Bryan Higgins Experiments and Observations made with the view of improving the art of composing and applying Calcareous Cements and of Preparing Quicklime. 1780 Cadell. London.

As the strength and duration of our most useful and expensive buildings depend chiefly upon the goodness of the cement with which they are constructed, I looked to the improvement of mortar as a subject of great importance, in this country particularly, where the wether is so variable and trying, and the mortar commonly used so bad, that the timbers of houses last longer than the walls unless the mouldering cement be frequently replaced by pointing…

I made several parcels of mortar…, the sand employed was coarse Thames sand…, the lime was slaked as soon as it cooled after being burned, and with the smallest quantity of water necessary for this purpose; it was sifted through a fine brass wired sieve as soon as it was fully slaked…and each parcel or mortar was beaten and briskly formed with the quantity of water which was barely sufficient to give it the normal consistence…

The workmen usually slake the lime mixed with the sand or gravel in great heaps, and do not screen it until the most useful part is debased by that which slakes after five or six hours or more, and which is little better than so much powder of chalk. **But if they would screen the lime in about half an hour after the water is thrown on it, the mortar would be much better,** although the quantity of lime in it should be much less; for I observed in all the foregoing specimens, that those which contained the smallest quantity of lime were the best; and **this quantity is much smaller than is usually employed in making mortar.**

P35…In a few months, I was satisfied that **the specimens made with the fresh lime were the hardest and best,** and that the others were worse as the lime of them had been longer exposed….

After this there remained no doubt that lime grows worse for mortar every day that it is kept in the usual manner in heaps or in crazy casks; that the workmen are mistaken in thinking that it is sufficient to keep it dry; that lime may be greatly debased without slaking sensibly, and that the superficial parts, of any parcel of lime, which fall into small fragments or powder without being wetted, and merely by exposure to air, are quite unfit for mortar…

I now saw more clearly another cause of the imperfection of our common cements: the lime being exposed a considerable time before it is made into mortar, and drinking in acidulous gas all the while, the quicker as it is the better burned, is incapable of acting like good lime , when it is made into mortar, and often approaches to the condition of whiting… In London particularly, they use lime

which is burned at the distance of ten or twenty miles or more, in Kent and elsewhere, with an insufficient quantity of fuel. This lime remains in the kiln, to which the air has access, for many hours after it is burned. It is exposed for some days in the transportation, and on the lime wharfs; and it undergoes further exposure and carriage before the artist slakes it for mortar. It is no wonder that the London mortar is bad…since the lime employed in it is not only bade when it comes fresh from the kiln, but becomes worse before it is used…

p37 *Experiments and Observations made to determine whether mortar be the better for being long kept before it is used.*

I am generally disposed to think that there is some good reason for any practice which is common to all men of the same trade…and seeing that **the builders slake a great quantity of lime at once, more than they can use for some days,** and that all those whom I conversed with **esteemed mortar to be the better for being long made before it is used; and that plasterers particularly follow this opinion in making their finer mortar or stucco for plaistering within-doors,** I was desirous to discover the grounds of these measures…

In the month of March 1777, I made about a peck of mortar, with one part of the (p38) freshest and best chalk lime, slaked, six parts of sand and (sufficient) water; for in a great number of experiments, I observed that this proportion of lime was better than any larger which I had tried, **or which the workmen observe in making mortar.**

I I formed the mortar into a hemi-spherical heap on the paved floor of a damp cellar, where it remained untouched for 24 days. (After)…this time, I found it hardened at the surface, but moist and rather (more) friable or short than plastic in the interior parts of it.

