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Physico-Mechanical Properties of Lime Mortar by Adding Exerted Egg Albumen for Plastering Work in Conservation Work

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Abstract

This work focuses on the effects exerted by egg albumen on the lime mortar's physical and mechanical properties. Five mortar mixtures were designed by maintaining a constant lime/sand/water ratio of 1:2:0.035. The control mixture comprised only lime putty while various percentages of egg albumen in the range of 2–10% were used to prepare the remaining mixtures. An experiment was then performed with different percentages of egg albumen to examine the lime mortar's axial compressive and flexural strength as well as the water absorption. The results indicate that the compressive and flexural strength of increases with the increasing percentage of egg albumen added into lime mortar until the mixture reaches 6% of egg albumen. With the addition of the 8% and 10% egg albumen made the compressive and flexural strength start to decrease. Lime mortar that contains 6% of egg albumen has the highest compressive and flexural strength compared to other mix design groups.

1. Introduction

At present, lime is frequently employed for restoring and conserving historic buildings and has become a chief material. Furthermore, its characteristics make it highly suitable and long lasting building materials, which is the reason for its use in mortars, paints and plasters for centuries. It has many favorable properties that make it optimum for use in masonry restoration. Lime mortars have antifungal, high mechanical resistance and better waterproof protection properties. Unlike framed structures with masonry veneers available these days, traditional masonry structures used to be only solid masonry [1]. The wall thickness would provide the strength and keep moisture out of the living space. This all worked out to be in good terms with plasters, lime mortars, and paints (lime wash) as lime had the property to absorb large water quantities and could easily release the moisture back into the atmosphere due to its porosity feature. Replacing the historic lime-based materials with modern materials could cause lock-in of moisture in the walls and could lead to many complications, including interior water damage, masonry unit failure, and structural failure of interior wall's wythes.

Traditional materials such as Roman mortar, lime mortar, and natural cement are optimum and thus recommended as they exhibit features like proper strength with ancient buildings and good compatibility. They are considered more effective than modern materials as established through modern research and history [2]. When used in mortars, lime provides benefit of higher bond strength when compared with unmodified non-lime mortars. Also, the particle size of lime is much smaller when compared with other common mortar binders. Subsequently, it can more effectively bond and fill the pours of a stone/brick. Moreover, addition of air entraining agents to the mix is not necessary as lime creates creamier mortars. Introducing air entrainment results in the formation of bubbles and reduces the surface area contact between the brick/stone and the mortar. However, few challenges prevail in the use of traditional lime materials. The curing process of lime is different and follows various mechanisms when compared with modern materials. Adverse weather conditions may also influence the process. Sometimes, even experienced masons and craftspeople that deal with modern materials face problems when installing lime materials. A simplified lime cycle and hydraulic set process [3] is presented in Figure 1.Portlandite$Ca(OH)_2$ crystals experience substantial particle sizelessening and morphological changes upon aging. Aging of the lime putty for excess of one year considerably altered the crystal size and morphology, leading to a reduction of prismatic particles into smaller platelets.

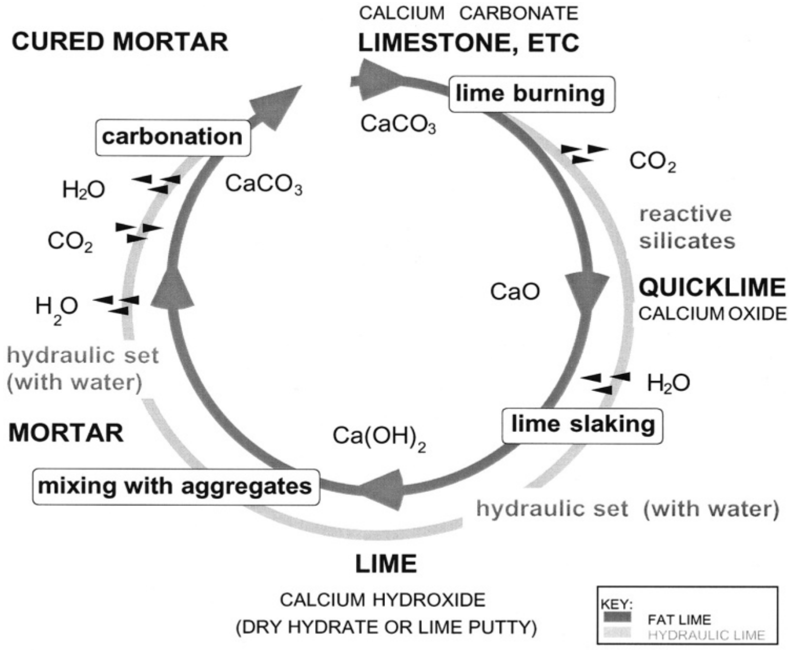

Figure 1: Simplified lime cycle and hydraulic set

It should be pointed out that slaked lime will set gradually and will lose water through the process of evaporation and will absorb carbon dioxide from the air therefore changing back from calcium hydroxide, Ca(OH)2 to calcium carbonate, CaCO3 [2].

