A Review on Modified Lime based Mortars - an Alternative to Cement Mortar

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Abstract

The use of lime mortars in building material has been increasingly studied due to their low negative impacts on the environment and higher availability on the earth. The use of natural and other forms of fibres have been extensively used as reinforcements of the lime mortar several thousand years ago with the objective of increasing their mechanical performance. Though the introduction of Portland cements have mitigated the use of lime mortars due to their high workability and compressive strength, the application of lime mortar in construction has gained momentum in recent years due to their versatility and eco-friendly nature. Several studies have been done on the usage of fibres as reinforcements to the lime mortars to enhance their performance especially their post cracking behavior. This literature review is mainly on the prominent research works done on the lime based synthetic and natural. This review is a summary of the efforts made to highlight the extensive research works done on lime mortar and thus proves to be an effective tool for promoting further research on these sustainable building materials which orients the building industry to contribute towards the sustainable future.

Keywords: Lime based mortar, cement mortar, properties, natural fibre, synthetic fibre, admixtures

I. INTRODUCTION

The ever-increasing manufacturing of Portland cements is tremendously releasing a quantum of Co_2 into the atmosphere and is being a source of environmental alarm. Apart from the greenhouse effect the Portland cement production is also a threat for health and peace human living. Thus priority is now being laid on the development of sustainable building materials which shows minimum impact on the occupants. Thus, traditional building materials are now replacing the modern cementitious materials and have probed the scientists to carry out studies on these materials. Lime mortar has been utilized for construction since ancient days and its usage dates back to several thousand years ago. Undoubtedly, lime mortar is a well-known green material and is less expensive compared to Portland cements. Lime mortars have also been used for plastering applications due to their favorable properties such as sticky nature, flexibility, workability, Freeze thaw resistance, water retention, higher strength, vapour permeability, autogeneous healing etc. The effect of fibres on the properties of the lime based mortar has been summarized in this paper with special reference to their fabrication methods.

II. PROPERTIES OF LIME MORTAR

Lime is considered to be a ubiquitous material and has several distinguished properties. Among them the most excellent property is its 'breathing capacity'. This explains the feature of easier loss of lime mortar by evaporation which is advantageous when compared to the conventional Portland cements where the only way of moisture movement is through the bricks in masonry that causes damping.

Hydraulic lime is essentially a combination of pozzoloan admixtures and hydrated lime which is extensively used as plasters. The lime plasters which consists of bases of quick lime as major component on reaction with carbon-di-oxide will result in the formation of calcium carbonate that acts as a binder and also as a sealant for the hairline cracks. The reaction is represented as

$$Ca(OH)_2 + Co_2 \rightarrow CaCo_3 + H_2O$$

Thus the formed calcium carbonate subsequently initiates the 'self-healing' property of the lime plaster. The plastic property of lime plaster is rendered by the hydration of quicklime at higher temperatures of about 1000ºC thus showing improved plasticity at maturity to be used as plaster.

The manufacture of lime plaster does not involve tedious and costly mechanisms similar to Portland cements and hence is economically liable. The neutrality of lime mortar in Co_2 emission makes it's a global construction material. Though lime mortar emits Co_2 during their manufacture process, the re-absorption of Co_2 takes place during the process of setting of lime plaster. Thus the emission of carbon-di-oxide is balanced by the absorption. Moreover the lime plaster holds a pre-dominant position in the plastering application due to their other remarkable features such as

1) The environmental friendliness due to their bio-degradability and recycleability.
2) The emission of carbon-di-oxide during the manufacture of lime plaster is comparably lesser than that produced during the manufacture of Portland cements.
3) The flexibility of lime plaster is higher than that of conventional cementitious substances.

4) The temperature at which lime plasters are manufactured are at minimal than Portland cements and hence is a source of economical and cleaner production.

