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Enhancing the Mechanical Charecteristics of Lime Mortar Over the Ages – A Review

KEYWORDS

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ABSTRACT *Many kinds of mortars such as mud, gypsum have been in use over ages. Lime because of its ecofriendly nature, good breathability, improved workability, autogenous healing, improved bond strength, resistance to rain penetration, greater final strength and recyclability, it plays a vital role as a binder in the durability of ancient structures. This review paper aims at bringing out the various modifications and contributions by the researchers in improving the mechanical characteristics of lime mortar. The utility of hydraulic lime, hydrated lime, egg shell as source of lime is discussed. Also the contribution of mineral additives such as Sodium Oleate, HPMC, Polypropylene, Taffea powder, Calcium Stearate and organics such as sticky rice, Opuntia Cactus etc. which have contributed to the enhancement of the mechanical strength is reviewed.*

1.1Introduction
Many kinds of mortars have been in use ever since ancient times. Among them, mud mortar was the first [1] used in ancient buildings, then comes Gypsum and asphalt which were used for joints of bricks and stones. [2] However, gypsum between the stone blocks was generally not regarded as mortar, but mainly as a lubricant. [3] The calcination of limestone was discovered in 2450 BC[1] in Europe. After that, lime was used as an important constituent of mortars. In ancient Greece, lime mortar was used in construction.[4] Romans have greatly improved the mortar technology ,and hybrid mortars like lime sand and lime gypsum mortar appeared. Later, hydraulic materials such as ground volcanic ash, ceramic chips, and ground brick were introduced [5]. This kind of hydraulic mortar was called "Roman mortar" and was widely used in Europe and western Asia until the appearance of modern cement in the 19th Century [6].

Portland Cement used simply with sand has proved to be a disaster. The cement sand mortars, particularly the stronger mixes such as 1:3 (cement : sand) are not porous. They shrink as they set and thermally they move at a different rate to the soft bricks. They further cause erosion of soft stones and brickwork

1.2Hydrated Lime Mortar
Hydrated lime mortars of 1:3 mix have been used down the centuries. Failures have occurred in recent times, the problem is that the modem hydrated limes are produced to the current British Standard and are too pure. The sands used today are also well washed and contain no impurities of significance whereas the traditionally specified mortars contained a natural pozzolana in the form of clay or silt in the sand or lime which gave it a chemical set. This does not apply with the normal pure hydrated limes provided by suppliers. Hydrated Lime can be delivered to site in lump form and can be slaked on site by mixing with water and left to stand for at least two weeks after the slaking. As the lime putty starts carbonation before being used the mortar sets off quite quickly.

1.3 Pozzolanic lime Mortars
Historically, Romans used pozzolanic additives to have a chemical set, rather than an air set. Brick dust, selected stone dust, ash and the natural impurities in the lime and sand have given mortars the chemical set required. These mortars give the necessary flexibility to our historic buildings.

1.4 Significance of Mechanical Strength
The mechanical strength of the mortar is of importance for the interaction between the mortar and the substrate [7]. An increased porosity gives lower strength. Large air voids or cracks are more crucial than several small pores especially for the tensile strength. A large maximum aggregate size lowers the strength but here the mortar strength also depends on the adhesion between aggregate and the binder.

2.1 Mechanical Strength of different lime mortars
Studies at Corfe Castle [21-22], suggest that hydraulic limes demonstrate significantly higher early compressive strength which also improves with age. This research used 12 different mortar types, labelled P1 - P12, made with air lime (P1 & P12), hydraulic lime (P4, P5, P6 & P7), mixtures of air lime and hydraulic lime (P8 & P9), and air lime with setting additives such as crushed brick, crushed tile and cement (P2, P3, P10, & P11). The data are presented in Fig 1.

