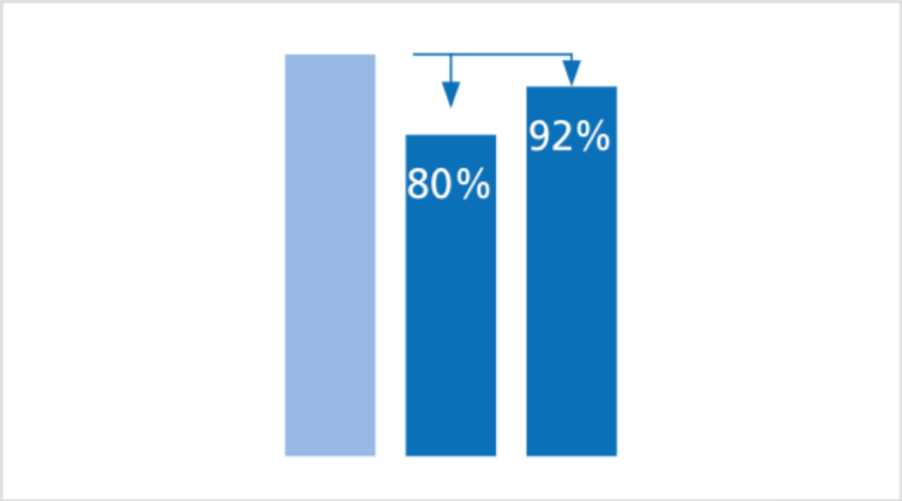
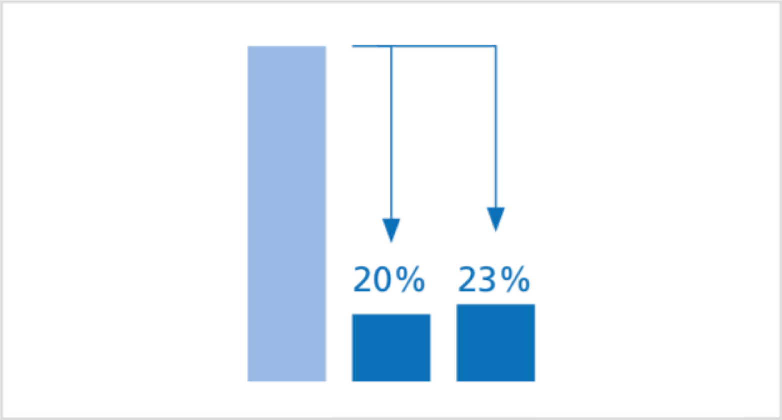


Air lime mortar (gradual increase over time).

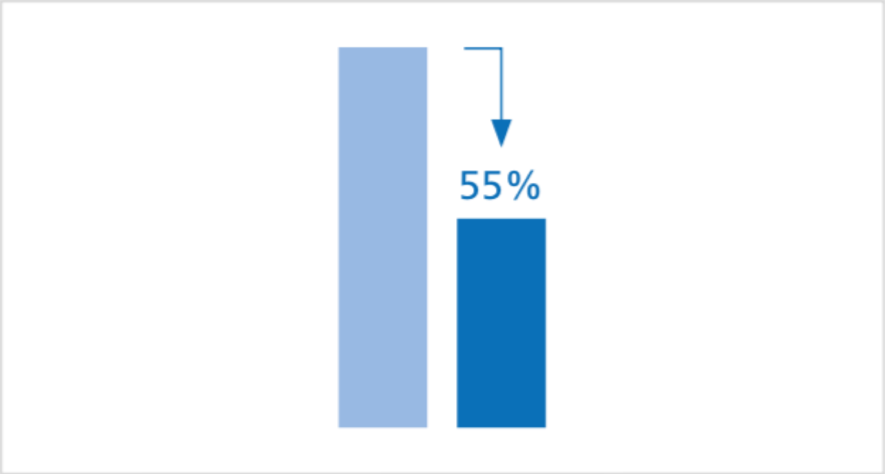
Life-time carbonation of air lime in mortars EuLA



Mixed air lime mortar (gradual increase over time).