A. *Lime mortar Vs Cement mortar:*

Natural hydraulic lime has acceptable mechanical strength and proves to be an effective binder. Though the lime mortars have been used since ancient times they present some inconveniences such as elongated setting and hardening time, weak inter-molecular cohesion and moderate mechanical property. However, the usage of lime mortar surpasses the usage of cement mortar since the cement based matrices are to be rigid and hard and are not permeable to water. Generally the permeability of mortar is desirable in the case of mortars since they must be able to vapor transport the water that contains damaging ions before they spread throughout the structure. The mortars used for the plastering and restoration techniques must comparatively weaker than the other masonry materials so as to accommodate the slight disturbances occurring in the building. Moreover, the higher thermal coefficient of the cement mortar is a serious drawback and it also contains several salts that are soluble and which can be leached out with time. Keeping in view the above listed disadvantages of Portland cements in comparison to lime mortars numerous studies have been done on the characterization of lime based mortar technology. However the lack of reliable information on the properties and mixing of lime mortars and little knowledge over this lime technology proves to be a hurdle in the standardized application of this lime plaster.

B. *Characterization of lime mortar:*

The study of mechanical behavior of masonry repair lime-based mortars cured and exposed under different conditions was developed by J.Lanas et al. They found that bending strength was strongly enhanced due to RH of the environment. And also at different environments the mechanical characteristics and durability was related to the porous structure. The strength was found to be reduced in the climatic chamber. During SEM analysis the sulfonation process on the surface of the mortar was confirmed.

The fresh state characterization of lime mortars with PCM additions was studied by S.Lucas et al. It was found that there was an increase in spread of flow table when the PCM capsules were incorporated in aerial lime mortars. Also the decrease in paste thickening was due to the evolution of viscosity and values of yield stress. It was noticed that the rheological characterization seems to be more difficult on the addition of PCM to aerial lime mortar.

A.Laborel-Preneron et al., made a study on the review of plant aggregates and fibres in earth construction materials. They gave a clear idea on the particles characterization, their treatments, material compositions, physical, mechanical, hygrothermal and performance of durability. They also suggested for the future investigations to promote these materials.

Characterisation of historical lime plasters by combined non-destructive and destructive tests was investigated by Wojciech Bartz et al. It was found that both the primer and the sgraffito plaster resulted from same technologies of production. The plaster composition, porosity, absorption of water and hygroscopic properties was explained through mineralogical analysis.

P.Thirumalini and S.K.Sekar made a review on the herbs used as admixture in lime mortar which is used in the ancient structures. They revealed the various types of herbs to be used for the traditional construction of building and also they explained the role of herbs on modifying the lime mortar properties such as fresh and hardened properties. They also concluded that the usage of natural admixtures in lime mortar will make a sustainable growth in the construction industry.

Characterisation of lime plasters used in 16th century Mughal monument was studied by M.Singh et al., in which the mineralogical results and physico-chemical investigation results of 16th century Mughal plaster were addressed clearly. They also explained the micro-morphological structure of lime plaster. They indicated crystalline formation of salt as a reason for the failure of plaster through SEM analysis. The study on thermal effect belongs to the plaster contamination with repair materials in restoration.

The Smeaton project which has factors affecting the properties of lime-based mortars was developed by Jeanne Marie Teutonico et al. They made both laboratory and field researches in order to improve the practical solutions and methods of testing. They provided better idea on the mortar selection, their manufacture and utilization under regional conditions.

The study on the factors affecting the mechanical behavior through masonry repair lime-based mortars was investigated by J.Lanas and J.I.Alvarez. They found that the mortar mixture showed a strong improvement in strength for 365 days curing when compared with 28 days curing. It was also noticed that increase in the total porosity by large amount of binder increases the strength of the mixture and a better interlocked structure was obtained. It also lead to the reduction of strength when the voids are increased. They concluded that by using the calcareous aggregates than the siliceous aggregates, the strength can be improved.