I beat the whole of it with a little water to its former consistence; and with this mortar and clean new bricks, I built a wall 18" square and half a brick in thickness, in a workmanlike manner. On the same day, I made mortar of the same kind and quantities of fresh chalk lime and sand, tempered in the same manner, and I built a wall with it, like the former, near it, and exposed equally to the weather.
(p39) I examined the mortar in the joints of these walls every fortnight, by picking it with a pointed knife, and could perceive a very considerable difference in the hardness of them; **the mortar which was used fresh being invariably the hardest.**

(After) 12 months, in pulling these walls to pieces, and by several trials of the force necessary to break the cement and separate the bricks, I found the mortar which had been used quite fresh, **to be harder and to resist fracture and the separation of it from** the bricks in a much greater degree than any other specimen….

I concluded that mortar grows worse every hour that it is kept before it is used in building, and that we may reckon as another cause of the badness of common mortar, that the workmen make too much at once, and falsely imagine that it is not the worse, but better for being kept some time.
Having in consequence of these observations had a great deal of conversation with workmen on this subject, I could perceive the origin of this error:

Some portions of every kind of lime used in this country, do not slake freely, by reason of their not being sufficiently burned, or of the admixture of…argillaceous matter; and these, like marle, slake in time, though not so quickly as the purer lime.

The plaisterers, who use a finer kind of mortar made of sand and lime, observe that their plaster or stucco blisters, when it contains (p41) small bits of unslaked lime; and as their purpose is to work their stucco to a smooth surface, and to secure it from cracking, or any such roughness…and as the hardness of the stucco is not their chief object, they very properly keep their mortar a considerable time before they use it, to the end that the bits of imperfect lime, which passed through the screen, may have time to slake thoroughly.

p42 The builders considering the plaisterers mortar…as a finer and better kind of mortar, think it not amiss **to imitate them** in those particulars which are not attended with any expense, and **especially in the practice of slaking a great deal of lime at once, and of keeping the mortar made some time;** and they do not seem to know, that such measures **prevent the mortar from ever acquiring that degree of hardness in which the perfection of mortar truly consists.**

p43 (Questions the efficacy of using plain water to slake lime and make mortar)
P44…I have found the quantity of water used for both these purposes to be twice the weight of the lime, at the least.

…On comparing specimens of mortar made with my best lime slaked with river water, and sand and water…with other specimens made with the same proportions of lime slaked with **lime water, and sand and lime water…**the latter, at every age of them, were **sensibly harder (with better adhesion to substrate)** than the former.

Experiments made with a view to approximate the best proportions of Lime, Sand and Water, for Mortar.

(Had found 1:6 – by weight – to perform very well, suspects…) that as a wall may be the weaker for its containing too much mortar, which widens the joints, so

mortar may be weakened by the introduction of more lime than is necessary to cement the grains of sand together (so set about determining best proportions).

(Tested 1:4; 1:5: 1:6: 1:7 and 1:8 quicklime to sand (by weight), slaked with limewater).
This latter specimen (1:8) was not sufficiently plastic for common use; or as the workmen express themselves, **it was too short.**

(Samples were) left in the sun, but duplicates in the shade…

(Concludes that) no more than 1:7 ought to be used in mortar which is to dry quickly…and if a greater proportion of lime to such sand improves the mortar in any respect, it is to used only where the mortar cannot dry so quickly as it did in the specimens exposed to the sun.

In the course of 9 months…those specimens which stood in the shade for the first 3 days were **harder**; and better in other respects, than those which were suddeny exposed to the sun.

(1:7 set most efficiently and in both circumstances and did not crack).

Mortar which is to be used where it must dry quickly, ought to be made as stiff as the purpose will admit…and…will not crack, although the lime be used in excessive quantity…

(Sets quicker the less lime there is to sand).