Cement-lime (also relevant to NHL) EuLA

In mixed air lime mortars the hydrated lime will set by carbonation to limestone, while the cobinder sets in another reaction, often by hydration.



Natural carbonation rate (gradual increase over time).

Hemp-lime, natural carbonation EuLA

Hemp lime material is made with hemp shiv, the chopped woody core of the stalks of the hemp plant. This is mixed with an air lime binder with pozzolanic cementitious or hydraulic lime additives …

EARTH-LIME 2.5% quicklime addition:

The case study in a road in Germany, where the soil stabilization with lime was carried out 25 years ago indicated that carbonation rate is ranging between 35-40%. 10-15%: still available as free CaO and 50% is used for puzzolanic reactions.

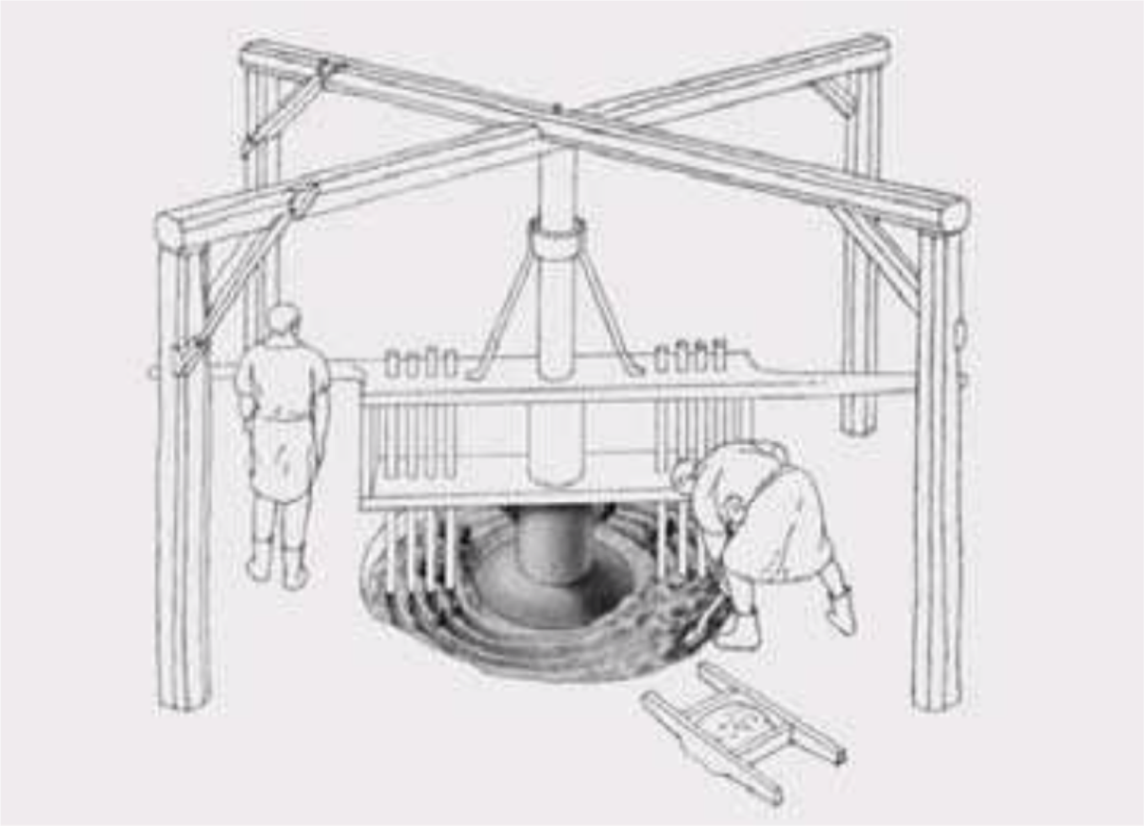


Fig. 2: Reconstruction of the mortar mixer discovered on Basel, Cathedral Hill: set into a circular flat-based pit a central post acts as a pivot for a horizontal beam with paddles, which would mix sand, hot lime and water as the horizontal beam was rotated (Illustration: Heidi Colombi, Archaeological Department Canton Basel-Stadt).