Shinobu Hashimoto et al., studied the fabrication of slaked lime compacts with high compressive strength using a warm press method. It was found that hardened compacts with pure calcium hydroxide were obtained after the warm pressing. They also observed that the strength in compression of hardened compacts increased when the applied uniaxial pressure, heating temperature and time taken for warm press was increased. On the basis of chemical thermodynamics, the calcium hydroxide and calcium carbonate phase stability relation was clearly discussed. They also concluded that this warm press technique helped in clarifying the mechanism of formation of natural hydroxide minerals.

C. *Effect of admixtures:*

Several researchers have been done on the evaluation of properties of lime based mortars by the addition of several ingredients or admixtures. The properties were drastically modified when compared to the natural hydraulic lime.

M.J.Mosquera studied the effect of addition of cement to the lime based mortars in which the lime binder was partially replaced by cement. Their properties were studied using Mercury Intrusion porosimetry which showed that the diffusivity values were comparatively higher for the lime/cement mixes rather than those which contained only hydraulic lime as binder.

The effect of pozzolanic admixtures on the mechanical, thermal and hygric properties of lime plasters were investigated by Robert Cerny et al, in which the major properties of the lime plaster such as strength in compression and flexural, conductivity of heat and their heat capacity, diffusivity of moisture, water sorptivity, coefficient of diffusion of water vapor, sorption isotherms, and coefficients of linear heat and hygric expansion were determined. They concluded that the designed lime-pozzolano plaster showed improved mechanical properties and exhibited better thermal and hygric properties. This study suggested the use of lime pozzolano plaster instead of the traditionally used lime plaster.

Shuqiang Xu et al. studied the natural hydraulic lime based mortars by using masonry waste powder as aggregate and diatomite/fly ash as mineral admixtures. Because of the pozzolanic reaction in the mortar among diatomite, fly ash and $Ca(OH)_2$, their properties were improved. On comparing diatomite and fly ash, diatomite was found to be stronger and better in the pozzolanic effect and also in improving the compressive strength of mortar.

The various properties such as mechanical, fracture-mechanical, hygric, heat and durability properties of lime-metakaolin plasters for renovating the historical buildings were studied by Eva Vejmelkova et al. They found that when compared with the reference lime plaster; there was an improvement in the mechanical parameters. And also the diffusion coefficient of water vapor was found to be decreased by 25%. The reduced liquid water transport was due to metakaolin. They concluded that the wide range in renovating the historical buildings could be done by lime-metakaolin plasters.

G.Cultrone et al., made a study on the forced and natural carbonation of lime-based mortars with or without additives with changes in both mineralogy and texture by using X-ray diffraction technique. The calcite crystals present in the pores and fissures was found to be prolifically well-developed, and the amount of Co_2 used in the process biased the carbonation. It was observed that depending on the type of additive used, the mortar's texture and mineralogy will be varying. Also the transformation speed of portlandite-calcite was not significantly changed and the texture of mortar was found to be altered by the air-entraining agent.

The study on the coating of lime-cement mortars with improved thermal and acoustic performance of building was carried by I.Palomar et al., in which the gap-graded and lightweight aggregates and fibers like polypropylene and cellulose were used to improve the thermal behavior and acoustic properties of lime-cement mortar. The open porosity and the early age shrinkage cracking were found to be modified by water-binder (w/b) ratio, and also the acoustic performance and mechanical behavior was affected by this open porosity caused. Hence they concluded that the thermal behavior and the acoustic performance of lime-cement mortar were improved by the combined effect of gap-graded, light weight aggregate and fibers.

L.Toniolo et al., studied the mechanical behavior of lime based mortars after the consolidation of surface, in which the different commercial products such as paraloid B72 (PB72), tetraethylorthosilicate (TEOS), and barium hydroxide were used for the consolidation of plaster. It was concluded that, by comparing with non-treated specimens the Paraloid B72 showed an enhanced bending strength and stiffness, which proved a suitable product for the plaster consolidation. The modulus of elasticity and the flexural strength was found to be of higher increase in case of TEOS. The unchanged color of the barium hydroxide product confirmed them to be most compatible with the plaster.

