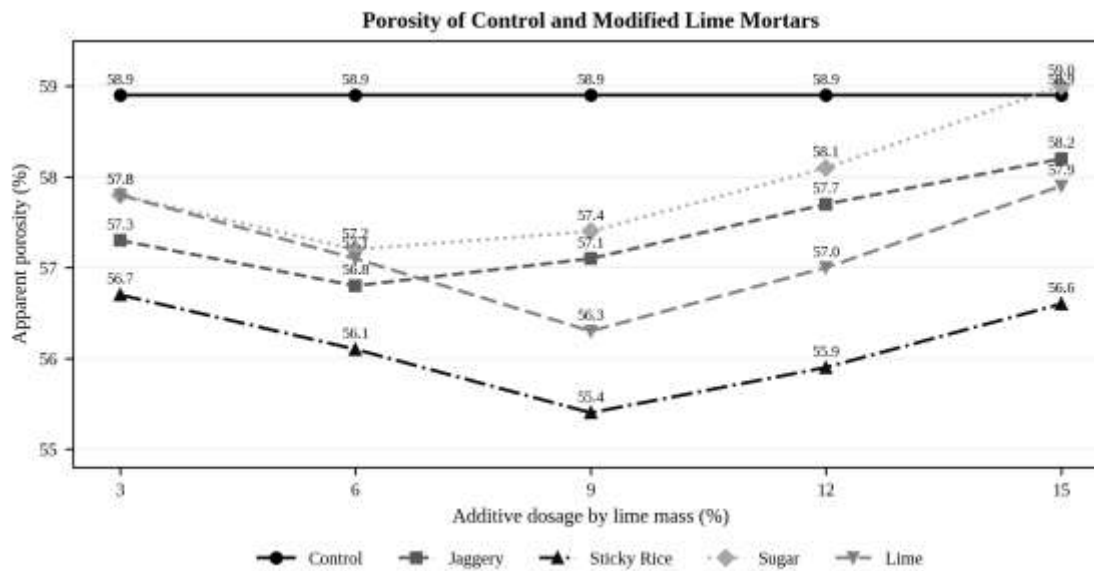


Figure 6. Percentage-wise porosity trends

Porosity decreased up to a moderate dosage and then increased. Sticky rice produced the deepest reduction and retained lower porosity than the other modifiers across the tested range. The high-dose sugar curve crosses above the control, demonstrating that workability improvement cannot compensate for a poorly developed hardened matrix. The parallel absorption and porosity profiles provide mutually supporting durability evidence.

5.4 Flexural Strength Test Results

Table 7. Seven-day flexural strength (MPa)

Dosage	Control	Jaggery	Sticky Rice	Sugar	Additional lime
3%	0.04	0.10	0.11	0.09	0.11
6%	0.04	0.13	0.12	0.10	0.12
9%	0.04	0.12	0.14	0.08	0.13
12%	0.04	0.10	0.12	0.07	0.12
15%	0.04	0.08	0.09	0.05	0.10

At 7 days, the control developed 0.04 MPa. Sticky rice at 9% achieved the maximum of 0.14 MPa, while jaggery at 6% and additional lime at 9% each reached 0.13 MPa. Sugar peaked at 0.10 MPa at 6%. At 15%, the corresponding values declined to 0.08, 0.09, 0.05 and 0.10 MPa for jaggery, sticky rice, sugar and lime, confirming that the optimum was below the highest dosage.