Historic Mortar Production in the First Millennium A.D. New Results from Archaeology and Scientific Dating

Sophie Hueglin (2017)

The lime, when slaked, must be **passed through a sieve so as to leave only a fine powder**; this is usually performed by means of a screen made of wire, set at an inclination to the horizon, against which the lumps of slaked lime are thrown. That which ought passes through it, the remainder or core falls on the side of the screen against which the lime is thrown. For mortar the core must be entirely rejected; it is, nevertheless, excellent as dry rubbish for filling in the sides of foundations, under wood floors, where they would otherwise lie next the earth, and the like.

The sifted or screened lime is now added to the sand, *the lime still hot?]* whose proportion to the lime must vary as the strength of the latter. Gwilt 1839.

Builders employ two methods of compounding their mortar: — First, when it is required to convey it in a dry state to the work, it is done by forming a bed of lime, surrounding it with sand, and then throwing on the lime a sufficient quantity of water to slack it, and covering it up immediately with sand; after it has remained some time in this state, it is turned over, and, if necessary, screened. The mixture is now in the state of a dry powder, and can be carted to the work, where more water is added and it is chafed up for use.

The other method is employed when there is convenience for making it up at the work. In this case it is what is termed " larryed. " Thus: — the lime is put into the middle of a bed of sand, and a large quantity of water thrown on, and with lime-hoes mixed up immediately until completely incorporated. It is then allowed to remain for a few hours, when it becomes set, and of proper consistency for use. The lime when turned up in this way will admit of a larger quantity of sand, as all the particles of lime are dissolved, whereas **by the first method there are always small particles of the lime which cannot be properly mixed, however much it may be chafed up.**

Davy 1839

In practice, the slaking of lime for mortar is conducted in several ways. **Either sufficient water is sprinkled over the lime to combine with it and resolve it to a powder, providing also an excess for that lost in the form of steam, or an excess is added at once, sufficient to make the finished mortar.**
The first method is in some ways the best, because a finer, looser powder is produced, in the manner already described, and **because the poorer limes are much more easily and thoroughly slaked in this way with the aid of the greater heat evolved. When too large an amount of water is used the development of heat is prevented, and the operation is much less complete….. all the water which is to be used should be added at once or nearly so. If it is added in small portions the effect is to cool down the whole mass and prevent thorough slaking.**
Richardson 1897.

Equivalent volumes of water and quicklime to dry slake; average 2.5 to wet slake, given all at once.

In *dry slaking* by hand the lime is spread on the ground in a layer, 4-6 in. thick, and is sprinkled with water by means of a rose on a watercan. It is mixed with the aid of a shovel and is then **heaped up and left to itself for a day**, so that it may be fully slaked**. It is advisable to cover the heap with sacks so as to retain the heat in it.** In an alternative method, the lumps of lime, in a basket, are immersed in water for a short time and are then withdrawn and placed in heaps or silos to prevent the escape of water. The lime slakes and falls to powder but is very liable to contain some unslaked lime. The dry, slaked lime is sifted, usually through sieves with 4-8 holes per running inch. Such coarse sieves are unsatisfactory, as they allow many particles, which have not been sufficiently burned, and also small clots of paste to pass through them…. the present tendency is to require all dry-slaked lime to leave less than 6 per cent, of residue on a 200-mesh sieve. (Searle 1935) (Copsey 2019).