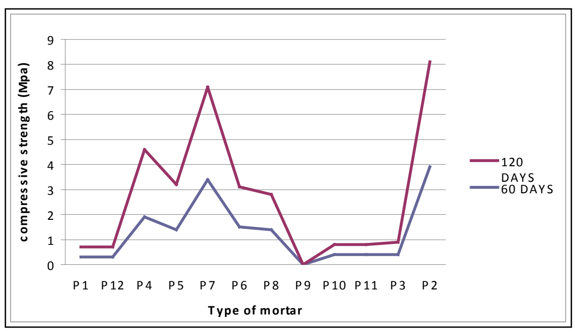

Figure 1: Compressive strength of each of the mixes, grouped by binder/additive ratio

2.2 Mechanical Properties of Natural Hydraulic Lime Mortars(NHL mortars)
Geoffrey.et.al[9] monitored the dewatering process in real time using impedance spectroscopy. Figure 2 shows the average compressive strength of both non-dewatered and dewatered mortars at 14, 28 and 56 days of curing in 100%Nitrogen (N_2) and Nitrogen (N_2)containing 400 ppm CO_2. The results presented show that, for NHL3.5, the failure stress increased when the mortars were cured in the environment containing 400 ppm carbon dioxide. Previous results indicated that 28 days was a sufficient period for the carbonation process to have initiated throughout the entire volume of the sample [11]. The NHL3.5 lime mortars showed a clear increase in strength at all curing times for dewatered mortar

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over the non-dewatered equivalent.

During the life cycle of a lime mortar a number of significant processes occur. First amongst these is the rapid process of dewatering when the mortar is placed upon porous masonry. Climate changes in humidity and temperature may then play a part in the rate of the stiffening process and subsequent changes in physical and chemical state. The process of wetting and drying of a lime mortar may also significantly influence its compressive strength. The magnitude of this effect was determined by a study of NHL3.5 mortars subjected to alternate cycles of wetting and drying, Much of the increase in strength was found to occur during the initial 28 days of exposure.

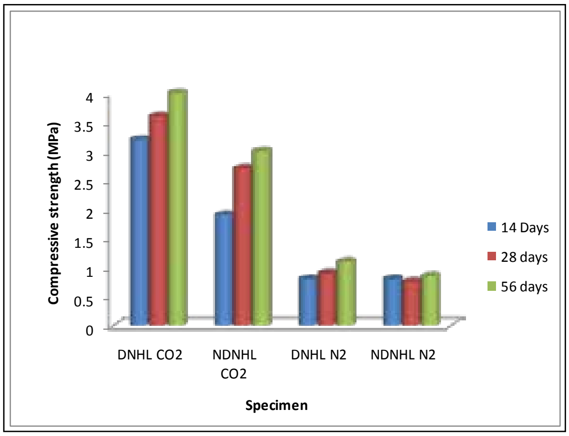

Figure 2: Compressive strength of dewatered and non-dewatered Mortar versus time after curing in pure N_2 and N_2 containing 400ppm CO_2. NHL3.5, (ND= Non-dewatered, D=Dewatered)

Concurrently with hydration, and over a longer period, carbonation of calcium hydroxide also occurs. Silicate phases were most readily identified in cycled samples compared to the equivalent control batch, represented in Fig 3. This suggested that the cycling regime encouraged hydration and consequently an increase in strength.

The study concludes that dewatering results in a dramatic increase in strength of the hydraulic mortars when compared with non-dewatered equivalent samples. It is suggested that dewatering of mortars prepared with hydraulic binders increases the rate of crystallisation of hydrated silicate phases within the matrix, influencing the mechanical strength. Moreover wetting and drying increases the compressive strength of natural hydraulic lime mortars by increasing the rate of hydration and carbonation.

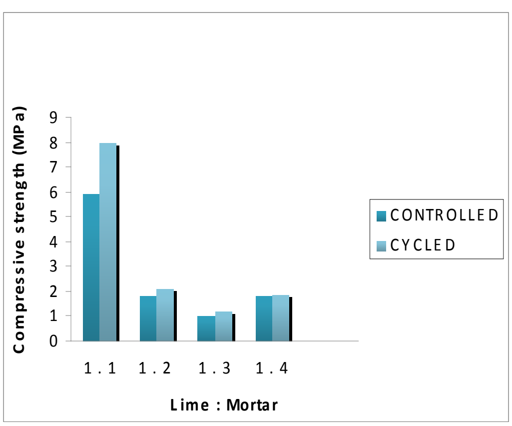

Figure 3 Enhanced development of compressive strength resulting from wetting and drying of natural hydraulic mortars of mix ratio 1:1, 1:2, 1:3 and 1:4 (lime:sand) over a period of 28–180 days.