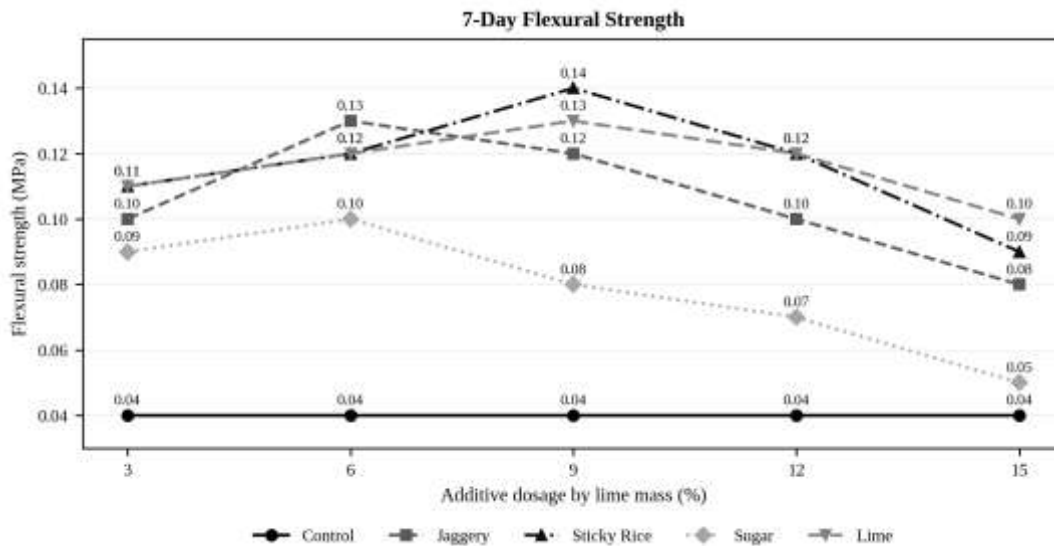


Figure 7. Seven-day flexural-strength trends

The early-age curves follow the same peak-and-decline pattern as the durability indicators. Sticky rice developed the highest bending resistance, consistent with improved cohesion and lower connected porosity. Additional lime and jaggery provided closely comparable secondary performance, whereas high sugar contents produced the lowest resistance to crack initiation.

Table 8. Twenty-eight-day flexural strength (MPa)

Dosage	Control	Jaggery	Sticky Rice	Sugar	Additional lime
3%	0.08	0.18	0.19	0.16	0.19
6%	0.08	0.23	0.22	0.18	0.21
9%	0.08	0.21	0.25	0.15	0.24
12%	0.08	0.18	0.22	0.12	0.21
15%	0.08	0.14	0.16	0.09	0.18

The control increased to 0.08 MPa at 28 days. Sticky rice at 9% reached 0.25 MPa, followed by additional lime at 9% with 0.24 MPa and jaggery at 6% with 0.23 MPa. Sugar at 6% reached 0.18 MPa. At 15%, sugar recorded only 0.09 MPa, while sticky rice and jaggery declined to 0.16 and 0.14 MPa. The age-related gain confirms continuing hardening, but dosage remained the controlling factor.

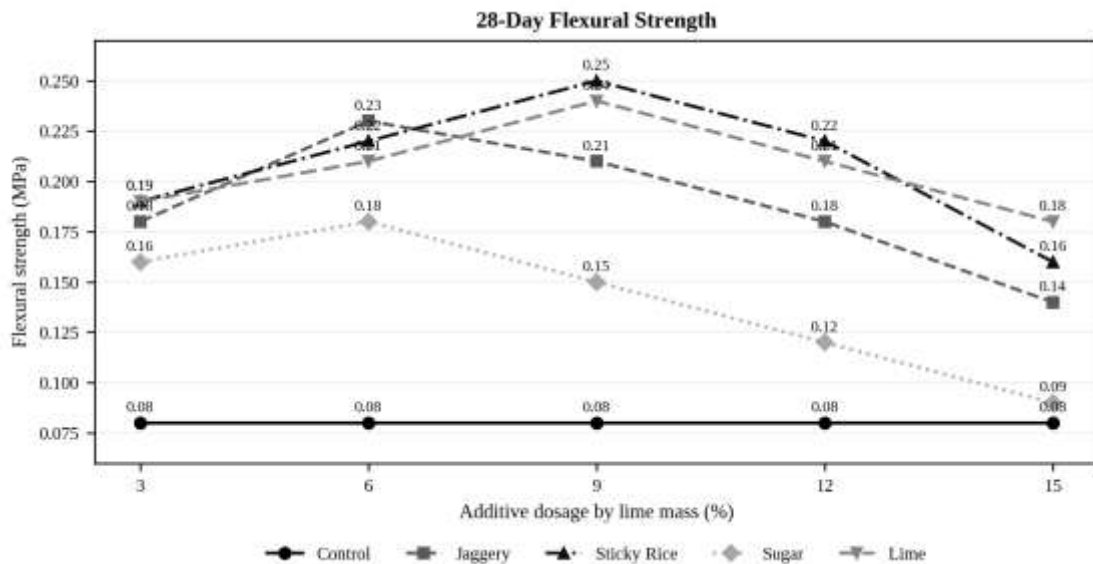


Figure 8. Twenty-eight-day flexural-strength trends

The 28-day graph preserves the same material ranking observed at 7 days, demonstrating that the optimum compositions were not temporary early-age effects. The sticky-rice peak coincides with the minimum water absorption and porosity. This alignment indicates that a more continuous matrix resisted both moisture penetration and flexural crack development.

5.5 Comparative Discussion

Table 9. Optimum fresh-state, durability and flexural results

Material	Optimum	Workability (mm)	Absorption (%)	Porosity (%)	FS 7 d (MPa)	FS 28 d (MPa)
Control	0%	16.1	14.4	58.9	0.04	0.08
Jaggery	6%	17.9	13.2	56.8	0.13	0.23
Sticky Rice	9%	17.6	12.5	55.4	0.14	0.25
Sugar	6%	17.5	13.6	57.2	0.10	0.18
Lime	9%	17.5	12.9	56.3	0.13	0.24

Jaggery produced the greatest workability, but sticky rice provided the lowest absorption and porosity and the highest flexural strength. Additional lime ranked second overall, and sugar ranked last among the selected optimum mixes. The comparison confirms that the engineering optimum must be based on multiple criteria rather than the maximum fresh spread alone.