"The term putty, better known as the cement for fixing glass in windows, is applied in brickwork to a very different substance, which is nearly the same **as hot lime grout**, It is made by **dissolving in a small quantity of water, as much hot lime as, when slaked,** and continually stirred up with a stick**, will assume the consistency of mud**…It is then sifted, in order to remove the unburnt parts of the lime, and **should be used without delay.**

It is only proper for gauged brickwork, or for the ornamental outside work of brick walls…." (9). Pasley 1826)

The Mortar in which rubbed and gauged Bricks are set is called Putty, and is thus made:

Dissolve in any small Quantity of Water, as two or three Gallons, so much fresh Lime (constantly stirred with a Stick) until the Lime be entirely slacked, and the whole become of the Consistency of Mud; so that when the Stick is taken out of it, it will but just drop; and then being sifted, or run through a Hair Seive, **to take out the gross Parts of the Lime, is fit for Use.**

Batty Langley 1750
London Prices of Bricklayers' Materials and Works

Aldby Park (1726)
Lime putty only mortars throughout.

“We make two contiguous basins which are communicated by a conduit; the smallest must be the highest; it is used to crush the lime and to retain foreign bodies which may be found there.... The largest is intended to serve as a reservoir suitable for containing a supply of slaked lime, proportionate to the size of the building it is located in. It's about building: in order to only let what needs to be received pass into this last basin, we take care to put an iron or wooden grate in the communication conduit, to stop all the rough parts. We fill the first basin with lime on which we first pour a litle water to begin to extinguish it. As this water is drunk, we continue to pour water until it is absolutely dissolved... After which we pour more to finish soaking the lime, taking care to stir it and harden heavily during this operation with a wooden plane.... The lime included in the small basin having therefore been sufficiently tormented on various occasions, it is allowed to flow by itself into the large basin, by opening the communication and continuing to shake it until it is empty; finally, when the lime thus soaked has taken on a litle consistency in the large basin, it is covered with one or two feet of sand to be able to keep it as desired, without fearing that it will lose its quality. »

By quenching the lime in this way, we make a much more considerable loss by abandoning the steam of the lime, the conservation of which is so expressly recommended by the most famous Architects (14).

Most often, the lime remains exposed to the influences of the air, rain and sun, in spongy basins, dries out there and ends up losing the litle quality that remained. The lime thus reduced to the “caput mortuum” no longer has the ability it had to atach itself to the bodies it was supposed to unite;

FLEURETC 1807. CRITICISING INITIALLY RUNNING TO PUTTY AND STORAGE OF THE SAME.

All rich limes may be slaked by mixing with a sufficient quantity of water, so as to reduce the whole to a thick paste. **Lump lime should first be broken into small pieces, placed in layers of about 6 inches thick and uniformly sprinkled with water through a pipe having a rose at one end, or by means of a large watering-can having also a rose, and covered quickly with sand.** It should be left in this state for at least 24 hours before being turned over and **passed through a riddle**. The layer of sand retains the heat developed and enables the process of slaking to be carried out slowly through the mass….The quantity of water should be properly regulated, as **if over-watered a useless paste is formed**. If a sufficient quantity is not supplied**, a dangerous powdering lime is produced. (*this is moistened but not wet – later pounding alone would bring to workability. Millar seems to be describing a hybrid method of wet and dry slaking).***

MORTAR.- This is a term used for various admixtures of lime or cement, with or without sand. For plaster work it is usually composed of slaked lime, mixed with sand and hair, and is termed 'coarse stuff', and sometimes 'lime and hair', also 'lime'. **In Scotland the coarse stuff is generally obtained by slaking the lump lime (locally termed shells) with a combination of water sprinkling and absorption. The lime is placed in a ring of sand, in the proportion of one lime to three of sand, and water is then thrown on in sufficient quantities to slake the greater portion. The whole is then covered up with the sand, and allowed to stand for a day; then turned over, and allowed to stand for another day; afterwards it is put through a riddle to free it from lumps, and allowed to stand for six weeks…to further slake by absorption. It is next 'soured' – that is, mixed up with hair ready for use.** (p43).

