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Production of Organic Lime Mortar to Adapt CO_2 for Construction of Scared Groves @ Auroville, Puducherry, India

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Abstract. Lime is one of the oldest construction material and it shows greater durability properties. The main aim of the study is to analyse the organic modified lime mortars used as bedding and plastering mortar at Sacred Groves, Auroville Pondicherry, India. Locally available organics namely kadukai (Terminalia chebula) and jaggery (Unrefined sugar) were used to alter the properties of lime based mortars as added by ancestors in traditional buildings. Organics on fermentation reduce to carbon - di - oxide and enhances the formation of calcite and alters the hydrated phases and mechanical properties of lime mortar. Lime and quarry dust in the ratio of 1:3 with fermented herbal extract were casted and tested for compressive, flexural strength. Organic modified mortars shown better performance than reference mortars. Analytical techniques XRD, FESEM with EDX and FT-IR were undergone to study hydrated phases, morphology and presence of organics.

Keywords: Lime mortar · Organics · Terminalia chebula · Jaggery
Compressive strength · Flexural strength · XRD · FESEM with EDX
FT-IR

1 Introduction

Lime mortar are one of the oldest construction building material used in practice [1]. The calcination of lime stone was first introduced by Europeans in 2450 BC [2]. Romans had greatly improved the lime mortars by adding sand, gypsum, volcanic ash and ceramics [3], this type of lime mortars are widely used in western Asia and European countries until the appearance of cement in 19th century [4]. The most famous Roman's Hadrian Aqueduct architecture survives in Carthage, which was built in 128 A.D, follows the rules set down in Vitruviu's De Architectura [5]. The durability of medieval defence wall of Lisbon constructed by Roman's was subjected to severe marine environment but it shown excellent durability [6]. In India lot of structures were constructed by kings and Mughals. Qutab shah's constructed many lime mortar based structures in and around Hyderabad. Charminar is world's first monument structure constructed by combination of lime mortar and granite stone [7].

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To alter the properties of lime mortar like workability, permeability, strength and durability of lime mortars ancestors are added locally available plant extracts in lime mortars [8]. The usage of different organics like pluses, molasses, boiled stems, oils, egg whites are rich in carbohydrates and proteins which may indirectly helps to improve the strength and durability properties of lime mortars [9]. The Vadakunnathan temple, India was constructed during 7^{th} century using lime mortars with natural herbs such as oojalvalli, kulamavu, kadukai, pananchikai and jaggery (Unrefined sugar) are added to change the properties of lime mortar. Characterization studies like XRD, TGA, SEM, FT-IR was undertaken to identify the mineral compositions. The temple was standing till know, it is an outstanding example of ancient construction technology [10]. Ventola et al. [11] experimented the effect of organic admixture like proteins, fats, polysaccharides on lime mortars and concluded that during fermentation process polysaccharides liberates carbon-dioxide which helps to increase the carbonation of lime mortars, proteins has double the compressive strength, fats (olive oil) reduce the pores of lime mortars by half. Nunes et al. [12] included linseed oil as admixture in lime mortars and achieved that, the addition of linseed oil greatly improves the hydrophobicity of lime mortars. Fang et al. [13] stimulated lime mortar with incorporation of blood as an admixture and concluded that due to addition, lime mortar has shown good binding strength and improved weathering resistance.

Sacred groves is the community formed with group of architects working as volunteers, which was located in Puducherry, Tamil Nadu, India. The main agenda of community is to construct eco-friendly structures. The materials used for construction are abode blocks as bricks, palm wood as beams and columns, lime mortar as binding material, bamboo as reinforcing material for lime mortar. The ongoing construction of eco friendly structure is shown in Fig. 1. In this study experimental investigation was under taken to identify the mineral and mechanical characteristics of lime mortars used for construction of structure. Analytical techniques like XRD, FESEM with EDX and FT-IR were chosen to study the hydrated phases, morphology and organic contents of mortars. The compressive, flexural strength were implanted to study the mechanical properties of mortars.

Fig. 1.

