Influence of Sticky Rice and Jaggery Sugar Addition on Lime Mortar

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Abstract-Lime mortar has many advantages, yet its durability properties are the most remarkable, making it very useful in building preservation. Traditional mortar for conservation and restoration work contains lime, which guarantees that the fresh mortar is applied to the underlying layer, increases its setting time, and gives adequate workability. This research aims to determine the durability performance, mechanical properties, and optimum percentage of organic admixtures to be used in lime mortar. Five mix proportions and one control lime mortar mix were prepared. Mixes with jaggery sugar and sticky rice with weight proportions of 3%, 6%, 9%, 12%, and 15% were compared with the control lime mortar mix. The results show that 9% sticky rice lime mortar achieved the highest performance in terms of mechanical and durability properties.

Keywords-lime mortar; conservation; jaggery sugar; sticky rice; water absorption

I. INTRODUCTION

Lime mortar is being replaced by modern materials in the renovation of old buildings, since the development of cement in the 19th century [1], because of the problems encountered with the use of lime mortar, including prolonged setting and hardening periods, especially at high relative humidity, low internal cohesion, poor mechanical properties, and high porosity [2]. Such properties make lime mortar susceptible to damage by salt contamination after being saturated with water [3]. However, issues also arise when modern materials and techniques are adopted in the renovation and reconstruction of existing ancient buildings. Moisture and salt gradually accumulate behind the impervious finishes and cannot evaporate, thereby accelerating timber decay, which allows the growth of beetles [4]. Consequently, high humidity causes the plastering to blister, makes the layers of paint fail and the joists rot, and, in time, the building may collapse. When lime is adopted as plaster in a building, the problems of condensation and blistering can be reduced. A building can withstand humid conditions by evaporating its excess moisture [5]. Nowadays, the utilization of lime mortar for the restoration of historic buildings is being revitalized because of the detrimental characteristics of Portland cement, such as its high thermal expansion coefficient and its brittleness [6]. The small pores of Portland cement that produce its low porosity can delay the movement of water within the masonry and cause deterioration to occur due to the presence of water in the cement matrix, while the salts are evaporated into the adjacent bricks [7]. Besides, lime is a standard universal binding medium for work including plastering and is used with mortars for building houses with historic masonry. One of the main reasons for its wide-ranging functions is that it allows buildings to breathe [8]. Hence, this study focuses on the potential utilization of sticky rice and jaggery sugar as additives in lime-based mortar.

II. MATERIAL CONSTITUENTS, MIX PROPORTIONS, AND TESTS

A. Materials and Tools

The materials involved in this research were lime putty, glutinous rice flour, jaggery sugar, and fine sand which were obtained from local suppliers. In addition, some tools were required in order to prepare, measure, and determine the mechanical properties and the performance of the samples. For instance, the researchers used an electronic balance, a mortar mixer, a mold (Figure 1), a vibrating table, an oven, a Gotech universal testing machine, a desiccator, a flow table, and a rice cooker.

B. Mix Design

A mortar mix design is defined as the procedure of identifying the appropriate proportions of lime: sand: water for the lime mortar to achieve effective levels of mechanical strength and good performance of the structures. The lime mortar mix design included some steps, calculations, and laboratory testing to identify the correct proportions of the mix. A group using the design mix of lime: sand: water with a ratio of 1: 2.5: 0.45, and another 10 groups of the design mix with the addition of additives in 3% increments of weight fraction, were prepared. The mix proportions and mortar designation ratios are illustrated in Table I.

C. Experimental Setup

1) Workability Test

The flow table test consisted of a table with a diameter of 300mm and a mould manufactured in the shape of a conical frustum. Firstly, the conical frustum was filled with mortar in

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two layers, and each layer was compacted by 10 blows with a tamping rod. The excess mortar was removed from the top of the conical frustum and flattened. After 15s, the conical frustum was removed slowly from the mortar with a steady upward pull, before immediately being lifted and dropped on the table by turning the wheel at a specified height and repeating this 15 times in 15s. Lastly, the final diameter of the spread sample was measured using vernier callipers.

Fig. 1. A mortar mixer was used to prepare the lime mortar.