A lime based grout for repairing cracks in the earthen constructions was developed by Urs Muller et al. They found that for strengthening the earthen material, low water content and shrinkage and good retention of water was required by the lime based grout. The performance of the grout during the injection tests was good. And also the process of hydration and carbonation may be delayed or can be stopped when the temperature was found to be too low. They concluded that when a structure is exposed to shear loads, grouting will not be the only available methods to repair but instead the polymer mesh reinforcement, glass fibre reinforcement strips, interconnection of perpendicular walls through corner keys may be required.

The study on the physical and chemical properties of external lime-sand plasters of historical buildings was made by Jerzy Bochen and Malgorzata Labus, in which the X-ray diffraction method, chemical tests and differential thermal analysis were made for the mineralogical composition of the plasters. The external layers exhibited higher density due to the physical-chemical properties and thus confirmed the lower porosity in relation with the backing layers. Stronger mashing was carried out for the plasters having greater hardness which leads to a higher compactness of plaster.

The study on the epoxy monomers consolidant for the lime plaster which is cured via redox activated cationic polymerization was performed by Alessandra Formia et al. Through SEM observations they evidenced the fine penetration of formulations with no polymers settled on their surface. They observed from the mechanical tests that after the treatment of consolidation there was an enhanced strength in compression. They concluded that the mechanism of cationic polymerization through redox reaction serves as a best alternate in curing the epoxy resins.

The effect of optimal composition on the calcined gypsum-lime-metakaolin binders was investigated by Alena Vimmrova et al., in which the components present in this system was synergically interacted to find the optimal composition. They found that there is better enhancement in compression, flexural and elastic modulus through the addition of metakaolin in the system, and also made a small decrease in coefficient of water vapor diffusion. They also concluded that this type of method was not suited for long lasting tests.

The improvement in traditional plasters through modified gypsum compounds was made by R.X.Magallanes-Rivera et al., in which the properties of commercial hemihydrates was improved through slag-pozzolanas pastes. They found that density was slightly greater when compared with the pure plasters but there was a triplicate increase in compressive strength of plain plaster. They observed excellent stability in dimension and low density through the addition of silica fumes.

The effect of hydrophobization on the properties of lime-metakaolin plasters by zinc stearate was studied by Eva Vejmelkova et al. They observed that increasing content of zinc stearate in plaster mix made a rapid decrease in the coefficient of water absorption and reasonable decrease in both flexural and compressive strength. They found the positive effect on open porosity, vapor diffusion and heat properties through the zinc stearate addition. They concluded that the 1% addition of zinc stearate in the lime-metakaolin plaster is an optimal solution.

The assessment of phase formation in lime-based mortars with the addition of metakaolin, sepiolite and Portland cement used for grouting was developed by Alberto Sepulcre-Aguilar et al., in which the products of hydration on metakaolin-lime mortar has both stable and metastable phases and they are selected mainly depending upon the water-lime ratio. They found that metastable hexago nal hydrate (C_4AH_{13}) was formed on the addition of sepiolite into metakaolin-lime mortar. They concluded that there was no remarkable difference when the blended lime-portland cement was compared with the natural hydraulic lime.

The effect of admixtures on the fresh state property of aerial lime based mortar was investigated by M.P.Seabra et al., in which the rheological behavior of mortar was changed considerably by the use of admixtures. The thickening and thinning effect was due to the water retaining agents and air-entraining agents respectively. The torque values were diminished by the usage of plasticizer since they increased the free water in the system. They observed that addition of air-entraining agents reduced the mortar flow resistance.

D. Effect of synthetic fibres:

The effect of a polypropylene fibre on the behavior of aerial lime-based mortars was studied by A.Izaguirre et al. It was found that when the fibre added in low dosage on aerial lime-based mortars, there was an improvement in various properties such as strength of mechanical parameters, permeability, macroscopic cracks reduction or freeze-thawing cycle's durability. It was concluded that only the crack reduction and material durability were improved on the addition of additives in larger amount.

