George Rowdon Burnell. Rudimentary Treatise on Limes, Cements, Mortars, Concretes, Mastics, Plastering, etc. first edition 1857.

Burrell represents himself as a '*scientist', keen to bring the insight of science to the building site. His primary thrust is to argue that all limes should be slaked to a 'paste' before being mixed with sand or other aggregates and that this will ensure maximum performance from the material. He frowns upon the practices of 'slovenly London bricklayers', who hot mix their mortars. The majority of Burnell's sources and references are to French treatises, beginning with Vicat. He is not advocating the making of putty lime to be stored or laid down. It is at the very least implicit that he is advocating the slaking of both air and water limes to a paste (quite a thick one) immediately prior to the addition of sand, so that the slaking quicklime paste would remain hot when the mixing of the mortar occurs. In the first edition, he is generally sceptical about the advantages or benefits of Portland Cement, continuing to prefer either hydraulic or pozzalanic mortars or 'Roman Cement' in damp or wet situations. An appendix to a later edition makes plain his unreserved conversion to Portland Cement, not simply for wet situations, but generally for external applications. If nothing else, this indicates where he was coming from all along and his divisiveness of air limes generally must be read in this context. He was, however, much aware of the influence of different sands and aggregates and discusses their potential reactivity at some length. At no point does he discuss or consider the influence of the heat of slaking upon the mortars made.*

Excerpts:

ON THE MAKING OF MORTAR

The making of mortar comprehends the slacking of the lime and the mixture of the ingredients worked up with it. As we have already seen, both the former process and the nature of the latter differ, according to the lime to be dealt with. **It is, however, a universal rule,** in contradiction to the slovenly practice of London builders, **that all limes, of what nature soever, should be reduced to a paste before being mixed with the other ingredients.**

People who have not studied the action of hydrates in a scientific and consecutive manner, **oppose the introduction of the previous manipulation of the lime on the score of the extra expense, and <u>on the pretence that the lime loses in strength thereby.</u>** As to the objection of the expense, that must, of course, be estimated by the importance of the works. The second objection is to be met by observing that the rich limes require to be for a long time exposed to the air to enable them to take up the carbonic acid gas; and that, therefore, so far from losing, they gain by exposure [*this is an uncomplying argument];* and moreover, the hydraulic limes being very difficult to slack, it is necessary that all their particles should be put into contact with the water. If the lime be not previously reduced into a state of a perfect hydrate *[he means a wet, not a dry hydrate],* it is always exposed to blister, and to disintegrate, in a manner depending upon the comminution of its particles before being employed *[gobbledy-gook];* for it is evident that if the lime be ground, the more inactive particles are in a more favourable condition for the absorption of the water.

The degree of consistence of this paste should vary with the nature of the extraneous materials. **It should be stiff whenever it is intended to form a gauge for substances whose particles are hard and palpable,** and which are capable of preserving sensible distances from one another. **It should be more liquid when the substances to be mixed with it are pulverulent, of impalpable and fine grains,** presenting an homogeneous appearance, and in which it is impossible to distinguish the separate elements, such as the puzzolanos etc. **<u>To secure a proper state of hydrate, it is of great importance, however, not to use too much water in slacking the lime</u>** [*almost universal practice for the last 40 years].* **So much should be used, and only so much, as is necessary to cause the quicklime to fall to powder** *[so - dry slake and immediately mix to a paste and then mix with sand?].* **It is also equally important not to mix up into the sate of paste more lime than is immediately required to be used.** *[or may the dry hydrate be stored, being made to a paste only for immediate use?].*

In France, where great care is required in the fabrication of mortars, **the lime is worked up into a paste in a mill, consisting of two vertical stones working in a trough. The lime, after going through this operation, is then mingled with the sand in a pug-mill, or by hand, upon a floor.** ***[In this case, the slaked lime paste would be hot when mixed to a mortar with the sand, clearly].***

The quantities of sand to be used vary…according to the nature of the limes, and also the sand itself…we find that, for the rich limes, the resistance is rather increased if the sand in the proportions varying from 50 to 240 % of the paste **measured in bulk in the state of a firm paste.** Beyond that point the resistance decreases. The resistance of hydraulic limes increases if the sand be mixed in the proportion of 50 to 180 % of the paste. from thence it decreases.The much greater proportion of sand the rich limes are able to support, may perhaps, **account for the partiality of the builders in their favour** *[A-ha!].*