P58 The…inconvenience arising from the excess of lime cannot easily happen in mortar compressed on all sides in massive buildings, but it manifestly occurs in the exterior parts of the joints in walls, where the mortar visibly swells, and after swelling, crumbles; it is likewise visible in the upper parts of walls of modern construction, where the swelling is not prevented by a superincumbent weight…

The strength and duration of the calcareous incrustations composed of lime and sand will be the greater as we depart further from the proportions of lime and sand **commonly used,** approaching (p59) to that of 1:7, because the stucco which hardens the soonest must be the least injured, whilst it is new, by the beating rains and various accidental impressions, because that which adheres most firmly to the other materials of buildings, and which acquires the greatest degree of induration, mus contribute most to the strength of the walls, and best withstand the shocks, attrition, and other trials to which the stucco is exposed…but above all, because the stucco made with one part of lime and about seven of sand, **is not disposed to crack**; for incrustations in this climate perish sooner by reason of the fissures than of any other defect, because the water imbibed into the slenderest of them, as well

as into those which appear on a cursory view; swells in the congelation, and dilates them; and frequent alternations of wetting and freezing, gradually widen them, until the stucco is bulged and torn from the walls.

p61…(by analysis and trials) I found that the quantity of lime in old cements made with clean sharp sand, and noted for their hardness, **was much less than is now commonly used in mortar; and that in the hardest, it was very near to that which my experiments indicate to be the best.**

a series of experiments with 1 part slaked lime to 7 sand, by weight

I learned that hasty drying prevents good mortar from ever acquiring the hardness which it otherwise would have; and that the more slowly the proper water of the mortar is exhaled or absorbed from it, in incrustations or brickwork, the more perfect will be the induration of it.

(Also) that mortar which is not suffered to dry, or which is supplied with moisture as fast as its proper water exhales, does not harden, or hardens only to a small degree…

p74 (So, for mortar that sets soonest and to highest degree and makes best cement)…it must be suffered to dry gently and set; the exficcation must be effected by temperate air and not accelerated by the heat of the sun or fire; it **must not be wetted soon after it sets**; **and afterwards it ought to be protected from wet as much as possible, until it is completely indurated…and then it must be as freely exposed to the open air as much as the work will permit,** in order to supply acidulous gas….

P75
The mortar made with bad lime and a great excess of it, and debased in watering and long exposure, is used with dry bricks and not infrequently, with warm ones. These immediately imbibe or dissipate the water and not only induce the defect (above) (but make it brittle and liable to loosen as work proceeds, causing shocks and vibrations).

But to make strong work, the bricks ought to be soaked in lime water, and freed from the dust which, in common bricklaying, intercedes the brick and mortar in many parts. By this method, the bricks would be rendered closer and harder; the cement, by setting slowly, would admit the motion which the bricks receive when the workman dresses them without being impaired; and it would adhere and indurate more perfectly….

P76 **In plaistering, the workmen always brush away the dust and wet the wall on which they are to lay the cement, because it will not otherwise adhere…**this ought to be done with lime water, and repeated as long as the wall is thirsty.

Advocates soaking sand for mortars with lime water before mixing, rather than adding water to the drier ingredients.

P86 I next endeavoured to ascertain the mixture of coarse and fine sand, (which most reduces the voids, therefore requiring less lime to fill these and) promises to make the hardest and most durable cement.

Series of experiments with different sands in combination

P90 The mixtures of rubble and mixed in any proportion greater than 5:1 were not fat enough, when fresh, to be conveniently used in building or stuccoing…Those which had the smaller quantities of lime in them were very rough on the surface, coarse in the grain, spongey and easily broken…those which contained more lime were not so bad in these respects. 1:5 optimum with 'rubble'.

P92 I was persuaded that a better cement can be composed with such sand as I call fine, than with a coarser sand whose grains are all larger than all those in my fine sand…

p93 Of the specimens made with rubble and fine sand, that was the best in which the fine sand was twice the quantity of the rubble…(but did not seem better than those made with fine sand alone)

Of the specimens made with coarse sand, fine sand and lime, those were manifestly the best which consisted of 4 parts of coarse sand, 3 of fine and one part or a little more of lime: for, whilst fresh, they were more plastic than the others, and were easily made to acquire a smooth surface; they were not disposed to crack …; they were not at all injured by wet or freezing or thawing; they were pretty close in grain and (p94) they grew so hard, in the course of 9 or 10 months, as to resist the chisel… (the best mortar he had made or tested).