$$CaCO3 + Heat \rightarrow CaO+CO2$$

Once slacked, the oxide from the lime component will combine with water and becomes hydroxide or referred as hydrated lime [2].

$$CaO + H2O \rightarrow Ca\ (OH)2 + Heat$$

During the setting stage, the calcium hydroxide loses its water via evaporation process and will absorb carbon dioxide from the air, becoming CaCO3 once again [2].

$$Ca(OH)\ 2 + CO2 \rightarrow CaCO3 + H2O$$

For a conservation repair work, a beforehand understanding and know-how regarding the building or structure is essential before undertaking any works. This is especially true and more important for lime-based works. Sometimes, even the original mortar may contain inherent defects. Also, over time, buildings and their surrounding environment may not remain the same all the time. For example, the building which was previously residential may now be a roofless ruin. To match with the new performance requirements, repair mortars may require a different design from original mortars to perform. This study involves the addition of an organic material (egg albumen) into the lime mortar to modify its properties.

2. Literature Review

For most part of the historical masonry building, lime was the common universal binding material for a majority of the works involving plastering and mortars. One of the many reasons for its wide-scale application is that it allows buildings to breathe [4]. As lime is permeable to vapour, it helped mitigate the risks of trapped moisture and protected the building fabric from damage. Also, its porous nature (open textured materials like lime plaster) offered a comfortable environment. Lime could release and absorb moisture to stabilise the building's internal humidity. It also helped lower mould growth [5] and surface condensation.

During construction, the role of fresh mortar is crucial and, at the same time, complex. The mortar should be easy to spread and remain workable for sufficient time to allow accurate lying to the level of the masonry units and the line. Also, it should retain water to avoid dry out or rapid stiffening of the walls, specifically when absorbent masonry units are employed. As a result, the hardening should follow within a reasonable time frame to avoid squeezing out or deforming.

The internal friction and the retention of water content determine the workability of lime mortar. These factors influence the flexural and compressive strengths, which in turn define a motor's overall quality and durability. The primary factor of workability is the water content, which directly defines the mortar's initial flow. For example, a large flow value can be achieved with the mortar with higher water content than the same mortar with less water content. Lime mortar regulates moisture movements through the building as it has high porosity and is high permeable. This also allows protecting other materials such as masonry materials from harmful salts. As lime allows the walls to breathe, it comforts people inside the buildings. Also, it helps in drying out the building and avoids problems of condensation as well. All these depend on the permeability and high porosity characteristics of lime mortars [6].

Egg albumen is also popularly known as egg white. Based on the egg size, 58–60% of the egg's weight is represented by egg albumen, which consists of 12% dry matter (primarily protein) and 88% water. A large egg's white portion comprises almost 17 calories and no cholesterol. The egg albumen can be categorised into three parts: the inner liquid layer, an outer liquid layer and a liquid layer thicker consistency. It stops bacteria from penetrating the yolk. Egg albumen is generally alkaline and contains almost 40 different proteins. The list of the proteins found in egg albumen is presented in Table 1 [7].

Table 1: List of proteins found in egg albumen

Percentage	Component of proteins
54%	Ovalbumin
12%	Ovotransferrin
11%	Ovomucoid
4%	Ovoglobulin G2
4%	Ovoglobulin G3
3.5%	Ovomucin
3.4%	Lysozyme
1.5%	Ovoinhibitor
1%	Ovoglycoprotein
0.8%	Flavoprotein
0.5%	Ovomacroglobulin
0.05%	Ayidin
0.05%	Cystatin

Egg white can act as a powerful binding agent in food because of the high protein concentration in egg albumen. Proteins have a tendency to bind together as they are slightly elastic in nature. It should be pointed out that egg contains high protein percentage made up of amino acids, which may affect the properties of cement. Some experimental studies highlight that the final strength of the corresponding tests specimens reduced with increase in alkali content in the cement. According to a study involving 199 commercial Portland cement, high levels of alkali in cement resulted in greater dynamic modulus of elasticity value holistically. The study involved measurement of 20 corresponding concrete specimens after 14 days. It then became pretty clear that the higher alkali content in cement led to increase in the strength development, especially in the short term. However, this also decreased the ultimate strength [8]. The structure of an egg is presented in Figure 2.

