Journal of Cultural Heritage xxx (2017) xxx–xxx

Available online at
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com/en

Original article

# Experimental investigation on physical and mechanical properties of lime mortar: Effect of organic addition

Selvaraj Thirumalini [a], Ramadoss Ravi [b], Murugan Rajesh [c,*]

[a] School of Civil & Chemical Engineering, VIT university, Vellore campus, 632014 Tamilnadu, India
[b] Department of Civil Engineering, Kattankulathur Campus SRM University, 603203 Tamilnadu, India
[c] School of Mechanical Engineering, VIT university, Vellore campus, 632014 Tamilnadu, India

ARTICLE INFO

*Article history:*
Received 17 February 2017
Accepted 16 October 2017
Available online xxx

*Keywords:*
Lime
Compressive strength
Porosity
Organic

ABSTRACT

Influence of organic addition in the lime matrix on its mechanical and physical properties has been investigated. Results revealed that addition of organics in the lime matrix enhances the mechanical properties of the mortar significantly as it improves the binding strength between two consecutive lime particle in the mortar. Physical property results reveal loading of organics in the lime mortar decreases the pore size due to formation of weddellite element in the lime mortar, which fills the gap between two consecutive lime particle in the mortar. Results also reveal that the addition of organics does not reducing total porosity due to formation of large numbers of smaller size pores in the lime mortar. However, addition of organics enhances the strength of mortar. Curing studies reveal that mortar with higher curing days enhances the compressive strength of composites while lower curing reduces the performance of mortar due to lower carbonation rate. X-ray diffraction and FT-IR analysis has been used to confirm the new element formation in the organically modified lime mortar due to interaction of protein and carbohydrate with lime particle.



## 1. Introduction

Lime mortar is one of the oldest type of mortar known, debated its use in construction since 10,000 years ago mainly in the countries like India, Italy, Greece and Egypt [1]. Air lime mortars were used by Egyptians as bedding mortars, hydraulic lime mortar with pozzolans were extensively used by Romans with enhanced strength and durability. Compared to other countries, in India, the strength and durability of lime mortar were improved by addition of plant and animal extract instead of adding pozzolan [2]. Hence, from the literature, it was found that various natural organics namely curd, jaggery, cactus extract, bel pulp, lentils and oil of margosa were added to lime mortar [3,4]. Though the exact role of adding natural organics is not known, they would have been added to enhance the strength and other properties of lime mortar.

In the repair and restoration works of ancient structures, it is always better to retain the original mortar as much as possible. Hence, the use of materials and techniques employed in the original construction should be thoroughly understood. Mitchell [5] has expressed that due to many historic variations in the original materials used, and their subsequent interaction with other elements, the use of tailor made mortar is not a realistic option. In general, lime mortar has higher capillary water absorption compared to cement mortar, which affects the durability of lime mortar [6]. To protect the old historical structure from water reaction, it is important to increase the resistance against water affinity of lime mortar [7]. Xiao et al. [8] characterized mortar sample using various technique such as SEM, TGA, XRD, FT-IR and found that presence of sticky rice plays important role to form dense and compact microstructure. Diana et al. [9] found that presence of amino acids in organically modified lime mortar enhanced the mechanical resistance of lime mortar. Ventola et al. [3] investigated the compressive strength, water-resistance, carbonation speed, porosity of animal glue added lime mortar. They found that addition of animal glue in the lime matrix enhanced the mechanical properties, carbonation speed and reduced pore size significantly. Centauroet al. [10] investigated the role of natural organic addition on physical properties of different lime mortars (natural hydraulic lime and aged lime putty). Zhao et al. [11] found that addition of 5% of sticky rice slurry in the lime mortar enhanced the compressive strength.

To improve the durability and strength of lime-based mortar, researchers suggested that addition of natural polymer in the lime matrix enhances various properties of lime mortar [12,13].

* Corresponding author.
*E-mail addresses:* p.thirumalini@yahoo.in (S. Thirumalini), ravistrucl@yahoo.co.in (R. Ravi), rajesh261288@gmail.com (M. Rajesh).

https://doi.org/10.1016/j.culher.2017.10.009
1296-2074/

Several researchers analysed the effect of organic extract and inorganic mineral addition in the lime matrix on mechanical properties. Results revealed that addition of admixtures alters the properties of the lime matrix and enhances the adhesion between two particle in the lime matrix because admixture act as a mechanical interlock which increases the adhesion [14]. Another reason behind this is, addition of organics in the lime matrix affects the crystallization nucleus for the precipitation of CH [15]. Thirumalini et al. [4] investigated the effect of traditional herbs on mechanical properties and found that addition of herbs enhanced the properties due to the formation of whewellite crystals.

Most of the researchers analysed the influence of curing time, type of aggregate, binder/aggregate ratio on porosity and mechanical strength of lime mortar. But very little work has been done by researchers on the effect of organic mineral in the lime mortar. From above literature survey, it is found that type of aggregate and its ratio with a binder material influences much on their strength. Hence, it is very important to analyse the effect of organic addition in the lime matrix on strength and porosity. Present work aims to improve the mechanical properties and porosity characteristics of lime mortar by addition of organic additives.