If it be required to mix common lime and puzzolanos, the best proportions, according to General Treussart, are 1 of lime in powder to 2 1/2 of puzzolano; 1 of lime to two of trass; or 1 of lime to 1 of sand, and 1 of puzzolano or trass. ***[It is clear from all 19th C texts that hydraulic limes were rarely, if ever, mixed at 1:3, most often at 1:2 or richer in lime. Similarly, pozzolans of all description were used in significantly higher proportions of the mortar than they have been over the last 40 years. The lime here is quicklime].***

The best hydraulic limes…lose much of their qualities if long exposed to the air; it is therefore advisable to work them only for the time absolutely necessary to ensure, firstly, their perfect reduction to the state of hydrates; and , secondly, he intimate mixture of the lime and sand. The rich limes, however…., inasmuch as they absorb the carbonic gas with difficulty, gain by being exposed for a longer period to the contact of the atmosphere [*not exactly…]….*it is advisable, then, to protract the operation of their manipulation as much as possible; it is even advisable *[or simply just possible]* to work up large quantities of such mortar beforehand, rendering it fit for use by a second manipulation.

Some of Vicat's experiments show that all limes lose 2/5 of their strength if mixed with too much water *[air limes do not necessarily and if the aggregates are limestone dust, their strength is improved, whatever the water content (Lawrence 2005)].* It is better to wet the materials to be used and to employ a stiff mortar, than to follow **the course usually adopted by masons and bricklayers of using very soft fluid mortar** *[however, a hot mix used hot will be the latter initially, becoming the former quite quickly…the best of both worlds?].*

There are conditions of the atmospheric state which affect the goodness of the mortars…For instance, **those made in summer are always worse than those made in winter….**Vicat asserts that (mortars) lose 4/5 of their strength if allowed to dry very rapidly. He recommends…that the masonry be watered during the summer months, in all constructions of importance, to guard against this danger. *[especially important for NHLs].* The freedom of the water from carbonic gas in solution is also a necessary condition of the successful use of the hydraulic limes *[really?].* Their success depends, to a certain extent, upon the slow, gradual manner in which they take up that gas from the atmosphere, and crystallise about the nuclei offered to their action.

The position in which a mortar of any description is to be used, also modifies the proportions of sand which it is desirable to mix it with. Underground, in the water, and in damp positions, less sand should be employed than in the open air, where it is exposed to the changes in the atmosphere.

CONCRETES

The term 'concrete' is usually applied to a species of rough masonry of small materials, consisting of gravel or broken stone mixed with a lime, either previously worked into a mortar or not, as the nature of the lime may require. It is principally used for the purpose of distributing the weight of a large heavy construction over the greatest surface possible; or for the backing of coursed masonry, in cases where walls are required of great thickness. Properly speaking, it would be better to apply the word 'concrete' to this sort of masonry, **when executed in the manner usually adopted in our country, by slacking the lime upon and in immediate contact with the gravel.** When the lime has been previously worked into a paste, the French word 'beton' might be applied, for the sake of distinguishing the two processes.

…The situations in which it is to be used are mostly those in which there is a great amount of humidity…it is necessary to employ only such materials as are susceptible of a rapid setting and continued progression of the powers of resistance…the limes which unite the above conditions are the hydraulic limes, obtained either from the argillaceous, or the magnesia-argillaceous, carbonates of limes. In their absence, some ingredients of the nature of puzzolanos, burnt clay, slag, or cinders must be used. But it should always be borne in mind, that these mixtures are but very imperfect imitations of the natural productions *[are they?]* ; they should never be used if the hydraulic limes can be obtained, even at an increased price; and….of the hydraulic limes, those obtained from the calcination of the limestone itself are preferable to those made artificially.

In almost every work upon the art of construction, we meet with descriptions of modes of making concrete. It is, however, very discouraging to observe that, in spite of all that may be said, **the majority of architects and engineers treat the subject with such utter indifference that the old imperfect systems are still retained, and the conduct of these works is left almost invariably to some url-of-thumb workman, who only knows that he has been accustomed to make concrete in a certain manner, without knowing any one of the principles which regulate the action of the materials he works with *[!!!!].*** We thus find that the greater part of the concretes made in or near London, where the building art ought to be the most advanced, is made simply **by turning over the ground stone lime - a very moderately hydraulic one, by the way, amongst the gravel. It is then put into barrows, and shot down from a stage.** Such a mode of proceeding is rapid and economical; but it is eminently unscientific…**Unfortunately, in England, we do everything in such a desperate hurry, especially since railroads have been constructed, that we cannot afford the time necessary for a perfect execution of the works.** Failures are consequently frequent, the waste of materials enormous; and, of course, between the two, the expense is out of all proportion to what it ought to be *[plus ca change! But hot-mixing not necessarily a function or a cause of this, predating by far Burrell's time].*