Jacek Katzer and Jacek Domski investigated the optimization of fibre reinforcement for waste aggregate cement composite. They used propylene fibres and engineered steel as a concrete reinforcement type. They examined the fibre reinforced concretes on the basis of ceramic waste aggregates. It was found that Integral simplex design was employed for better optimization effect. They also defined the optimal mix needed for the reinforcement of fibre for waste aggregates.

Studies of hair for the use in lime plaster as part of a maintenance and conservation was developed by Craig J.kennedy et al. They showed that the keratin and lipid structure of the hair was disrupted during their cleaning process. They also maintained the helical structure of the protein through crysteine oxidation. They concluded that the cleaning level of hair played a major role on the suitability as a repair material for plasters.

Ernest Bernat-Maso et al. investigated the experimental assessment of Textile Reinforced Sprayed Mortar (TRSM) strengthening system for the brickwork wallettes. They studied the influence of mortar and fibre grid type. They also found that there was a significant influence on failure mode during the strengthening of mortar. The performance of TRSM was found to be better in case of ductility when compared with the Textile Reinforced Mortar (TRM).

E. Effect of Natural fibres:

The study on the characterization of flax lime and hemp lime concretes for determining the hygric properties and moisture buffer capacity was performed by M.Rahim et al. They described these materials behavior in both equilibrium and dynamic stages through the moisture properties and their buffer capacity obtained from their buffer value. They concluded that both these bio-based materials showed better hygric performance with excellent buffer capacity of moisture.

A study on the durability of natural fibres and the effect of corroded fibres on the strength of mortar was investigated by G.Ramakrishna and T.Sundararajan. They presented the chemical composition variation and tensile behavior of fibres like sisal, jute, coir and Hibiscus cannabinus. It was found that after exposing these fibres under various medium such as water, saturated lime and sodium hydroxide, there was a considerable reduction in their chemical composition. They also found that among the other fibres the coir fibre has leading and higher percentage regarding the strength aspects. They also noticed that the usage of corroded fibres on the natural fibre reinforced mortars gave less compressive and bending strength when compared with the reference mortar.

F.Iucolano et al., studied the fibre-reinforced lime-based mortar as a possible resource for ancient masonry restoration. They used the fibre reinforced hydraulic lime-based mortars for the repairing of historic structures. They found that the mechanical behavior of hydraulic lime-based mortar was modified by the basalt and glass fibres. They also observed an improvement in post-cracking behavior and toughness in the reinforced mortars. They concluded that there was a better resistance in freeze-thaw cycles and a considerable mechanical behavior in post-cracking.

The effect of natural fibres reinforcement in lime plasters was studied by G.Di Bella et al. They used three lime based mortars with each fibre such as polypropylene, sisal and kenaf respectively. They experimentally showed that the use of natural fibres was an alternate to the polypropylene reinforced lime plaster. It was observed that the freeze-thaw cycles result showing decreased mechanical property was compared to flexural condition of load. And the sisal fibre reinforced plaster showed decreased compressive strength which is found to be lower than the other fibre reinforced plasters.

An overview was made on the developments on vegetable fibre-cement based materials in Brazil was made by V.Agopyan et al. They suggested that vegetable fibres can be conveniently used for brittle matrix reinforcement as a material although they had a poor performance in durability. They also approached to adopt the alternative binders with controlled free lime or ground

granulated blast furnace slag to improve the poor durability of vegetable fibres. It was found that the coir fibres was the most suited vegetable fibre for reinforcing, and eucalyptus pulp, sisal can be used as replacement during roofing as their component.

The behavior of lime mortars with the natural fibres was studied by Milos F.Drdacky and Dagmar Michoinova. They summarized the technical data for various reinforced fibre mixtures such as lime, sand, natural fibres, saw dust, husk, and polypropylene fibres. They brought out the scientifically proved usage of reinforced fibre mortars on the aspect of technical practice and conservation.