TABLE I. MIX PROPORTIONS AND MORTAR DESIGNATION RATIOS

Mortar group	**Weight fraction (%)**	**Ratio lime: sand: water: admixture**				
		Lime putty	**Fine sand**	**Water**	**Sticky rice**	**Jaggery sugar**
Control	0	1	2.5	0.45	-	-
Sticky rice lime mortar	3	1	2.5	0.45	0.03	-
	6	1	2.5	0.45	0.06	-
	9	1	2.5	0.45	0.09	-
	12	1	2.5	0.45	0.12	-
	15	1	2.5	0.45	0.15	-
Jaggery sugar lime mortar	3	1	2.5	0.45	-	0.03
	6	1	2.5	0.45	-	0.06
	9	1	2.5	0.45	-	0.09
	12	1	2.5	0.45	-	0.12
	15	1	2.5	0.45	-	0.15

2) Water Absorption Test

The water absorption test was conducted in compliance with BS EN 1881-122 [9]. Nine cylinder specimens with dimensions Ø75mm×100mm high were used. The samples were removed from the curing tank 3 days before the test and were oven-dried at 105±5°C for 72±2h. Then, the samples were taken from the oven and were allowed to cool to room temperature. Immediately after cooling, the samples were weighed under standard conditions. Then, the samples were immersed in water for 30±0.5min. Then, the samples were removed from the bucket and the water on the surface was removed using a dry cloth.

3) Porosity Test

The porosity test was conducted in compliance with BS EN 993-1 [10], as shown in Figure 2. Cylinders measuring Ø45mm×50mm were withdrawn from the curing tank 3 days in advance. Then, the samples were dried in the oven at a temperature of 105±5°C for at least 72±2h to remove all the moisture and the dry samples were weighed after the heat had radiated. The dry samples were immersed in a vacuum water-saturated machine and were covered with the lid by slipping off the lid carefully to maintain airtight conditions in the desiccator. Then, the vacuum pump was turned on and the samples were soaked in water for 48±2h. Afterwards, a dry cloth was used to wipe the liquid from the surface of the samples before the saturated samples were weighed with an electronic balance. The readings were recorded, and the difference was measured.

Fig. 2. Porosity test was carried out with the vacuum saturation method.

4) Compression Test

The compression test was carried out in accordance with BS EN 1881-116 [11]. Three specimen cubes measuring 150mm×150mm×150mm were obtained before the test. One day before the test, the specimens were taken from the curing tank and were dried for 24h in the oven. Once the specimens had cooled to room temperature, the test was conducted with the Gotech Universal Testing Machine. Figure 3 illustrates the setup of the axial compression test.

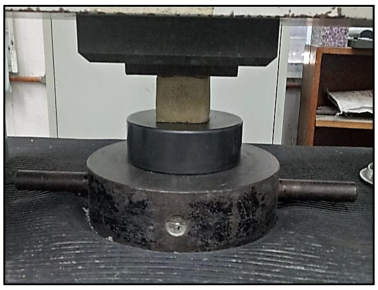


Fig. 3. Compression test setup.

5) Flexural Test

According to BS EN 1521 [12], the flexural test was conducted on 40mm×40mm×160mm lime mortar prisms, as shown in Figure 4. The specimens were removed from the curing tank and oven-dried for 24h before the test. The specimens were then placed on two supporting rollers, with a third roller situated above the specimen and midway between the supporting rollers. Next, the samples were slowly moved down the roller to ensure that the top surface of the prism was in contact with the loading roller. The load was applied to the prism at a constant rate until failure.

Fig. 4. Flexural test setup.

III. RESULTS AND DISCUSSION

A. Workability

Figure 5 illustrates the results of the fresh lime mortar workability with different percentages of sticky rice and jaggery sugar. The workability of the control group (lime mortar without sticky rice or jaggery sugar) was 16.1mm, which was the lowest workability of all the fresh lime mortars. The consistency increased to 16.5mm, 16.9mm, and 17.6mm with the addition of 3%, 6%, and 9% sticky rice respectively. However, the workability of the mortar mix decreased to 16.7mm and 16.3mm when 12% and 15% of sticky rice were added. Moreover, the addition of 3% and 6% of jaggery sugar increased the workability to 16.8mm and 17.9mm respectively, while the workability of the mortar mix started to decrease when 9%, 12%, and 15% of the jaggery sugar were added. When the concentration of sticky rice reached 9%, the lime and sand particles slid against each other easily.