Millar (1897) Plastering Plain and Decorative.

(By this time…) in most parts of England the lime for making coarse stuff is generally slaked by immersion, and is run into a pit, the sides of which are usually made up with boards, brickwork or sand, the lime being put into a large tub containing water. When the lime is slaked, it is lifted out by means of a pail, and poured through a coarse sieve. It is sometimes made in a large oblong box, having a moveable or sliding grating at one end to allow the lime to run out, and also to prevent the sediment from passing through.

In preparing lime for plasterwork, the general practice in the North of England is to slake it for **three weeks** before using….Now, while all this precaution is taken in regard to plastering, **in making mortar for building the lime is slaked and and made up at once, and it is frequently used within a day or two.** But this is not all. Limes which are unsuitable for plasterwork, known as **hot limes**, and which, when plasterers ate obliged to use, must be slaked for a period of…nearly three months before using….**are the limes mostly used for building purposes.** (p42).

Grinding is another process for making mortar or 'lime' and if made with any kind of limestone is beneficial. **It thoroughly mixes the material, increases the adhesion, adds to the density, and prevents blistering.** When there is a mortar-mill, **either ground or lump lime** can be used, and the coarse stuff may be made in the proportion of 1 part lime and 3 parts sand…The process should not be continued more than thirty minutes. Both material and strength is economized if lump lime is slaked before being put in the mill. (p43).

Millar Ibid.

the value of old air-slaked lime,, was preserved as a secret of the trade in Italy, **whilst the rest of Europe was advocating the exclusive use of newly burnt and hot slaked lime.** Compare the method of slaking recommended by Vitruvius and that of the skilled Italian plasterer with the **modern method of slaking the lime in the middle of a ring of sand and almost immediately hoeing in the sand.**

In the present practice more often than not, the plaster is placed on the wall or the mortar laid between the bricks within a few hours.

…. From all the advantages possessed by hydrated lime it would appear to be the **best form** of lime to be used. It is perfectly logical that the process of slaking **should be taken away from the haphazard manner used on the work and done at the point of manufacturer of the lime, where skilful supervision is possible. (80)**

Lazell (USA) 1915

Mixture	Flexural strength	Compressive strength	Dynamic modulus of elasticity	Bond strength
	MPa	MPa	GPa	MPa
LP	0.089	0.509	2.011	0.017
AL	0.299	0.941	2.742	0.037
HL	0.322	1.061	1.815	0.044

Stefanidou et al (2023) Testing air lime mortars produced with lime of different technology

LP = Lime putty; AL = dry hydrated lime: HL – hot mixed lime.

Mixture	Absorption (%)	Sp.gravity	Porosity (%)
LP	15.41	1.74	26.76
AL	12.92	1.83	23.71
HL	18.17	1.68	30.50

Table 3. Physical properties of the produced mortars.

Stefanidou et al (2023).