2 Experimental Activity

2.1 Materials Used

In this study for preparation of mortar, lime is procured from Thanjavur, Aastra dealers, Tamil Nadu, India. The chemical composition of lime is obtained from X- Ray fluorescence Spectrometer (XRF). The Hydraulic Index (HI) and cementation Index (CI) are calculated according to Boynton formula [14] given in Eqs. (1) and (2).

$$\text{Hydraulic Index (HI)} = \frac{Al_2O_3 + Fe_2O_3 + SiO_2}{CaO + MgO} \tag{1}$$

$$\text{Cementation Index (CI)} = \frac{1.1Al_2O_3 + 0.7Fe_2O_3 + 2.8SiO_2}{CaO + MgO} \tag{2}$$

Quarry dust is a tailing material obtained from the extraction and processing of rocks to make fine particles of size less than 4.75 mm. Well graded quarry dust free from debris is selected for experimental investigation.

2.2 Preparation of Herbal Extract

The preparation of herbal extract requires selected herbs (kadukai and jaggery), water and container with closing lid with capacity of 60 litres. The mix proportion for preparation of herbal extract is 1 : 1.19 : 38.5 (kadukai : jaggery : water). According to the proportion, herbs are crushed and make it in to fine powder. The container is filled with required amount of water and then crushed powder is added in the container with water and stir continuously for thoroughly mixing. The container lid is closed and kept it aside for minimum 7 days for fermentation process. After completing fermentation period, herbal extract is used for preparing specimens. The materials, herbs and fermented container were shown in Fig. 2.

Fig. 2. **a**: Lime, **b**: Quarry dust, **c**: Herbs, **d**: Herbal extract

2.3 Mortar Preparation

The preparation of lime mortar is divided in to two phases namely LM-R and LM-KJ. In both the cases the mixing procedure is same. Ancient mixing procedure is adopted for grinding the lime mortars. First select the flat ground surface and clear all the debris.

A circular channel of depth 0.6 m, width 0.6 m and radius 5.4 m was created on the ground surface. A circular stone of diameter 1.5 M is erected vertically in the circular channel. The circular stone is connected to the centre of circular channel through steel rod. The mechanism is created in such a way that, the circular stone can freely movie

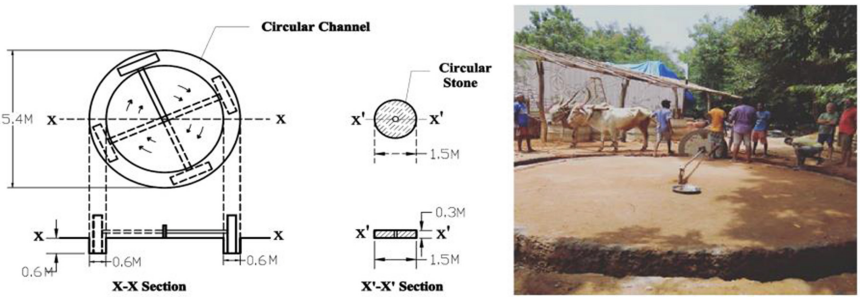

Fig. 3.

inside the circular channel by pulling of external forces (Animal force). The entire setup was shown in Fig. 3.

Lime, quarry dust in the ratio of 1:3 is mixed thoroughly, than herbal extract is added to the equal proportions of lime. After mixing the entire quantity is placed in the circular channel and start rolling the circular stone over the mix. The circular stone is pulled with the help of animal force. For making mortar as more fine, the circular stone is rolled nearly 150 times. After completing the process, entire mortar is discarded from the circular channel and kept aside for minimum 7 days for uniformity. The procedure for preparing LM-R is same, but in place of herbal extract, water is added to the mix. Before using for construction practice the workability of mortar can be altered by adding the water content. To identify the consistency, the mortar is taken in the hand, than leave the gap between the fingers and tilt the hand upside down if mortar is not falling than consistency is good. Due to the mixing of lime mortar through rolling, the properties of lime mortar greatly improves.

2.4 Mechanical Properties

The cubes of size 50 × 50 × 50 mm and prisms of size 40 × 40 × 160 mm were cast for testing compressive and flexural strength. The two mixes as proposed earlier LM-R and LM-KJ are cast separately, after 3 days specimens are demoulded and kept in open atmosphere at temperature 27 ± 2 °C for air curing. After 28 days cubes and prisms are placed low capacity universal testing machine for testing compressive and flexural strength as per IS 6932 part VII – 1973. The testing was shown in Fig. 4 below.