2.3 Mechanical Strength of Egg Shell Lime (ESL)

Kevin Beck et.al used eggshells as the source of lime, which are known to be very rich in calcium carbonate. Eggshells are coarsely crushed and quicklime is then obtained from the decarbonisation of eggshells at 1000 °C. Tuffeau powder from tuffeau limestone comes from the quarry at Usseau (Vienne, France). Both materials come from waste recovery.This innovative combination represents a relevant opportunity for sustainable development.Results of compressive and flexural strength tests (performed according to European normative EN 1015-11:2000) are presented in Table 1 and Table 2, respectively. For each mortar, three 40 x40x460 mm prismatic samples were tested to provide consistent results. The flexural strength of undamaged ESL mortars, which does not significantly vary according to the lime content, was found to be slightly higher than that of the tuffeau. The compressive strength of undamaged ESL mortars is slightly lower compared with tuffeau limestone. It should be noted that pozzolanic reactions take much longer than 28 days to achieve significant strength [15]. As a consequence, performances will increase with time..

Table. 1. Compressive strength of tuffeau and ESL mortars before and after the first drying cycle

Description	Tuffeau	ESL 10%	ESL 15%	ESL 20%	ESL 25%	ESL 30%
Compressive strength before the first drying cycle (MPa)	5.53	3.59	.92	33.58	3.83	3.73
Compressive strength after the first drying cycle (MPa)	5.53	2.43	2.12	1.71	2.55	2.80

Table 2. Flexural strength of tuffeau Powder and ESL mortars before and after the first drying cycle

Properties	Tuffeau	ESL in percentage				
	Powder	10	15	20	25	30
Flexural strength before the first drying cycle (MPa)	1.27	.71	2.42	12.03	2.38	2.42
Flexural strength after the first drying cycle (MPa)	1.27	0.06	0.12	0.13	0.07	0.16

2.4 Effect of Chemical Additives on the Mechanical strength

El-Turki et.al [6] studied the influence of additives such as Sodium oleate(SO) and Calcium stearate(CS) on the mechanical strength of lime mortars, moulded in prismatic 40x40x160mm casts and de-moulded 5 days later [15]. Final strength value is comparable to that of the reference mortar represented in Fig 4 . Sodium oleate clearly improved strength, furthermore, maximum compressive strengths were reached in a shorter period of time. The tested SO-lime mortars also show a smaller number of cracks.

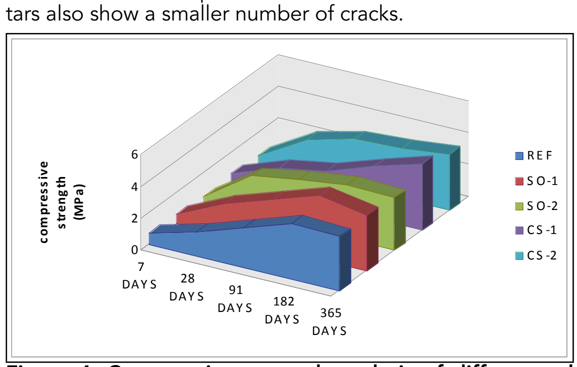

Figure 4. Compressive strength analysis of different admixtures over The ages

2.5 Mechanical Strength of Hardened Mortar using Sticky Rice

Fuwei Yang et.al [8]developed distinctive inorganic−organic composite mortars by adding sticky rice soup, the juice of vegetable leaves, egg white, tung oil, fish oil, or animal blood,[18]. The performance of lime mortars can be greatly improved, and these mortars are believed to play an important role in the longevity of ancient Chinese buildings[19] Among these mortars, sticky rice−lime mortar was the most widely used in the important buildings like city walls, palaces, tombs, and even water conservancy facilities.

The results presented in Table 3 suggest that the mechanical strength of lime mortar can be improved by the addition of sticky rice soup. However, when a 3.0% sticky rice solution is present, the strength is improved gradually and reaches the maxima of 0.38 and 0.94, MPa, respectively. The sticky rice component in moderation is helpful in the development of the strength of lime mortar, because its water retentivity favours the carbonation reaction of lime and the subsequent increase in mechanical strength.[20].However, organic matter in excess will work as a retarder and restrain the carbonisation reaction[21] of lime mortar.