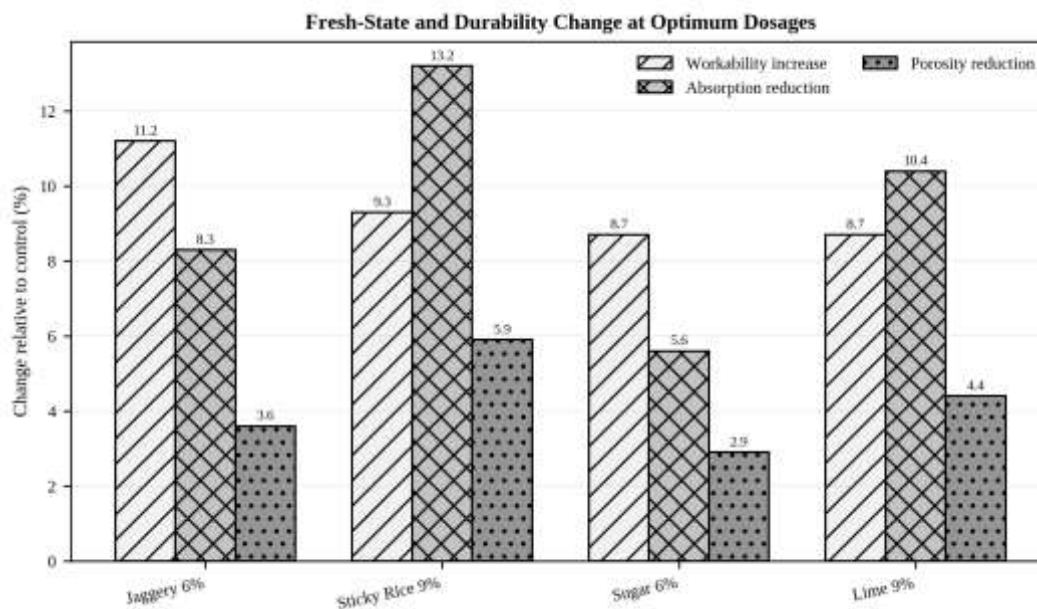


Figure 9. Percentage change of optimum mixes relative to the control

Sticky rice at 9% reduced water absorption by 13.2% and porosity by 5.9%, larger reductions than the other materials, while increasing workability by 9.3%. Jaggery produced the largest workability increase of 11.2% but smaller durability gains. Additional lime showed intermediate improvement, and sugar produced the lowest reductions. Together with the 212.5% increase in 28-day flexural strength reported for 9% sticky rice, the graph supports its overall selection.

The strongest relationship in the dataset is the agreement among porosity, water absorption and flexural strength. The 9% sticky-rice mix combined 55.4% porosity, 12.5% absorption and 0.25 MPa at 28 days; the 15% sugar mix combined 59.0% porosity, 14.9% absorption and 0.09 MPa. This contrast shows that connected voids reduce both durability and effective resistance to bending. Moderate organic addition appears to improve particle cohesion and moisture retention during hardening, but excessive dosage causes retardation, weaker carbonate bonding or entrapped voids. For repair mortar, the selected mix should remain breathable, so the objective is not zero porosity; it is the reduction of harmful connected pores while retaining compatible moisture transport.

6. Conclusion

This paper evaluated the combined fresh-state, flexural and moisture-related behaviour of lime mortars modified with jaggery, sticky rice, sugar and additional lime at 3–15% by lime mass. The control produced 16.1 mm workability, 14.4% water absorption, 58.9% porosity and flexural strengths of 0.04 MPa at 7 days and 0.08 MPa at 28 days. Jaggery at 6% gave the highest workability of 17.9 mm, but the best overall performance was obtained with 9% sticky rice. That mix combined 17.6 mm workability with the lowest absorption and porosity, 12.5% and 55.4%, and the highest flexural strengths, 0.14 and 0.25 MPa. Relative to the control, its workability increased by 9.3%, absorption decreased by 13.2%, porosity decreased by 5.9%, and 28-day flexural strength increased by 212.5%. Additional lime at 9% ranked second, reaching 12.9% absorption, 56.3% porosity and 0.24 MPa at 28 days, while 6% jaggery achieved 13.2%, 56.8% and 0.23 MPa. Sugar was the most dosage-sensitive; at 15%, absorption and porosity rose to 14.9% and 59.0%, and 28-day flexural strength fell to 0.09 MPa. The results confirm a direct engineering relationship between reduced harmful pore connectivity, lower water uptake and improved resistance to bending and crack initiation. The optimum is not the mix with the highest flow, but the one that combines practical placement with restrained liquid-water entry and superior bending resistance. For breathable masonry repair and compatible lime-mortar applications, 9% sticky rice is therefore the recommended optimum within the tested programme.

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