2.5 Analytical Analysis

X- ray diffraction technique, FESEM with EDX and FT-IR were chosen as an analytical tools for identifying the hydrated phases, morphology and presence of organic

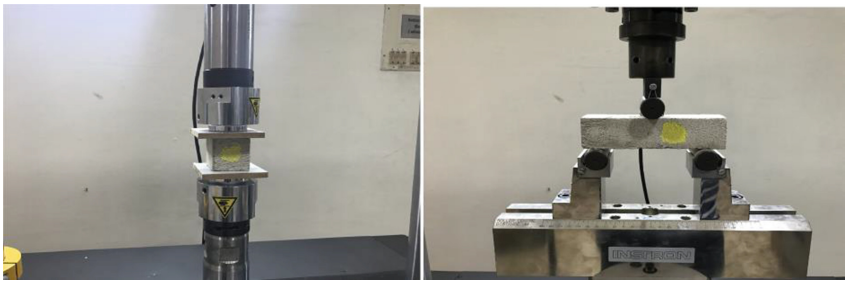

Fig. 4.

content in mortar mixes. After testing mechanical properties, the crushed pieces of two mortars (LM-R, LM-KJ) are collected separately. For XRD and FT-IR, the crushed pieces are made in to fine powder and it is sieved through 75 microns, the passing material is collected and utilized for testing.

3 Results and Discussions

3.1 Characterization of Lime Powder

The Characterization of lime powder was examined through XRF (X-Ray Fluorescence Spectrometer). The oxide composition of lime powder, Hydraulic index and cementation index are presented in Table 1. From the calculated percentages it was clear that the domination of clay minerals. The hydraulic index of lime powder (HI = 0.37) obtained was varying in between 0.30–0.50, means lime is weakly hydraulic [15]. Lime contains 24.48% clay minerals, hence it also justified that the lime is eminently hydraulic. The cementation index of lime powder is (CI = 0.87) in between 0.70–1.10, hence it exhibits more hydraulic properties [16]. This type of lime has capable to set with in one day after adding water and used for construction of hydraulic structures and chimneys etc.

Table 1. Description of the table.

Components of lime	Precentage of components
Cao	70.26
Mgo	0.161
SiO_2	19.94
$Al_2\ O_3$	4.315
$Fe_2\ O_3$	1.833
HI	0.37
CI	0.87

3.2 Characterization of Herbs

The identification of percentage of polysaccharides, proteins and fats present in plant extracts is very important. As discussed earlier, the presence of organics in lime mortar directly effects the strength and durability properties. The percentage of proteins, fats was identified through Kjeldhal and crude fat method [17]. Polysaccharides content is determined through equation given below. The percentage of polysaccharides, fats and proteins of kadukai, jaggery are shown in Table 2

$$\text{The percentage of polysaccharides content} = (100 - (\text{percentage of fat} + \text{percentage of proteins} + \text{percentage of ash})) \quad (3)$$

Table 2. Description of the table.

SI.No	Herbs	Polysaccharides (%)	Proteins (%)	Fats (%)
1	Kaddukai	80.12	4.21	0.62
2	Jaggery	85.2	3.12	0.90

3.3 Spectral Analysis

In case of LM-R mix, the smaller absorption band are identified at 873.7 cm^{-1} and broader bands are recognised at 970.1, 1419.61 cm^{-1}. The peak 873.7 cm^{-1} indicates the formation of vaterite, 970 cm^{-1} chance to be formation tobermorite and 1491.6 cm^{-1} indicates the presence of calcite [18] as shown in Fig. 5a. In case of LM-KJ mix very small and broader peaks are identified at 713, 1413 cm^{-1} which confirms the formation of calcite. The peaks at 1091, 977 cm^{-1} indicates development of calcium aluminium silicates and tobermorite. The band vibration at 3417,3641 cm^{-1} recognised as hydroxyl ions and isopropanol which conforms the formation of portlandite as shown in Fig. 5b. The broader and larger peaks are identified in case of organic modified mortar compared to reference mortar.