## 2. Research aim

Lime mortar is one of the oldest construction material used from ancient time period and compared to modern construction material cement, it has low strength. In south India, there is a traditional practice of using variety of plant and animal extract in lime mortars and more specifically kadukai, jaggery and kulamavu has used to improve various properties of mortar. However, the exact reason behind the use of herbs towards the strength and durability was unknown. This paper address the influence the addition of organic admixture on strength and porosity of the mortars. The interaction of carbohydrate, protein and fat in organics with lime matrix with respect to mechanical and physical properties was investigated. Amount of pore and its size influence much on strength of lime mortar hence it is quite important to analyse the influence organic interaction. Mercury intrusion porosimetry (MIP) was used to quantify the amount of pore and its size range and XRD, FT-IR analysis has been employed to confirm the new complex formations due to reaction of protein and carbohydrate in the organic with lime mortar. For restoration of ancient building, this study will be useful for understanding the organic based lime mortars.

## 3. Experimental work

### 3.1. Hydraulic nature of the lime

The hydraulic nature of the lime was established by wet chemical analysis and modern methods. The method of test as per IS: 6932 (Part VII) - 1973 [16] according to specification mentioned in IS: 712 - 1984 [17]. Atomic Absorption Spectroscopy (AAS) was used to find the amount of Al2O3 and Fe2O3 whereas the analysis of calcium and magnesium was carried out by chemical analysis and Silica was found using gravimetric method. The hydraulic index (HI) and cementation index (CI) is calculated as per Eqs. (1) and (2) respectively.

$$\text{Hydraulic index (HI)} = (Al_2O_3 + Fe_2O_3 + SiO_2)/(CaO + MgO) \quad (1)$$

$$\text{Cementation index (CI)} = (1.1\,Al_2O_3 + 0.7\,Fe_2O_3 + 2.8\,SiO_2)/(CaO + MgO) \quad (2)$$

The identification of lime based on hydraulic index ranges developed by Taylor [18] is

If

$0.30 < HI < 0.50$ – weakly hydraulic
$0.50 < HI < 0.70$ – moderately hydraulic
$0.70 < HI < 1.10$ – higher the index, more hydraulic properties

The classification of lime based on cementation index developed by Eckel [19] is

If

$CI < 0.15$ – air lime
$0.15 < CI < 0.30$ – sub hydraulic lime
$0.30 < CI < 0.50$ – weakly hydraulic
$0.50 < CI < 0.70$ – moderately hydraulic
$0.70 < CI < 1.10$ – higher the index, more hydraulic properties

### 3.2. Preparation of herbal

The preparation of herbs was done as per current practice carried out in restoration of ancient structures in India. Approximately, 0.5 kg of kulamavu leaves, 1 kg of kadukai seeds and 3 kg of jaggery were taken and crushed separately. They were mixed with 10 L of water in a separate container and fermented for a minimum period of 7 days. Five hundred ml of kulamavu extract is mixed with 10 L of water (5%) for the preparation of LKu mortars. Similarly 500 mL of fermented kadukkai, Jaggery extracts were mixed with 10 L of water (5%) for the preparation of LK and LJ mortars respectively. Finally equal quantities of fermented kadukkai and jaggery extracts (250 mL each) were mixed together in 10 L of water to prepare LJK mortars.

### 3.3. Mortar preparation

Hydrated shell lime passing through 850 micron sieve, was mixed with herbal extract in equal proportion. Well-graded river sand free from organics was used as fine aggregate in the investigation. The lime to aggregate ratio was taken as 1:3 by weight as per Indian codal provision IS 712-1984. The lime was thoroughly mixed with an equal quantity of (water/organics extract) for 5 minutes, and the resulting putty was used for preparing the mortar. The prepared lime putty along with sand that was brought to a plastic mix state have been grind mixed to bring the requisite homogeneity to the mix. Grinding of lime mortar was done to break the unslaked lime particles. The water/binder ratio(W/B ratio) is maintained as 0.65. The prepared mix was filled into non corrosive cube moulds cubes (50 mm × 50 mm × 50 mm) and left in atmospheric conditions at a temperature 27 ± 2 °C and 90% relative humidity. Moulds were demoulded after 3 days and kept at same environment in air curing for 25 days, (for 28 days strength). Description of organically modified lime mortar used in the study are given in Table 1. The different type of lime mortars used are LJ (lime + jaggery), LK (lime + kadukai), LJK (lime + jaggery + kadukai), LKu (lime + kulamavu) and LR (lime + water).

### 3.4. Compressive strength

Lime mortar was prepared as per IS: 6932-1973(Part 2) [20] for compression sample. Low capacity universal capacity machine has been used with loading rate of 50 N/s to analyse the compressive strength of different lime mortar used in the study.

### 3.5. Pore structure

Porosity of lime mortar used in the study was measured using MIP. For that, parameters of mercury such as contact angle, surface tension and density 141.0°, 485.000 dynes/cm, 13.5000 g/mL

Please cite this article in press as: S. Thirumalini, et al., Experimental investigation on physical and mechanical properties of lime mortar: Effect of organic addition, Journal of Cultural Heritage (2017), https://doi.org/10.1016/j.culher.2017.10.009