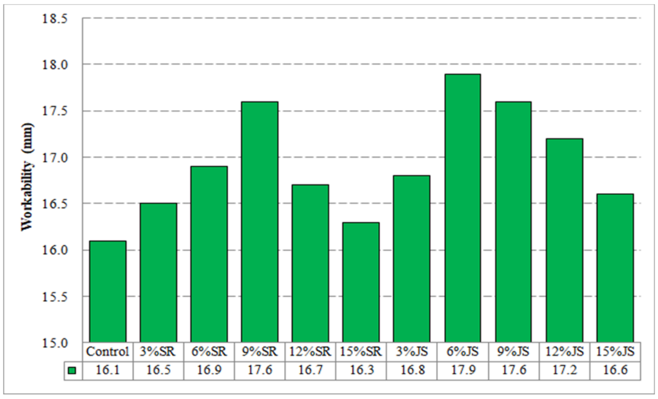


Fig. 5. Workability of lime mortar with different percentages of sticky rice and jaggery sugar.

Sticky rice functions as a viscosity modifier that improves the consistency of lime mortar. On the other hand, when the concentration reached 12%, the workability decreased due to the high adhesive strength of the sticky rice which caused the lime and sand particles to bind together easily, thus preventing the particles from sliding against each other [13]. Sticky rice acted as a lubricant, making the mortar easier to spread. Apart from that, the addition of jaggery sugar extended the setting time of the lime mortar due to the formation of a thin layer on the mortar particles and the delay in the process of hydration. The calcium ions improved the solubility and prevented the formation of calcium hydroxide. This improved the setting properties of the lime mortar.

B. Water absorption

Figure 6 shows the result of the water absorption of lime mortar with different percentages of sticky rice and jaggery sugar. The control group achieved the highest water absorption, which was 14.4%. The water absorption of the mortar mixture dropped drastically to 13.7%, 13.1%, and 12.5% with the addition of 3%, 6%, and 9% sticky rice solution respectively. However, it increased to 13.3% and 13.6% when 12% and 15% of sticky rice solution were added. On the other hand, the water absorption was 14.1% when 3% of jaggery sugar were added, and this decreased dramatically to 13.2% when 6% of jaggery sugar were added. However, the water absorption of the mortar mixture increased again with the addition of 9%, 12%, and 15% jaggery sugar.

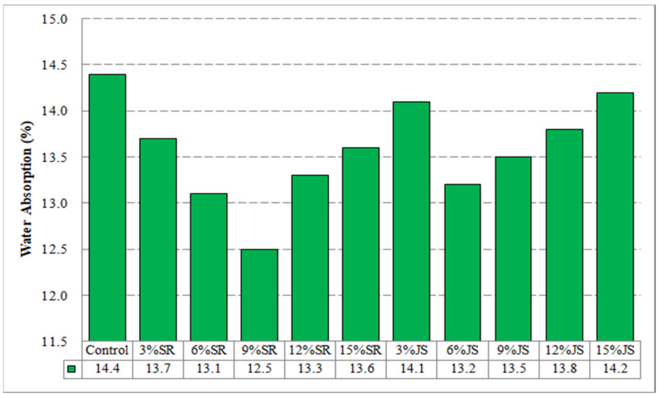


Fig. 6. Water absorption of lime mortar with different percentages of sticky rice and jaggery sugar.

The control group of lime mortar had the highest water absorption due to the presence of capillaries that enabled the water to access the mortar easily [14]. The presence of sticky rice produced a more compact mortar structure. The interaction between the sticky rice polysaccharides and calcium carbonate was also one of the factors that caused the lowest absorption of lime mortar. During the curing of the sticky rice lime mortar, the amylopectin controlled the growth of calcium carbonate and produced a compact structure with less calcium carbonate, which reduced the penetration of water and increased durability [15]. Moreover, the addition of jaggery sugar provided a thin layer of coverage on the mortar surface, which led to reduced contact between the pores and restricted the transport of water. The addition of sticky rice and jaggery sugar into lime mortar lessened both fresh and hardened bulk density values under both dry and humid curing [16]. As stated above, sticky rice can be considered an aqua gel. When evenly integrated into fresh mortar mixes, it becomes encased within the mortar. As mortar dried, the aqua gel shrank, and void spaces were developed. Moisture from within the aqua gel particles slowly diffused to the surface of the mortar and evaporated, further reducing the water absorption capacity.