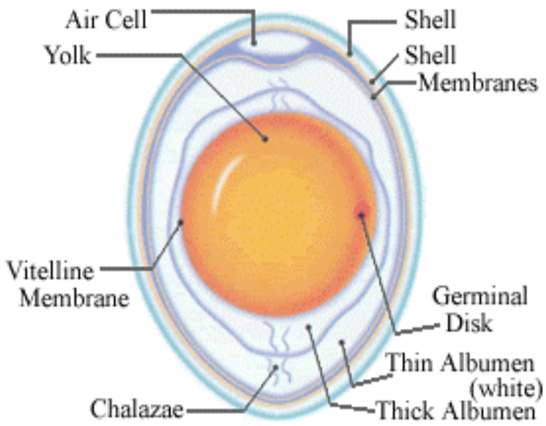

Figure 2: Structure of egg [8]

3. Experimental program

3.1 Materials used

Materials used in the experiment include: Lime putty manufactured by the Great Lime Factory Co. Ltd; Egg Albumen; and normal fine sand. Figure 3 shows that the egg albumen is removed and Figure 4 shows that the egg albumen is beaten until it is foamy and stored in an airtight container.

Figure 3: The egg yolks were removed

Figure 4. Egg albumen was beaten until it is foamy and stored in an airtight container

3.2 Instruments used

The instruments that are used to prepare, measure and assess the characteristics of the fresh and hardened lime mortar include: an electronic balance, mortar mixer (Figure 5), wood moulds (prism), a vibrating table (Figure 6), a flow table (Figure 7), an oven, and an Autotest 3000 BS/ELE Compression Testing Machine.

3.3 Mix proportion

The mixing proportion adopted is Lime Putty: Egg Albumen: Fine Sand: Water. Table 2 shows the density of each material, Table 3 shows the mortar designation ratio for each mix design and Table 4 show the weight of each material needed for each mix design.

Figure 5: Mortar mixer which is equipped with 10 liter stainless steel mixing bowl and a blade

Figure 6: Compacting the mortars on the vibrating table

Figure 7. The diameter of the lime mortar was measured to determine the workability

Table 2. Density of each material

Lime	Egg albumen	Sand	Water
1400kg/m³	1040kg/m³	2650kg/m³	1000kg/m³

Table 3. Mortar designation ratio for each mix design

Mortar Group	Lime Putty	Egg Albumen solution	Fine Sand	Water
0% (Control)	1	0	2	0.035
2%	1	0.02	2	0.035
4%	1	0.04	2	0.035
6%	1	0.06	2	0.035
8%	1	0.08	2	0.035
10%	1	0.10	2	0.035

Table 4. Weight of each material needed for each mix design

Mortar Group	Lime putty (kg)	Egg Albumen (kg)	Fine Sand (kg)	Water (kg)
0% (Control group)	2.2606	0	4.5213	0.0791
2%	2.2321	0.0446	4.4642	0.0781
4%	2.2043	0.0882	4.4085	0.0771
6%	2.1771	0.1306	4.3542	0.0762
8%	2.1506	0.1721	4.3013	0.0753
10%	2.1248	0.2125	4.2496	0.0744

3.4 Specimen preparation and curing

All the specimens are prepared according to the instructions prescribed in ASTM C109/C109M-07[9]. Cube size is 50mm x 50mm x 50mm while prism size is 40mm x 40mm x 160mm. All the mortars are mechanically mixed in a laboratory using a mortar mixer. After that, the mortars are mechanically compacted into prism moulds using a vibration table. These specimens are compacted in three layers, as prescribed by ASTM standards. All the specimens are allowed to cure in the moulds for at least 24 hours prior to de-moulding [10] and air-dried until they reached the testing ages that are suitable for carrying out the test. Figure 8 shows the prism wood mould with specimens.