(Burrell then advocates the same procedure as for mortars - slaking the quicklime to a 'thick paste' before engagement with the aggregates or pozzolans. Concrete should be wheeled in and laid before being 'beaten with a rammer' avoiding any separation of the ingredients due to be dropped from height and keeping the distribution of the binder constant *[but would it do this better than a hot mix, which holds onto water better than putty lime mortars, which readily generate separation and laitance?]*

…A very excellent concrete for either sea or river works is made by a mixture of a mortar made of **three parts of fine sand to one of hydraulic lime unslaked, with equal quantities of gravel or broken stone.** No water should be mixed with the mortar and gravel during their manipulation; the mortar itself, if possible, should be prepared in a pug-mill, and mixed with the gravel being frequently turned over on a platform…the concrete thus made should be spread in layers from 10 inches to 1 foot in thickness, and well rammed, until the mortar begins to flush up at the top. …

When the works are left to the care of mere workmen, as they too often are with ourselves, a very absurd mode of making concrete is often adopted where there is much water to be contended with. **The lime is mixed with the gravel, without having been previously slacked and left to absorb the water necessary for its passing to a hydrate as it may.** Such a course is unphilosophical and dangerous in the highest degree, and cannot be too carefully guarded against. (argues that hydration is 'robbed' from other lime in the mix and 'must disintegrate the mass')…

Broken limestone appears to add very much to the qualities of concretes, batons and mortars. Very probably this may be attributed to the affinity between the molecules of the already formed carbonate of lime, and that which is in the process of formation; the new crystals may group themselves more easily about bodies whose form is similar to the one they are themselves to assume. Or possibly there may be **a tendency in the chemical elements to arrive at a state of equilibrium; and the carbonate of lime may, therefore, be supposed to part with a certain portion of its carbonic acid gas.** *[seeding carbonation…].*

ON THE SANDS AND OTHER INGREDIENTS USED IN CONJUNCTION WITH LIME TO MAKE MORTAR.

These ingredients are of several natures, **and they exercise very different and very important effects upon the qualities of the respective combinations into which they enter.** They are 1, the sands…whether fluvial or pit sand; 2, the clays, either in their natural or their burnt state; 3, the puzzolanos, trass, or other volcanic productions; and 4, the produce of artificial calcination, such as cinders, slag of furnaces, or scoriae….

1 Sands….

The generally received opinion that the sand should be perfectly free from all earthy matters, is only true to a certain extent. (discussion of the use of 'arenes' for construction in France - between 25% and 75% clay mixed with chalk aggregate, and used with rich limes for waterworks…). Some of the decomposed grauwacke rocks also yield an argillaceous sand, composed of quartz, schist, feldspar and particles of mica agglutinated by a species of clay, which is very valuable, whether used in its natural state, or calcined to make artificial puzzolanos, like the arenes. The granitic rocks of Devonshire, some parts of Brittany and of the extreme NW of Spain, all of which are characterised by a remarkable excess of feldspar, yield a sand of great value for building purposes, especially when the mortars composed of it are not immediately exposed to the effects of running water. In all probability, the potassa present in the decomposed and decomposing feldspar may influence the setting of the limes mixed with the sands thus obtained.

2. The Clays

The clays are rarely used in their natural state in combination with lime, **unless it be to give a certain degree of consistence to mud walls or pise work [*and for earth mortars and plasters throughout the UK and elsewhere!].*** When burnt, they act somewhat in the manner of puzzolanos; and for all cases in which the mortars thus made are not exposed to the action of sea water, they appear to answer very well.

3 The puzzolanos

The puzzolano is a volcanic substance of a pulverulent character, and a violet red colour, which was fist employed in the fabrication of mortars by the Romans…

Its aspect varies, however, very much; sometimes it is in a state of powder, at others in coarse grains; often in the form of pumice, scoria, or of tuffa or in small rubble-stone. Its colour is often brown, or yellow, or grey, of black, even in the same locality.