C. Porosity

The porosity of lime mortar with different percentages of sticky rice and jaggery sugar is shown in Figure 7. Based on the data collected, the porosity of the control group (58.9%)

was the highest among the lime mortar mixtures. The porosity of the lime mortar mix dropped to 56.7%, 56.1%, and 55.4% when 3%, 6%, and 9% of sticky rice solution were added into the lime mortar respectively. When the concentration of sticky rice reached 12% and 15%, the porosity increased again to 55.9% and 56.6%. When the jaggery sugar solution was added at 3%, the porosity was 57.3%. The porosity dropped to 56.8% after the addition of 6% jaggery sugar and rose to 57.1%, 57.7%, and 58.2% for 9%, 12%, and 15% of jaggery sugar addition. The control group had the highest porosity since the addition of the admixture influenced the microstructure of the lime mortar. Changing the pore size distribution increased the volume of air voids and led to the highest porosity among the lime mortar mixtures. According to [17], reduced porosity with the increase in weight fraction of sticky rice (up to an optimum of 9%) and jaggery sugar (up to an optimum of 6%) could indicate diminished pore size, volume, and capillary interconnections, which should be due to the continuous formation of hydration products, taking up more space in mortar pores, making mortar denser and more compact with a reduction in porosity. When the mortar is first mixed, it is a dense slurry, with the sand and sticky rice/jaggery sugar uniformly distributed and surrounded by water. Primary porosity is developed through the movement of water due to either absorption into the surrounding masonry unit or evaporation to the air. Authors in [18] stated that these pores are highly interconnected and fluid transport through these pores is by capillary transport. The total porosity is further influenced by the carbonation of $Ca(OH)_2$ to $CaCO_3$. Accommodation of the volume change is taken up by a reduction of total porosity but no significant shift in pore size distribution with the addition of jaggery sugar/sticky rice.

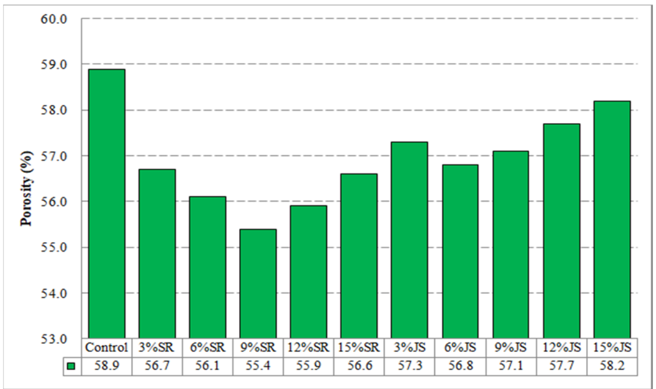


Fig. 7. The porosity of lime mortar with different percentages of sticky rice and jaggery sugar.

D. Compressive Strength

The results of the compressive strength of lime mortar after 7, 28, and 56 days with different percentages of sticky rice and jaggery sugar are illustrated in Figure 8. Compared with the control group of lime mortar, the compressive strength of the mortar mixes surged when 3%, 6%, and 9% of sticky rice solution were added and declined when 12% and 15% of sticky rice were added. Moreover, the addition of 3% and 6% of jaggery sugar enhanced the compressive strength, which dropped steadily for 9%, 12%, and 15% addition. The 9% sticky rice lime mortar showed the highest compressive strength as the sticky rice was able to accelerate the process of setting and hardening, which improved the bonding ability. Furthermore, the addition of sticky rice helped to refine the size of portlandite and calcite crystals to produce a more compact microstructure [19]. However, it was found that 6% of jaggery sugar had the second-highest compressive strength. According to [20], this is because the existence of sucrose in the jaggery sugar improved the initial and final setting times, but it did not affect the compressive strength. Authors in [21] found that sticky rice could significantly improve mechanical strengths and compatibility of air lime mortars and control the growth of $CaCO_3$ crystals. Authors in [22] reported that the addition of 5% of sticky rice in air lime mortars could accelerate mortar setting and hardening, increase compressive and bonding strength, while, at the same time slightly reducing mortar density and water resistance.