Figure 8: The prism wood mould with specimens

3.5 Experimental work

Egg albumen was added into lime mortar as an additive. The different proportions of the admixture (egg albumen) are 0%, 2%, 4%, 6%, 8% and 10%. There are a total of 6 mix design groups. The prisms of 40x40x160mm were tested. The lime mortar specimens will be tested for following the tests:

- Workability of the fresh lime mortar with different percentages of egg albumen that according to BS EN 1015-3[10] and ASTM C109.
- Flexural strength after 7 days, 14 days, 21 days and 28 days curing using standard prism specimen according to ASTM C348-97[11].
- Compressive strength after 7 days, 14 days, 21 days and 28 days curing by using broken prism according to the ASTM C349-97[12].
- Water absorption test for 7 days, 14 days, 14 days and 28 days after the specimens had been stored in the oven for 3 days.

4. Analysis of results and discussion

The results are obtained from the experimental programs of testing the flexural strength and compressive strength of the lime mortar containing egg albumen in different percentages. Before the flexural and compression test, the testing of workability of fresh mortar is carried out in order to study how different percentages of the egg albumen solution will affect the workability of the fresh mortar and the results are recorded. After that, the water absorptions of lime mortar containing egg albumen in different percentages are examined.

4.1 Workability of fresh lime mortar

The workability of the control group (lime mortar without any addition of egg albumen) is 16.00cm. Figure 9 clearly shows that the lime mortar with 10% egg albumen has the lowest workability, which is only 15.9cm.

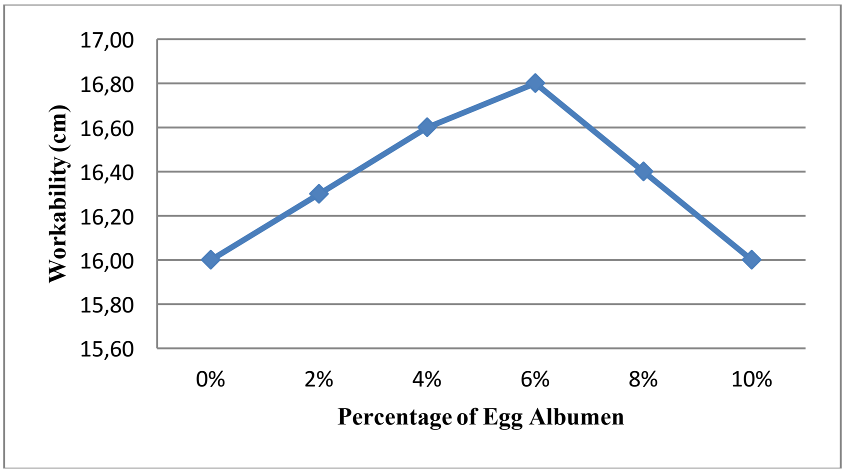

Figure 9: Workability of fresh lime mortar with different percentages of egg albumen

When the 2%, 4% and 6% of egg albumen are added into the lime mortar, mortar consistency increases to 16.3cm, 16.6cm and 16.8cm respectively. However, when 8% and 10% of egg albumen mixtures are added into the lime mortar, the consistency of the lime mortar starts to decrease, which makes workability less than 16.8cm.

The reason for this phenomenon is likely because, as the concentration of egg albumen increases, the adhesive strength of the egg albumen solution also increases. For egg albumen solutions which have concentration up to 6%, the lime and sand particles slide more easily with each other because the egg albumen functions as a lubricant, thus making the mortar spread more easily. However, when the concentration reaches 8%, the workability result drops due to its high adhesive strength. High adhesive strength means that the lime and sand particles stick together easily and prevent particles from sliding with each other. Under this condition, the microstructure of lime mortar will be less compacted and hence leading to lower compressive strength.

4.2 Compressive Strength

As shown in Table 5 and Figure 10, the lime mortars with the addition of 2%, 4% and 6% egg albumen on days 7, 14, 21 and 28 show an increase in the compressive strength as compared to the control mix of lime mortar without any addition of egg albumen.

Table 5. Compressive Strength of lime mortar with different percentages of egg albumen

Test Day	COMPRESSIVE STRENGTH (N/mm2)					
	0%	2%	4%	6%	8%	10%
7th	1.4	1.6	1.7	1.9	1.7	1.3
14th	2.3	2.8	2.8	3.3	2.8	2.1
21st	3.2	3.4	3.7	3.9	3.5	2.8
28th	3.3	3.5	3.7	4.1	3.4	3.1

In my opinion, this phenomenon is probably due to the effects of the proteins in the egg albumen on the mortar. This is because of the potential that the proteins are able to form bonding interactions with other proteins and surfaces. This can be proved in an experiment in which the egg albumen is spilled on two eggs and until it is dried; after this occurs, it is hard to pull the two eggs apart without breaking at least one of them. The compressive strength of lime mortar increases until the percentage of egg albumen reaches 6%. It started to fall when 8% and 10% of egg albumen were added into the lime mortar. It can be proven that, with the addition of more egg albumen, the alkali content of the mortar will increase since the egg albumen is an alkaline solution. This may have harmful effect on the mechanical properties of aggregates which are not susceptible to alkali-silica reaction.