The Tripoli, and the sandstones and limestones altered by contact with the rocks of eruption, also frequently take the character of puzzolanos and may be classed, therefore, as pseudo-volcanic products of a similar category….The puzzolanos are principally composed of silica and alumina, with a little lime in combination, mixed with potash, soda, magnesia, and oxide of iron. The iron appears to be in a peculiar state of magnetism; for although in very feeble proportions, it is capable of affecting the needle.

…it is evident that the effect produced by the mixture of the puzzolanos and trass is eminently useful in rendering the rich limes fit for every description of works executed in either sea or fresh water….Less (puzzolano) id required when hydraulic limes are used, than when they are mixed with the rich limes. **The latter will bear at the same time a large quantity of sand or gravel, the former only a very small quantity.**

4. The term ‘slag’ is usually applied to the vitrified earths which are left in furnaces, either for glass or iron, after the purer products are withdrawn. ‘Scoriae’ are the lighter, more porous, and less perfectly vitrified earths, which arise principally from the puddling and refining of iron; the term is also applied to the less compact portions of the slag. Cinders are the earthy residues from the combustion of woods, peat, coal, or other combustibles.

The slags and scoriae….principally consist of silica, with a feeble proportion of alumina, magnesia and very large proportions of the oxides of iron and manganese.

(compared to pozzolano and trass…’a very remarkable difference in the proportions’ in slags and scoriae, as also between scoriae and slag, with the latter having little iron, the scoriae a lot).

Coal cinders…when properly mixed appear to render the rich limes moderately hydraulic.

Wood cinders are often objectionable in consequence of (an) excess of alkali: if this be removed by washing, they may occasionally be useful in the absence of other materials capable of communicating hydraulic properties.

Vicat classes the different materials named and described above still further, **according to the energy of their action upon the limes with which they are mixed:**

He calls ‘**very energetic**’ any substance which, after being mingled with lime **slacked in the usual manner, and brought to the consistence of a thick paste,** produces a mortar capable of setting **from the first to the third day; of acquiring after the lapse of 12 months a degree of hardness equal to a good brick;** and of giving a dry powder if sawn with a tooth saw after that time.
‘**Simply energetic’,** any substance which will determine the setting **from the fourth to the eighth day;** and which is capable of acquiring **after twelve months the consistence of soft stone, and of giving a damp powder under the tooth saw.**

‘Slightly energetic’, when the setting only takes place between **the tenth and the twentieth day; the consistency of hard soap…after 12 months, and the mortar would then clog the tooth saw.**

‘Inert’ when the materials, if mixed with rich limes, exert no influence upon their action under water.

In all these cases the mortars are to be immersed immediately.

might this, without immersion, be a reasonable rule-of-thumb method?]

(Vicat maintains that no pozzolano added to rich limes can make them set under water…)

General Treussart, however, does not agree with Vicat, in supposing that the chalk, or rather the rich limes, cannot be rendered capable of setting by the mixture of pozzolanos; and, indeed, **the experience of almost all builders would lead us to believe that Vicat has, in this case, been carried away by the love of theory.**

OF CEMENTS

A peculiar class of the argillaceous limestones yields on calcination a species of lime capable of setting under water with considerable rapidity, of acquiring a great degree of hardness within a very short space of time, and of being employed without the admixture of any foreign substance.

(First discovered by Parker, 'Roman Cement' using septoria from the Isle of Sheppy) ;
Mr Atkinson introduced another made from the nodules of the argillaceous limestone of the secondary formations of Yorkshire [*Sandsend, near Whitby], (*subsequently Frost, using septoria of the coast of Essex)

On the coast of France a similar material was found in 1802, at Boulogne. Lacordaire discovered it also at Pouilly in…Burgundy…It occurs in the Isle of Wight, in the Bay of Weymouth…

…The mineralogical composition of the stones from which the cement is made differs very much; but the **characteristic type may be said to consist of above 30% and below 60% of clay and other extraneous matter in combination with the carbonate of lime.**

The Sheppy stone usually contains 55 parts of lime, 38 of clay and 7 of iron; **the Yorkshire stone contains 34% of clay; 62% of carbonate of lime and 4% of iron;** the Harwich stone contains 47% clay; 49% carbonate of lime, and 3% of oxide of iron.

…The cement stones are burnt in conical kilns with running fires, and, in England at least, with coke or coal….the precise point of calcination does not appear to affect its qualities.