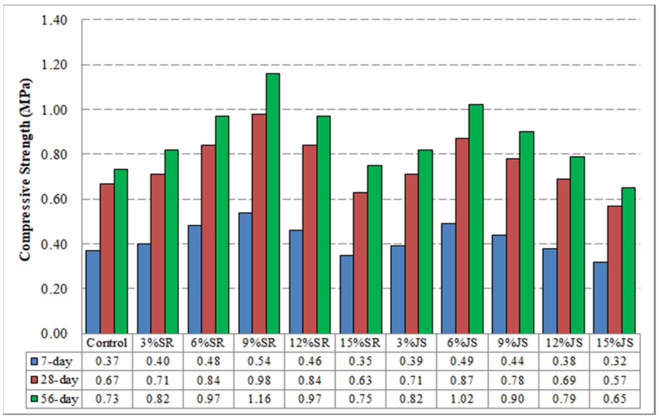
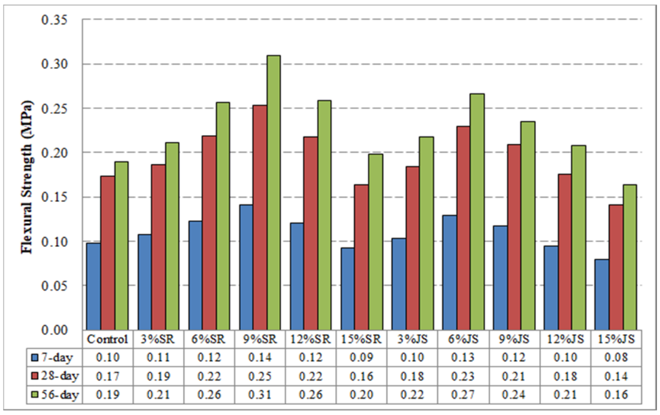


Fig. 8. Compressive strength of lime mortar with different percentages of sticky rice and jaggery sugar on days 7, 28 and 56.

E. Flexural strength

Figure 9 presents the flexural strength of lime mortar with different percentages of sticky rice and jaggery sugar after 7, 28, and 56 days. The flexural strength rose when 3%, 6%, and 9% of sticky rice were added to the lime mortar, but this fell with the addition of 12% and 15% sticky rice. Therefore, the sticky rice in a proportion of more than 6% limited the improvement in the lime mortar strength. The addition of jaggery sugar in proportions of 3% and 6% increased the flexural strength of the mortar. However, the flexural strength fell when 9%, 12%, and 15% of jaggery sugar were added. Authors in [23] reported that the mechanical strengths of lime-sticky rice mortar can be considerably boosted by cyclic wetting–drying and dilute sulfate acid actions, causing more porous matrices and coarser particles. Authors in [25] concluded that sticky rice inclusion could stimulate noticeable conglomeration in mortar, leading to inhomogeneous strain field and creating micro-cracks during wetting–drying cycles. The results in [25] showed that biomineralization may occur in lime-sticky rice mortars, where sticky rice functioned as a template to control the growth of $CaCO_3$ crystals. The addition of an appropriate amount of sticky rice can improve the strength of lime mortar due to its water retention, which is beneficial to the carbonation process of the lime, increasing mechanical strength. However, excessive organic matter will act as a retarder and limit the carbonation of lime mortar [26]. Therefore, the addition of sticky rice exceeding 9% reduced performance in terms of flexural strength. Meanwhile, the addition of jaggery sugar resulted in the reduced performance of lime mortar in terms of flexural strength compared to the addition of sticky rice.



	Control	3%SR	6%SR	9%SR	12%SR	15%SR	3%JS	6%JS	9%JS	12%JS	15%JS
7-day	0.10	0.11	0.12	0.14	0.12	0.09	0.10	0.13	0.12	0.10	0.08
28-day	0.17	0.19	0.22	0.25	0.22	0.16	0.18	0.23	0.21	0.18	0.14
56-day	0.19	0.21	0.26	0.31	0.26	0.20	0.22	0.27	0.24	0.21	0.16

Fig. 9. Flexural strength of lime mortar with different percentages of sticky rice and jaggery sugar on days 7, 28 and 56.