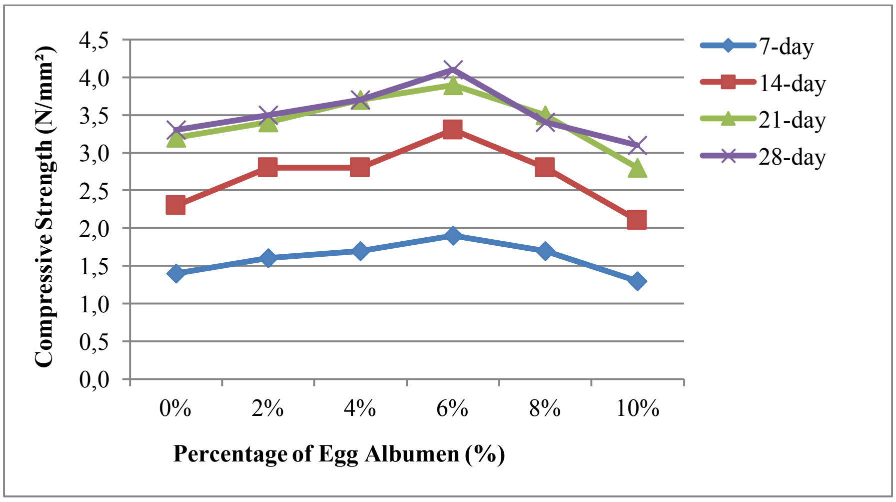

Figure 10: Compressive Strength of lime mortar with different percentages of egg albumen

4.3 Flexural Strength

As seen in Table 6 and Figure 11, the flexural strength of the lime mortar showed increases from when 2% of egg albumen is added into lime mortar until when 6% of egg albumen is added at all the testing ages (including7, 14, 21 and 28 days). The lime mortar that contained 6% of egg albumen showed the highest flexural strength compared to other mixtures. However, the flexural strength of the lime mortar started to drop after 8% and 10% of egg albumen were added into the lime mortar. Flexural strength can be influenced by many factors. The decrease in strength of the lime mortars can be caused by the formation of micro cracks due to drops in humidity in the room where the specimens are stored [13]. According to the recorded results, the lime mortar with 6% of egg albumen has the highest flexural strength while lime mortar with 10% of egg albumen is the weakest mixture.

Table 6: Flexural Strength of lime mortar with different percentages of egg albumen

Test Day	FLEXURAL STRENGTH (N/mm2)					
	0%	2%	4%	6%	8%	10%
7th	0.32	0.39	0.41	0.48	0.44	0.34
14th	0.57	0.72	0.74	0.84	0.71	0.54
21st	0.79	0.87	0.93	0.99	0.89	0.71
28th	0.85	0.89	0.95	1.05	0.86	0.82

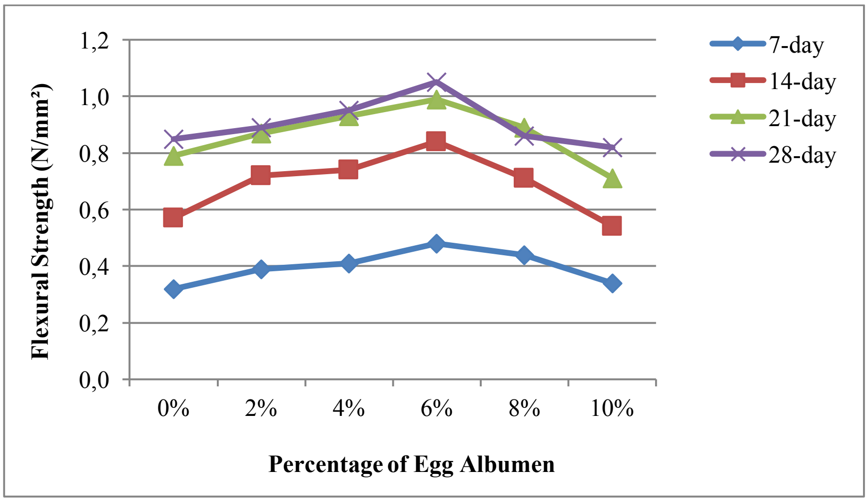

Figure 11: Flexural Strength of lime mortar with different percentages of egg albumen