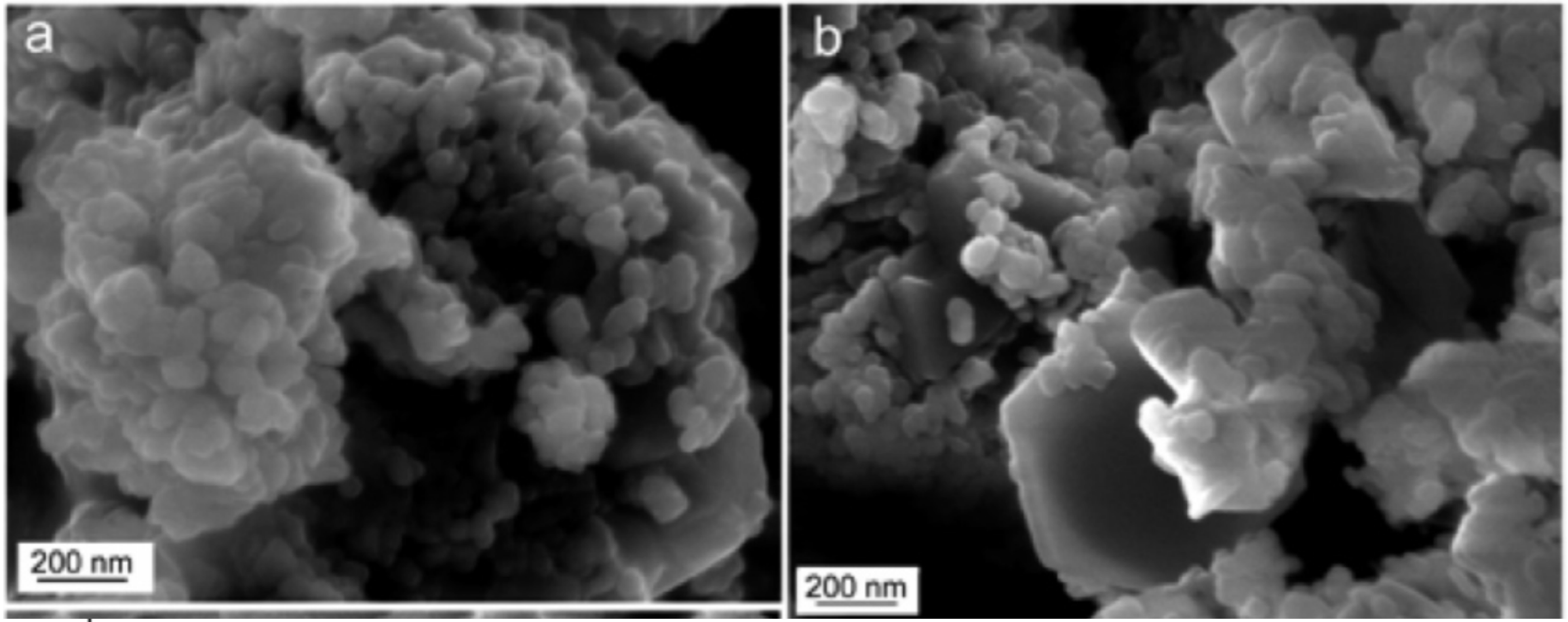


Figure3. FESEMphotomicrographs of (a)oven dried slaked lime putty showing agglomeration of plate like $Ca(OH)_2$ nanocrystals and (b) commercial dry hydrated lime, also displaying extensive agglomeration. In both parts a and b, randomly oriented and crystallographically oriented aggregates are present.