…In stuccoing walls, the rubble promised to be useful in pointing and in the first coat; because a roughness of this coat makes the finer exterior coat adhere more firmly.

(Experiments with fine 'house sand' commonly used in London and much finer than the sharp fine Thames sand).

Mortar containing the quantity of lime necessary to the plasticity and other desirable properties of it, or a greater quantity of lime, is the more liable to crack in drying, as the sand if it is finer.

Mortar made with this finest sand and lime does not grow so hard, or resist fracture so forcibly, as that made with my fine Thames sand and lime. …

P99 Mortar composed of lime, my fine (but sharp) Thames sand and the finest sand is the worse as the quantity of finest sand is greater…

(Notes that the roundness of the grains of the finest sand is the problem).

P109

In great cities, where gravel cannot be procured so cheap as the rubbish of old walls, which the workmen lay in the streets to be ground to powder by the passing carriages, they use this rubbish screened, in the place of sand or gravel, in making mortar. It consists of the gross powder of bricks, and of mortar indurated, as much as bad mortar can be, by time; and some builders affirm that it is (p110) better than sand or gravel for mortar. It is certainly eligible when the price is chiefly considered; in any other view, it is not so.

(So, made some trials….)

I found that less lime was required to make fat lime mortar with this ground rubbish, than with my best mixtures of sand…but the mortar made with this rubbish appeared in every stage of induration, and in every comparison except that of the plasticity, to be greatly inferior to that made with mixed sand and lime in the same proportions.

If the workmen would confine their opinion to the comparison of such rubbish mortar (p111) with that in which clayey gravel is used, or with the cements made with the ashes and ordure of the town, dug out in preparing foundations for houses…they might maintain it on divers grounds…but otherwise it is erroneous.

p117 To guard a recent incrustation from the rain, and to secure it from cracking…I proposed **the expedient of hanging sail cloth on the cornices and scaffolding**; but the expense of this measure, and the danger of it in windy weather, are strong objections.

p124 A mortar made of terras powder and lime was used in water fences by the Romans, and it has been generally employed in such structures ever since…It is preferred before any other, for this use, because it sets quickly, and then is

impenetrable to water: **whence some people hastily conclude that it is the best kind of mortar for any purpose**. But by experience I know that mortar made of lime and terras powder, whether coarse or fine, **will not grow so hard as mortar made with lime and sand, nor endure the weather so well; but…is apt to crack and perish quickly in the open air.** The efficacy of it in water fences is experienced only where it is kept **always wet.**

Then

Experiments shewing the effects of Plaister Powder, Alum, Vitriolic Acid, of some metallic and earthy Salts, and of Alkalines, in Mortar, Practical Inferences.

Then

Experiments shewing the Effects of Skimmed Milk, Serum of Ox-Blood, Decoction of Linseed, Mucilage of Linseed, Olive Oil, Linseed Oil and Resin, in Mortar; and the Effect of painting calcareous Incrustations.

P133 (All no less liable to crack; encouraged organic growth and prevent the mortar reaching normal hardness).

P134 Olive oil mixed with good mortar, or substituted in the place of a part of the lime water, (p135) rendered the cement defective, as the quantity of oil was greater. The greatest quantity used as half that of the lime.

Linseed oil…makes the mortar fatter, retards the drying of it and prevents it from acquiring in any way so great a degree of hardness as it otherwise would have….In smaller quantities it was less injurious than olive oil.

I have reason to conclude that no oil ought to be used in a cement which consists chiefly of sand, lime and water

I infer that cow-dung, which I have not tried, would impair good mortar. It makes the common mortar fatter, and in that respect more convenient for the pargeting of the interior surface of chimney flues; it seems likewise to prevent the parget made with bad lime from drying so clearly and cracking so much…the fibrous part of the dung being capable of contributing largely to the latter effect.