4.4 Water Absorption

Table 7 and Figure 12 show the results of the water absorption test of the lime mortar with different percentages. Based on the data collected, it shows that after 30 minutes of immersion in water, the water absorption of lime mortar decreases when mixtures with 2%, 4% and 6% of egg albumen are added into the lime mortar on days 7, 14, 21 and 28.

Table 7: Water Absorption of lime mortar with different percentages of egg albumen

Test Day	WATER ABSORPTION (%)					
	0%	2%	4%	6%	8%	10%
7th	17.8%	17.1%	16.2%	15.2%	16.6%	17.9%
14th	17.6%	16.9%	15.9%	14.9%	16.3%	17.7%
21st	17.3%	16.6%	15.3%	14.3%	16.0%	17.5%
28th	17.1%	16.6%	15.1%	14.1%	15.8%	17.3%

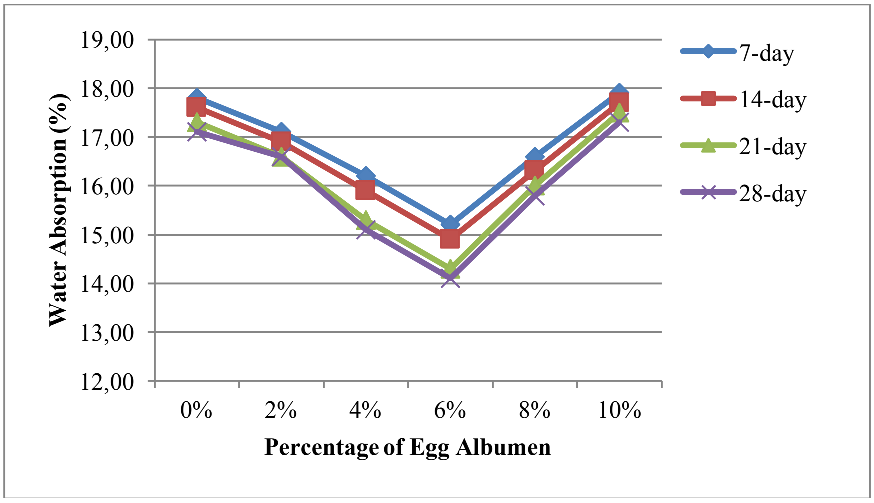

Figure 12: Water Absorption of lime mortar with different percentages of egg albumen

However, it starts to increase again with the addition of the 8% and 10% of egg albumen mixtures. The lime mortar with 10% of egg albumen has the highest water absorption compared with the other mix design due to its many less compacted pores, which are easily accessible to water as compared with other egg albumen lime mortars. The mixture that absorbed the lowest percentage of water is lime mortar with 6% of egg albumen. The addition of the egg albumen can decrease the capillarity by various mechanisms. It makes a thin film spread evenly over the mortar's structure, covering the grains of binder, which results in decreased connectivity between pores and limits water transport. Furthermore, the addition of the egg albumen is also changing the pore size distribution in a way which decreases capillary transport.

Conclusions

Based on all of the data obtained from the laboratory investigation done on lime mortar mixes with various percentages of egg albumen, the following conclusions can be derived:

- The workability of fresh lime mortar increases when 2%, 4% and 6% of egg albumen are added into the lime mortar.The lime mortar with 10% egg albumen has the lowest workability.
- The compressive and flexural strength of the lime mortar increases with the increasing percentage of egg albumen added into lime mortar until the mixture reaches 6% of egg albumen.
- The addition of the 8% and 10% egg albumen made the compressive and flexural strength start to decrease. Lime mortar that contains 6% of egg albumen has the highest compressive and flexural strength compared to other mix design groups.
- It is believed that the characteristics of the egg albumen act as a lubricant in lime mortar making the mortar easier to compact and fill the smaller void inside the mortar, thus egg albumen lime mortar is stronger than plain lime mortar.
- The 6% egg albumen lime mortar has the lowest percentage of water absorption.The addition of egg albumen changes the pore size distribution in a way that decreases capillary transport.
- The high surface water absorption decreases the compressive strength of the lime mortar.

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