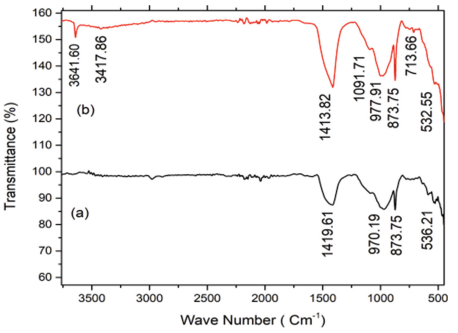

Fig. 5. **a**: LM-R; 5 **b**: LM-KJ

3.4 Strength vs XRD

The compressive strength of LM-KJ mix is increased 37% compared to LM-R mix. In case of LM-KJ mix due to addition of herbal extracts, accelerated carbonation is taken place which leads to formation of more calcite crystals compared to LM-R mix. The flexural strength of LM-KJ mix is nearly 34% more than LM-R mix. Hence the addition of herbal extracts made the LM-KJ mix more are flexible. The comparison of compressive and flexural strength results are shown in Fig. 6a (CS – Compressive strength, FS - Flexural strength). X – Ray powder diffraction is an analytical tool to identify the hydrated phases in lime mortars. In case of LM – R, the main hydrated phases identified are calcite, aragonite, vaterite and portlandite. Along with these traces of tobermorite are identified. Aragonite crystal structure is different from calcite, it contains orthorhombic crystal system it is obtained through the biological process [18]. Vaterite is another polymorphic form, it has higher solubility than other two phases of calcite [19]. In LM – R Mix the formation of calcite is undergone due to the carbonation from atmosphere. In case of LM – KJ mix, along with formation of calcite, vaterite and aragonite, the major strength causing hydrated phases gismondine, hydrogranet and tobernorite are also identified in mix as shown in Fig. 6b.

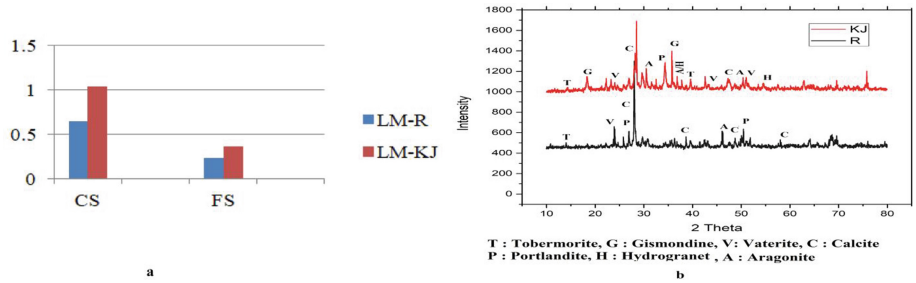

Fig. 6. **a**: CS, FS; **b**: XRD

3.5 FESEM vs XRD

In XRD, different hydrated phases are identified in lime mortars. To confirm the formation of hydrated phases, these are compared with another analytical tool FESEM with EDAX. It was chosen to study the morphology and mineral elements in lime mortars. In case of LM-R mix as the Fig. 7a,b shows a clear picture of formation of different shapes. The hexagonal flakes shows the formation of portlandite, needle shape rods shows Aragonite and round (boulder) shape signifies the presence of vaterite. In case of LM-KJ mix Fig. 7c,d, the image shows the rigorous formation of different shaped crystals. The formation of calcite, Aragonite and vaterite are more, because the addition of organics increases the production of Co_2 in lime mortars, which leads to more crystals formation. Compare to LM – R mix, Gismondine, tobermorite, hydrogarnet is also found in organic modified mortars. The results from EDX also strengthen the formation of crystals in mortars.

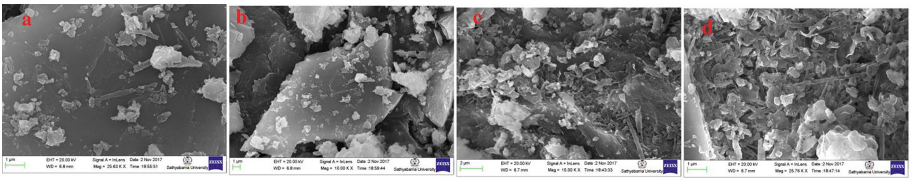

Fig. 7. **a,b** shows images of LM-R and **c,d** shows images of LM-KJ

3.6 Conclusions

The addition of organics to the lime mortar had greatly improved the properties of lime mortars. The polysaccharides in herbs played an important role to accelerate the process of carbonation in lime mortars. The compressive, flexural strength of lime mortars with organics was increased 37% and 34% compared to the reference mortars. To examine the hydrated phase, morphology and presence of organic content of lime mortar, analytical techniques like XRD, FESEM with EDX and FT-IR were chosen. In XRD, the identified peaks are confirmed with FESEM, FT-IR analysis and concluded that the formation of calcite, Aragonite, vaterite are more in organic modified mortar and additional minerals like gismondine, tobermorite, hydrogranet are also identified. The main reason for strength increase in organic modified mortars is due to the formation of additional minerals compared to reference mortar.

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