2.6 Cactus in Lime Mortar

Cárdenas et.al[2] prepared Calcium hydroxide and commercial slaked-lime paste mixed with varying concentrations of nopal juice at ratios of 0.65%, 1% and 1.95% of cactus juice to commercial slaked lime. The dry paste thus obtained was evaluated by a penetration-breaking test. Increasing amount of cactus juice resulted in a drastic reduction of the maximum stress and deformation values of the paste as compared to those of the control sample. These lime mortars have a high mechanical resistance, increased waterproof protection, and antifungal properties (Gomez del Campillo and Dorrego, 1995). The nopal juice is added as an organic adhesive that prevents the mortar from drying too quickly and helps retain the necessary moisture that the mixture needs to set correctly,

Table:3 Mechanical Strengths of Hardened Mortars

Strength	Sticky Rice Soup (%)				
	0	1	2	3	4
Flexural strength (MPa)	0.24	0.35	0.36	0.38	0.36
Compressive strength (MPa)	0.60	0.82	0.907	0.94	0.93

2.7 Pozolanic Earth as an Admixture

A.Moropoulou et.al [23]studied the strength development and lime reaction in mortars. Hydraulic lime mortar (NHLA) acquires quasimaximum strength within the first month, with no significant variations of compressive strength afterwards. Flexural Strength presents an increase of approximately 24% from the first to 15 months of curing presented in Table 4. Mortar with lime putty (LPA) presents a 126% and 88% increase of compressive and flexural strength respectively, while mortar with lime powder (LPoA) exhibits on overall compressive strength increase by 222%. From the above comparison, it is clear that LPoA presents a better behavior than LPA and this can be, mainly, attributed to the higher binder content in this mortar (24).LPoA almost triples compressive strength value, while LPA doubles the corresponding value from 1 to 15 months of hardening. As far as flexural strength is concerned ,a slight variation was observed for LPA,while remarkable differences were detected for LPoA.

Mortars with pozzolanic additions (natural and artificial) and lime putty as binder acquire their maximum strength within 3 months. Mortar with natural pozzolanic addition (LPMA) presents a final increase of compressive and flexural strength of approximately 82% and 47% respectively. A similar behaviour is exhibited by mortar with artificial pozzolanic addition (LPCPA).

Table 4. Flexural And Compressive Strength Of Different Mortars

S No	Mortar	Ratios per weight	Mix	Curing (months)	Flexural strength (MPa)	Compressive strength (MPa)
1.	NHLA	NHL2:Aggregates(a)	1:2:3	1	0.63	3.05
				3	0.69	3.25
				9	0.62	2.53
				15	0.78	3.02
2.	LPA	Lime putty:aggregates	1:1.5	1	0.25	.69
				3	0.46	.97
				9	0.52	1.34
				15	.47	1.56
3.	LPoA	Lime powder:aggregates	1:1.8	1	.40	.90
				3	.54	1.18
				9	.76	2.40
				15	.95	2.90
4.	LPMA	Lime putty :earth of milos:aggregates	1:1:2	1	.34	.63
				3	.41	1.13
				9	.40	1.12
				15	.50	1.15
5.	LPCPA	Lime putty:ceramic powder:aggregates	1:1:2	1	.37	.84
				3	.43	1.22
				9	.46	1.23
				15	.48	1.34
6.	LPoC-PA	Lime powder: ceramic powder:aggregates	1:1:2	1	0.38	1.37
				3	.62	2.36
				9	1.03	4.36
				15	1.30	4.6

2.8 Fibres on Lime Mortar

A.Lzaguirre et.al [11] studied the influence of polypropylene fibres on the mechanical strength of lime mortars. Mortars were moulded in prismatic 40x40x160mm cast and demoulded 5 days later. Compressive strength test was conducted on the fragments of each specimen resulted from the flexure .