Rosamaria Codispoti et al., performed study on the mechanical behavior of natural-fibre reinforced composites for the strengthening of masonry. They used various fibres such as hemp, flax, sisal, jute, coir and investigated them both mechanically and physically. They produced composites with the fibres having good performance and from the experimental analysis the natural fibres potentials regarding strengthening can be easily understood.

An experimental study on the application of sticky rice-lime mortar in conservation of the stone tower in the Xiangji temple was developed by Guofeng Wei et al. They performed the study through the characterization of property, SEM, thermal and XRD analysis. They indicated that the most efficient admixture in enduring freeze-thaw cycle and also in increasing the sticky rice-lime mortar's compressive strength was the paper fibre. And also the usage of aluminium sulfate reduced the values of drying shrinkage and increased the compressive strength due to the ettringite formation in the mortar. From their laboratory experiments they concluded that 3% replacement of paper fibre in the sticky rice-lime mortar was the suitable material for performing grouting.

The study on the mechanical and thermal properties of lime and hempcrete manufactured by a projection process was performed by S.Elfordy et al. They observed that the variation of density within the block was moderate and there is an importance of projection distance regarding density. From the theoretical study they described that due to the mortar density both mechanical property and heat conductivity was increased.

` Sabrine Hamza et al., performed the study on the physico-chemical characterization of Tunisian plant fibres and its utilization as reinforcement for plaster based composites. They made a study on the possible usage of rush stems, alfa leaves, leaflets of palm as a building reinforcement material through the commercial fibres replacement. Based on origin and morphology the hygroscopic parameters showed various behaviors. It was found that palm tree stripe was the most sensitive one compared with the other fibres regarding the impregnation yield and degree of saturation. The extractives were found to be acceptably high under various solvents and ash contents.

Brahim Mazhoud et al., studied the hygric and thermal properties of hemp-lime plasters. They made the experimental study on the basis of sorption isotherm measurement, permeability of water vapor, buffer value of moisture and heat conductivity and diffusivity. Special investigation was made on the buffer value of moisture and thermal property to determine their temperature effect. It was found that the hemp lime plaster with small hemp shrive was a better hygric regulator than large hemp shrive and they are also more conductive. They concluded that the heat conductivity was decreased in parallel with water content due to the increased temperature during wet state.

The study on mechanical properties of natural hydraulic lime-based mortars was performed by J.Lanas et al. They discussed the compressive and bending strength based on their time of curing, binder/aggregate ratios, porosity and aggregate attribute. The greater strength and porosity was found on the specimen containing the larger amount of binder on them. They also concluded that usage of small grain size aggregate was advisable instead of the usage of rounded-shaped aggregates.

The influence of various chemical treatments on the interactions between hemp fibres and a lime matrix was studied by Marianne Le Troedec et al. The various chemical treatments were applied on the hemp fibres and the surface treatment of fibres was studied. It was found that the chemical treatments with NaOH, EDTA induced the modification on fibres which played a significant role regarding the strength aspect of lime/fibre interface.

III. CONCLUSION

This review article was done with the view to explore the possibilities of using lime mortar as a replacement for traditional concrete which can be used to mitigate the environmental pollution caused due to modern construction chemicals and cementitious materials. The review of literatures on lime plaster suggested the following conclusions:

1) The natural fibres when used in lime mortar were found to increase the mechanical properties when compared to the reference mortar.
2) The results obtained from the usage of synthetic fibres such as glass and polypropylene were also found to enhance the mechanical behaviour of hydraulic lime based mortars.
3) The lime mortar reinforced with fibres can be proposed as construction materials used especially for repair works of historic monuments due to their high compatibility with the ancient materials and high durability in terms of freeze- thaw resistance.
4) The post cracking behaviour of lime mortar due to several animal hairs and fibers change the failure of the lime mortar from brittle to pseudo- ductile behaviour.
5) The self- healing nature of lime mortar is an excellent property that also proves to be effective against creep and shrinkage cracks.
6) Thus it can be concluded that lime mortar can be a perfect substitute for cement mortar satisfying all the desirable properties required for construction and other technical practice when efforts are put on the inputs for further research works.

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