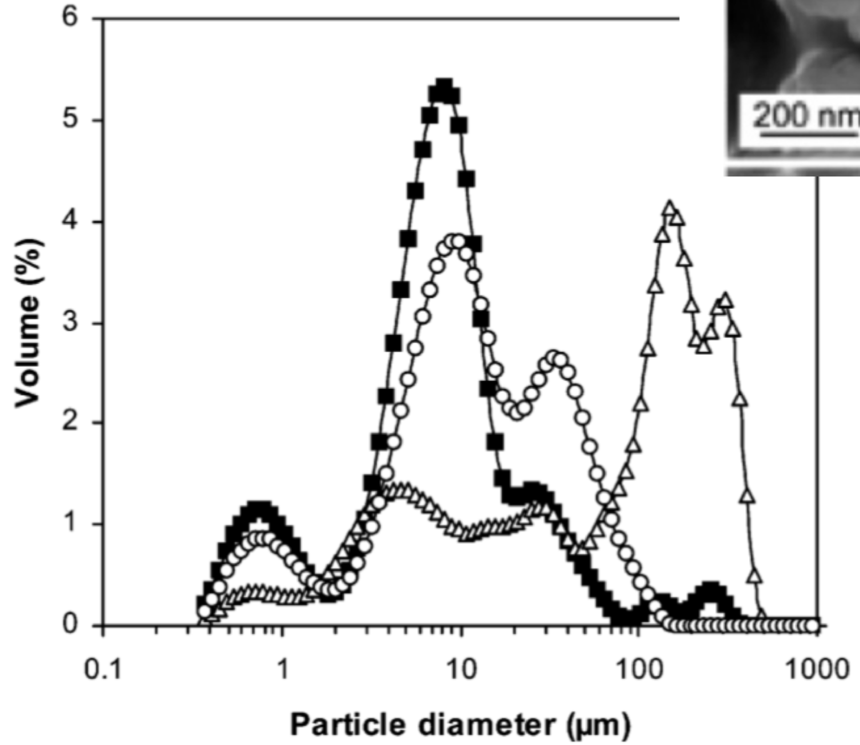


Figure 1. Particle size distribution of (■) slaked lime putty, (△) oven-dried slaked lime putty, and (○) commercial dry hydrate lime putty.

C. Rodriguez-Navarro,*,† E. Ruiz-Agudo,† M. Ortega-Huertas,† and E. Hansen‡ (2005)

Nanostructure and Irreversible Colloidal Behavior of $Ca(OH)_2$: Implications in Cultural Heritage Conservation

The industrial dry hydrate showed numerous compact clusters of submicron particles (Figure 6a). Cluster size ranged from a few up to tens of micrometers. Many aggregates displayed preferred crystallographic orientation of the constituent nanoparticles (Figure 6b). Overall, little differences were observed when comparing oven-dried slaked lime and industrial dry hydrate samples. In both oven-dried slaked lime and commercial dry hydrate samples, HRTEM images showed the presence of crys- tallites with a thickness of 10-20 nm (measured along [001]) making up larger crystals and aggregates (Figure 7). Both disoriented (Figure 7a) and oriented (Figure 7b) aggregates were observed. Crystallites were crystallo- graphically oriented either along 〈100〉 or equivalent 〈110〉 or along [001]. In most cases, however, some mismatching existed between nearby crystallites within an aggregate (resembling a mosaic crystal). Both SAED analyses and the latter HRTEM observations suggest that oriented- aggregation contributes to particle agglomeration.

Comparison of freeze-dried and oven-dried slaked lime samples indicates that oriented aggregation operates both before and during drying. In the first case, oriented aggregation is very limited, while randomly oriented aggregation is dominant. In the second case, it appears that drying triggers oriented aggregation. This is indicated by the large amount of aggregates with preferred crystal- lographic orientation in both the oven-dried slaked lime putty and the commercial dry hydrate. IBID

Particle aggregation and coarsening occurs upon drying of traditionally slaked lime putty. This effect takes place early during industrial production of dry hydrated lime. The aggregation results in porous, micrometer-size aggregates.

industrial dry hydrate lime or dried traditional slaked lime experiences a significant and irreversible particle aggregation, which results in an increase of particle size and a reduction in surface area. (LOWER WATER DEMAND OF THE MORTAR; LESS VISCOUS THAT PUTTY (HIGHER VISCOSITY FROM OVER OR SUPER-SATURATION?)

Properties of putties

Slaked lime putty can be described as an irreversible colloid, which changes properties if the material is dried. Putty made from hydrated lime, on the other hand, behaves differently when initially constituted (mixed with water) due to the massive irreversible crystal coarsening (aggregation or agglomeration of crystals) that is triggered during drying in the production process. As a result, there are differences in the rheological (flow) properties, workability and density of the two types of putty.

Correlating fundamental properties with individual stages of the lime cycle is important conceptually because lime types may vary from one another in one stage of the cycle yet be similar to each other in another stage of the cycle. Thus, if the plasticity of slaked lime putty is generally greater than the plasticity of hydrated lime putty, and if ease of application is the most important consideration for particular types of construction such as plastering, then the slaked lime putty might be a more appropriate choice. However, if overall strength is the most important consideration and both lime types provide sufficient strength, then either type of lime might be suitable.