Fig 5 and Fig 6 shows the evolution of mechanical strength over time can be observed that flexural and compressive strength showed a similar behavior. F-1 mortar followed an evolution similar to that of the reference mortar but improved during the last step. After 182 days of curing, plain lime mortar achieved its final strength, while these properties continued increasing up to 365 days in mortar with a low amount of fibre (F-1). However, the highest dosage led to a reduction in final flexural and compressive strength, Puertas et al.[25] found that mechanical properties worsened with the incorporation of polypropylene fibres in cement mortars, and they related this behaviour to the fact that this additive gave rise to a less workable material whose compaction was, therefore, poorer [26] When it was used at 0.06 wt%. the mortar obtained was more compact than the reference material, thus leading to lower water vapour permeability and higher mechanical strength.Therefore the use of polypropylene fibres at relatively low dosages may be advantageous to improve mechanical strength.

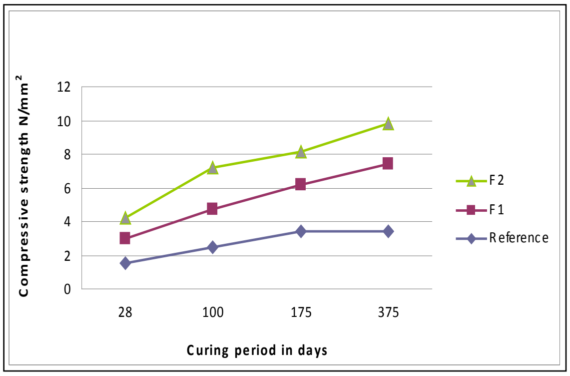

Figure 5. Compressive strength analysis of fibre lime mortar

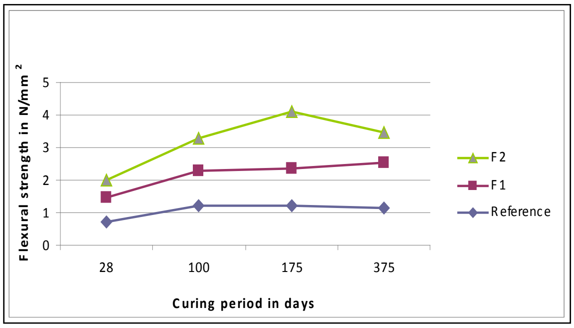

Figure 6. Flexural strength analysis of fiber lime mortar

2.9 Chemical admixture

A.Izaguirreet.al [12] studied the ageing of lime mortars with admixtures, durability and strength assessment . Six different additives were tested, and were incorporated to the mixture individually in order to check clearly the influence that each one of them exerted on mortar durability. The results are tabulated in Table 5. These selected additives were two different water-repelling agents: sodium oleate and calcium stearate (CS) and two different water-retaining agents: hydroxyl propyl methylcellulose (HPMC) from Hercules (HPG) a polypropylene fibre (PP) and a potato starch polymer (PS).

Table 5. Compressive strength analysis

S. NO	Specimen	Compressive Strength (Mpa)			
		7 Days	14Days	21Days	28 Days
1	Reference	2.65	2.05	1.9	1.6
2	HPMC	1.5	1.93	2.1	1.75
3	HPG	2.4	2.70	2.8	2.4

3.0 Concluding Remarks

The above review can be summarised as follows

- Hydraulic limes showed some favourable characteristics with non-hydraulic limes but demonstrate significantly higher early compressive strengths which also improves with age.
- The NHL3.5 lime mortars showed a clear increase in strength at all curing times for dewatered mortar over the non-dewatered equivalent. Also the strength increased with curing time.
- The flexural strength of undamaged ESL mortars was found to be slightly higher than that of the tuffeau powder where as the compressive strength falls down slightly.
- Sodium oleate clearly improved the mechanical properties and maximum compressive strength was reached in a shorter period of time.
- The sticky rice favours the carbonation reaction of lime and the subsequent increase in mechanical strength. Maximum flexure and compressive strength is reached for 3% sticky rice.
- Increasing amount of cactus juice resulted in a drastic reduction of the maximum stress and deformation values of the paste as compared to those of the control sample.
- Mortars with pozzolanic additions (natural and artificial) acquires their maximum strength within 3 months.The best mechanical behavior was observed with artificial pozzolanic addition.
- The use of polypropylene fibres at relatively low dosages say 0.06 % may be advantageous to improve mechanical strength.
- Among the chemical admixture HPG faired better with ageing.

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