Then,
Experiments shewing the Effect of Sulphur, introduced by different Methods, in Mortar.

Then
Experiments shewing the Effects of Crude Antimony, Regulus of Antimony, Lead Matt, Potter's Ore, White lead, Arsenic, Orpiment. Martial Pyrites and slaked Mundic, in Mortar

Then

Experiments shewing the Effects of Iron Scales, washed Colcathar, native Red Ochres, Yellow Ochres, Umber, Powder of coloured Fluor, coloured Mica, Smalt, and other coloured Bodies, in Mortar. Advices concerning coloured Incrustations, Inside-Stucco, and damp Walls.

(Condensation):

The plaisterers, finding their stucco, which is as fine and close as they can make it, to contract these damps, especially on the principal walls of houses, case them with lath-work, on which the incrustation is laid distant from the wall. In this way, (p157) they obviate the appearance of damp; but they at the same tme contract the rooms, and narrow passages and staircases sensibly, at a great expense. This is enhanced by the repeated plaistering necessary to fill the slender cracks which disfigure their incrustation during the drying, and by the oiling or painting which is finally required to hide this defect completely, if not to give colour. Thus the work becomes costly, though the plaisterer's profit is moderate.

(then sings the praises in this regard of his coloured patent mortar)

Experiments shewing the Effects of common Wood-ashes, calcined or purer Wood-ashes, elixated Ashes, Charcoal Powder, Sea Coal-ashes, and powdered Coak, in Mortar…

The ashes of wood and sea coal are frequently mixed with water, or used in the place of sand, **in laying tiled floors and even in external incrustations.**

Some workmen say they are used in the former case to save sand; others that **they serve to resist moisture…and that they hasten the drying and induration and prevent the cracking of mortar which is laid very thick**in order to fill the depressions of walls which are to be stucco'd and that they are used in finer incrustations with the sole view of preventing cracks.

P164. After a great number of experiments…with the elixated ashes, I found that they rendered the mortar spongey, disposed it to dry and harden quickly, and prevented it from cracking, more effectively than the like additional quantity of sand would do it.

p168

From these experiments, I conclude that…these powders are eligible in this order: elixated wood-ashes freed from the finest powder in washing, first; powdered coak or sea-coal cinders, next; charcoal powder next; rough wood ashes powdered, last.

Experiments shewing the Effects of white and grey Bone-ashes and the Powder of Charred Bones; and Theory of the Agency of these in the best calcareous Cements.

p180

(Has convinced James and s Samuel Wyatt to use his patent mortar on their buildings).

p184

The Specification made in Consequence of Letters Patent

Specification,

Lime water used to slake.

Let 56 pounds of…lime be slaked, by gradually sprinkling on it, and especially on the unslaked pieces, the cementing liquor, in a close clean place. Let the slaked part be immediately sifted…let the lime which passes be used instantly or kept in air-tight vessels…This finer, richer part of the lime which passes through the sieve, I call purified lime.

(56 parts of coarse sand: 42 parts fine sand: 14 parts purified lime added to the wetted sand; beat together then add 14 parts fine bone ash. Use as soon as possible after mixing).

This I call the water cement coarse-grained, which is to be applied in building, pointing, plaistering, stuccoing, or other work, as mortar or stucco now are, with this difference chiefly, that, as this mortar is shorter than mortar or common stucco and dries sooner, it ought to be worked expeditiously in all cases…(and all surfaces well-wetted before applying).

p214

The inexperience of the workmen, their obstinate adherence to their own notions, and the opinion which they entertained that some of the rules prescribed to them were insisted on rather through an affectation of mystery than for any useful purpose, operated strongly against the best endeavours of Messieurs Wyatt, in the incrustations first made on a great scale for use or ornament. In consequence…their stucco, although it excels others beyond comparison and is far from being perishable, is not quite so hard as it might have been made….