F. Porosity-Water Absorption Relationship

Figure 10 shows the water absorption versus porosity using different percentages of additives with lime mortar. The relationship between the water absorption and porosity increased exponentially with a correlation coefficient (R2) of 0.8234.

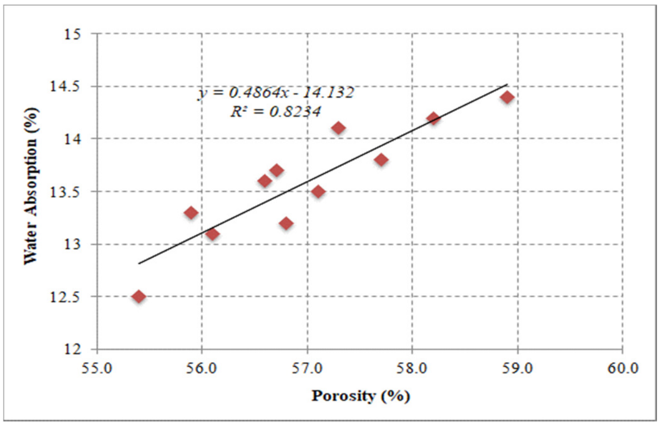


Fig. 10. Relationship between water absorption and porosity of the lime mortar.

The results show that the control group of lime mortar had the highest porosity-water absorption relationship. Normally, lime mortar mixtures with higher water absorption and porosity are less durable. The porosity influences the water absorption of lime mortar. As the porosity decreases, the pore sizes decrease, leading to a reduction in water absorption. The presence of additives makes the structure of lime mortar denser and harder. In this research, different percentages of sticky rice and jaggery sugar were used to improve the durability properties of lime mortar. The sticky rice addition of 9% was considered the best solution to be used with regard to the improvement of the durability performance of the mortar. The sticky rice influenced the microstructure of the lime mortar causing the pore sizes to reduce and thereby decrease the volume of air voids. This led to the lowest porosity levels among the lime mortar mixtures. Hence, the water absorption reduced as the water could flow through the porous gaps, and the water had been removed from the mortar through the capillary forces.

G. Compressive-Flexural Strength Relationship

Figures 11-13 show the compressive strength against the flexural strength of lime mortar mix on days 7, 28, and 56 respectively. These figures show that the relationship between the compressive strength and flexural strength increases with a very high correlation coefficient (R2) of 0.9627 (day-7), 0.9509 (day-28), and 0.9917 (day-56).

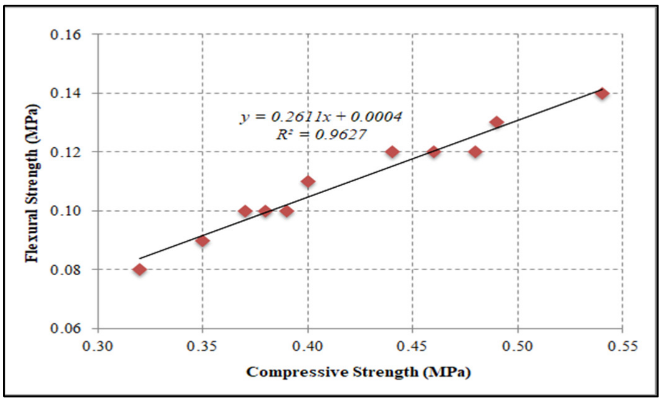


Fig. 11. Compressive-flexural strengths relationship on day 7.

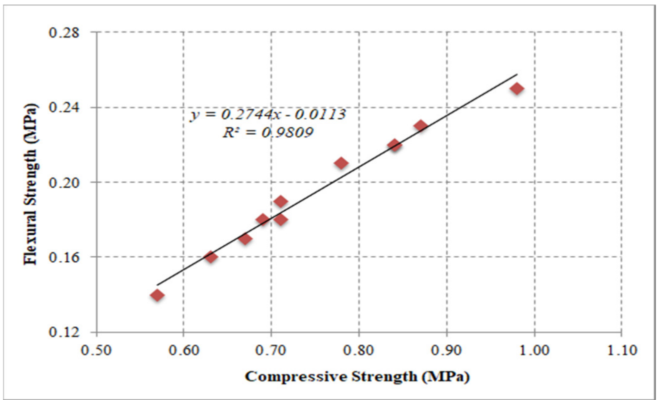


Fig. 12. Compressive-flexural strengths relationship on day 28.