Aging of lime putty

The aging of calcium hydroxide is shown to modify the shape and size of calcium hydroxide crystals. The aging process slowly affects the working properties of the slaked lime putty as a result of these modifications, and ultimately it also affects the course of carbonation and strength development in a mortar made with aged slaked lime as a binder.

Understanding the crystallization and particle formation processes in lime putties provides a key basis for scientific understanding of subsequent processes. All high-calcium lime putties (traditional and industrial) are chemically similar (portlandite is the mineral form of calcium hydroxide). The differences in behavior such as working properties, among others, between the high-calcium slaked lime putty and that made from hydrated lime are dependent upon the texture or microstructure (or more precisely, the nanostructure) of the portlandite crystals in the putties.

Balance between adhesiveness, cohesiveness and ease off the trowel,
Mortars can be too sticky and have too much available water (as putty does,
but which hot mixes and freshly slaked lime does not.

Lime Putties and Mortars: Insights into Fundamental Properties 2007
Author(s): Eric F. Hansen, Carlos Rodríguez-Navarro and Koenraad Van Balen

Table 2 *Testing of putties from Hansen et al. [8]*

Properties	Slaked lime putty	Putty from dry hydrate
Water content (% by weight)	66	50
Density ($g \cdot cm^{-3}$)	1.27	1.42
BET surface area ($m^2 \cdot g^{-1}$)	14.9	31.1
Particle Size Distribution	Bimodal	Bimodal
Median diameter (μm)	1.86	4.35
Plasticity (Emley), mean/s.d.	421 ± 40	229 ± 7
Water retention (% flow), mean/s.d.	90 ± 1.2	88 ± 1

Reported results are based upon three tests performed on each putty batch.

Table 3 *Mortar properties after curing time periods from Hansen et al. [8]*

Property	Curing time (months)	Slaked lime mortar	Dry hydrate lime mortar
Carbonation area % (based on rim width)	1	20 (6.2 ± 0.3)	19.4 (4 ± 0.5)
	3	75 (15 ± 2.1)	53 (10.5 ± 0.4)
	12	100	100
Compressive Strength (MPa)	1	0.59 ± 0.08	0.97 ± 0.14
	3	0.87 ± 0.04	1.22 ± 0.03
	12	0.91 ± 0.03	1.66 ± 0.23

Results based on commercial hydrate which is artificially dried after slaking, and not on freshly slaked dry hydrate not Subsequently subjected to false drying regime. This is what causes agglomeration and significant increase in particle size.

However, the results of testing the 16-year-old putty suggest several additional reasons why aging may have been used in the production of historic mortars. The 16-year-old putty, decanted as the above lime putties, showed a solids content of 67% (33% water by weight) while still retaining a high Emley plasticity value (480) and water retention (84%). Compare this with the above-mentioned value of 33% solid (or 66% water content) of the recently slaked lime. Thus, aging of this putty resulted in an extremely dense putty. Carbonation of smaller portlandite crystals in aged putty resulted in smaller, more interlocking calcite crystals than observed when hydrated lime was used, which may lead to a more resistant mortar at the same binder content [1].

Another effect on mortars formulated with aged lime putty is the induction of a novel pattern of carbonation or Liesegang pattern [18, 19]. Carbonation of aged putty, as qualitatively estimated by phenolphthalein staining, revealed that the carbonation of aged lime putties follows a complex discontinuous diffusive path which results in periodic calcite precipitation as rings, as opposed to what is normally expected from carbonation (i.e., a normal diffusion-limited continuous path that progresses from the mortar surface into the interior). The implications for a Liesegang pattern of calcite formation are yet to be determined, but aged putty was found by XRD to carbonate faster than the hydrated lime putty. Interestingly, such a ring-like Liesegang pattern is observed in some ancient lime mortars that have undergone differential weathering (shown in Figure 7).

IBID