Before being burnt, the stone is of a fine close grain, of a peculiar pasty appearance; the surfaces of fracture are rather greasy to the touch, and somewhat warmer than the surface of the stone…It sticks easily to the tongue; it does not strike fire; its dust, when scraped with the point of a knife, is a greyish white for the most part, especially when derived from the blue lias formation. It effervesces with nitrous acid, and gives off nitrous acid gas, During calcination the cement loses about 1/3 of its weight, and the colour becomes of a brown tinge, differing with the stones from which the cement is obtained. When burnt it becomes soft to the touch, and leaves upon the fingers a very fine dust; and it sticks very decidedly to the tongue….

Calcined cement (is) of no use until it is pulverised, this is always done at the mill of the manufacturer…it is usually put into casks well closed when thus ground and may be preserved for a very long time; but contact with the atmosphere rapidly deteriorates its quality….

Though all cements and limes tend to reassume a state of carbonisation similar to that in which they existed in the stones from which they were extracted, **they only do so to a very imperfect degree…**Cements, on the contrary, harden very rapidly; but we have no instances *[in 1857]* of their).18620.acquiring the strength of the original stone.)

It is always dangerous to be obliged to rely upon the skill or integrity of workmen, who either do not understand the necessity of taking pains with their work, or who, from being paid by the piece, have an interest in slurring it over.

A small quantity of water only is necessary to work up cements to their greatest point of resistance, which General Treussart found to be the most successfully attained when the water was employed in the proportion of **one third of the cement in volume.** It is necessary to beat up the cement very frequently; indeed, the more it is turned over before the setting commences, the harder it becomes. The time of setting varies with the nature of the water used and the quantity of sand present. With sea water the time is longer than with fresh, and the sand retards the process of setting considerably. When the cement is new…the time of setting, if it be used pure, should never exceed half an hour, a quarter of an hour being the normal period. (but sometimes 5 or 6 minutes).

Pure cement has much greater powers of resistance [*compressive strength]* than when it is mixed with sand in any proportion whatever - in this again differing from the limes.

…Cement adheres very strongly to iron, to granite, and to bricks….

From these considerations, it would appear that **the best mode of using the natural cements is to employ them without sand in all works under water, or where a great crushing weight is to be brought upon them at once. For foundations in damp situations, where rapidity of execution is desired, they may be mixed with 2 parts of sand to 3 of cement; the same proportions are suitable for cornices, or coatings exposed to weather. 3 parts of sand to 2 of cement make a good mixture for perpendicular faces…**

In England, owing to the cheapness of the so-called Roman cement, whether specifically identified as Atkinson's, the Medina, or merely called Roman, **almost all the works executed in water at the present day are executed with it.** But there are reasons to make us doubt whether we do not in this case adopt a system **which is at least open to objection. Cement is so convenient, that engineers and architects neglect to study the qualities of lime;** and some very unfortunate accidents have arisen from that neglect.

…good hydraulic limes in time attain a degree of resistance sufficiently great for all practical purposes, and at much less expense. **To use a hard, quick-setting material upon a yielding base, is a degree of ignorance totally unaccountable on the part of any professional man of average discernment.** In fine, the uses of these cements are many and various; we, in our country, are rather inclined to abuse them.

There are many sorts of artificial cement employed which are obtained either from the over-calcination of the hydraulic limes (all of them possessing the faculty of acquiring a more rapid setting, and a greater degree of hardness when so burnt), such as the Portland cement before mentioned; or from the mixture of burnt clays with the rich limes. In some parts of the continent, where the natural cement stones do not exist, the latter are much used, and they yield a very tolerable substitute for the articles they replace….but they are far from attaining the hardness of either the natural cements or the overburnt artificial ones. **Their use is principally confined to a mixture with the slow-setting limes when they are employed in damp situations, and in these cases they succeed remarkably well.** The cess-pools and water tanks throughout the interior of Normandy are lined with a mortar made in this manner, and they resist perfectly…

It is to be observed, that although the Portland cement is occasionally exposed to the before-mentioned inconvenience of expanding whilst setting, it has other qualities of a very remarkable nature. It becomes, in equal times, after the first setting (which, by the way, is very irregular), **much harder than the Roman cements. It will admit of a much greater quantity of sand for every purpose; and, moreover, as it does not absorb the humidity of the atmosphere with the same facility it consequently resists the action of frost more successfully, and is less exposed to discolouration by the formation of vegetation.** *(this is, of course, early, less refined Portland cement, hence its variability. Even so, Burrell identifies its lack of porosity as marking it out].*

…