Compressive and flexural strength are important as they reveal the behavior of each mixture. The results show that the highest compressive-flexural strength relationship was found in 9% sticky rice lime mortar. The hardened properties of lime mortar enable the delivery of compressive and flexural stress within the units of the structure. In this study, it was discovered that the addition of admixtures, especially sticky rice, enabled the mortar to withstand a higher amount of movement, under compressive or flexural loads. Different percentages (3%, 6%, 9%, 12%, and 15%) of sticky rice and jaggery sugar were applied to improve the mechanical properties of lime mortar. However, 9% sticky rice was considered as the best additive in improving the durability and mechanical properties. This happens because the sticky rice can accelerate the process of setting and hardening, and results in good adhesion properties between the sand and lime.

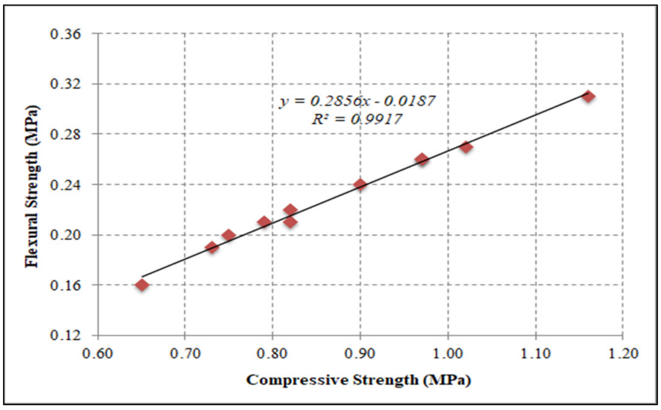


Fig. 13. Compressive-flexural strengths relationship on day 56.

H. Discussion

Replacing or repairing masonry buildings is usually necessary for the restoration of historical constructions, but the selection of a proper lime-based mortar is often challenging. An improper selection can lead to failure of the restoration work, and perhaps even further damage. Therefore, thorough understanding of the original lime-based mortar technology and the production of suitable replacement materials is important. Many kinds of materials have been used over the years in masonry mortars, and the technology has gradually evolved from the single-component mortar of ancient times to hybrid versions containing several ingredients. This study was performed to systematically examine the potential use of sticky rice and jaggery sugar in lime mortar to help determine the proper courses of action in restoring ancient buildings. Lime mortars with varying sticky rice and jaggery sugar content were prepared and tested. The durability and mechanical properties of lime mortar were found to be significantly improved by the introduction of sticky rice and jaggery sugar, suggesting that sticky rice-lime mortar is a suitable material for repairing mortar in ancient masonry. Moreover, the amylopectin in the lime mortar was found to act as an inhibitor. The growth of the calcium carbonate crystals is controlled by its presence, and compact structure results, which may explain the enhanced performance of this organic-inorganic composite compared to single-component lime mortar.

IV. CONCLUSION

Overall, 9% of sticky rice is determined to be the best proportion of additive to use in lime mortar. More specifically, the presence of sticky rice can quicken the setting and hardening times and improve the bonding between the sand and lime particles. The inclusion of 9% sticky rice and 6% jaggery sugar in lime mortar also resulted in lower porosity. The presence of polysaccharides in sticky rice produced a compact microstructure of the lime mortar. The water retention properties of the sticky rice were beneficial, in terms of carbonation process, in improving the flexural strength of the lime mortar. To summarize, 9% sticky rice and 6% jaggery sugar were the optimum percentages of additives to be used in lime mortar. The sticky rice was discovered to be a better additive than jaggery sugar. The sticky rice not only improved the setting and hardening times but also increased the compressive and flexural strengths. The test results show that the inclusion of 9% of sticky rice and 6% jaggery sugar in lime mortar has more stable durability properties, greater mechanical strength, and is more compatible, which makes it a suitable restoration mortar for ancient masonry buildings. The possible practical application of the mortar with sticky rice and jaggery sugar upon the results of the performed study includes foundation settlement and plant growth, and cracks between building blocks. Sticky rice and jaggery sugar lime mortar can be used as joint mortar.

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