THE USE OF LIME IN MORTARS

by J. Vernon

Lime has been used in mortars for many centuries; it was less than 100 years ago that Portland cement was first used as an alternative material.

The apparent advantages of cement—such as the rapid gain in strength and the elimination of the costly process of slaking lime and maturing it in specially dug pits on site—were soon recognized. Hence, the amount of lime used in mortar diminished considerably, but it was quickly realized that the new cement-based mortars had many shortcomings. In order to make such mortars workable the cement content had to be high, and the very strong non-resilient mortar thus produced made no allowance for the inevitable small movements that occur in any building due to drying and settlement. The result was that the stresses and strains in the structures eventually reached a point where they could no longer be accommodated, and serious unsightly cracking of the mortar and brickwork occurred. With the previously used and relatively weak lime mortars the stresses had been relieved in a large number of joints, and serious cracking was rare.

However, with the increasing pace of building over the years it was also obvious that straight lime/sand mortars did not achieve a sufficiently high early strength to allow speedy construction and the durability of some lime-based mortars was inadequate and frequent pointing was necessary.

Improved mortars

By trial and error and subsequently by controlled research a compromise was reached and cement/lime/sand mortars became generally accepted and, over a long period of time, have proved their value. The lime gives such mortars high workability and water retention, thus ensuring that joints are properly filled; it improves adhesion and hence resistance to rain penetration, while the cement gives the early strength to allow quick construction and resistance to frost attack which is so important during the early stages in winter. At the present time all relevant British Standard Codes of Practice, such as CP 121:101 for brickwork, recommend cement/lime/sand mortars and make a special point of advising against the use of cement/sand mortars, except where a strong dense mortar is essential, such as where engineering bricks are used or in some classes of work below ground level. Even in these circumstances a small proportion of lime is permitted to improve workability.

In view of the above it was surprising to find, from a market survey made last year, that cement/sand mortars without any additive at all are used on a large scale in this country.

The market survey also showed that most architects specified cement/lime/sand mortars, but there was evidence to suggest that many of them allowed the use of alternative materials—such as air-entraining agents and masonry cements, which are said by the manufacturers to give adequate workability and strength to the mortar. It is perfectly true that adequate workability and strength can be obtained with these materials for general building purposes, if they are used in accordance with the manufacturer's instructions. The bonding properties are not as good, however, and this property and the

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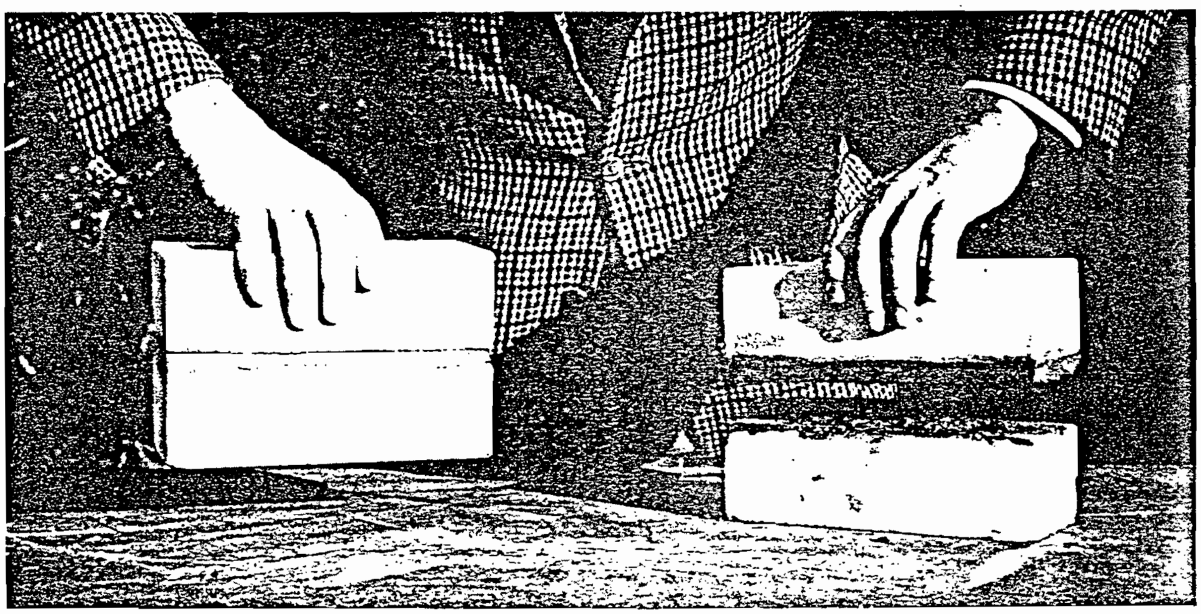
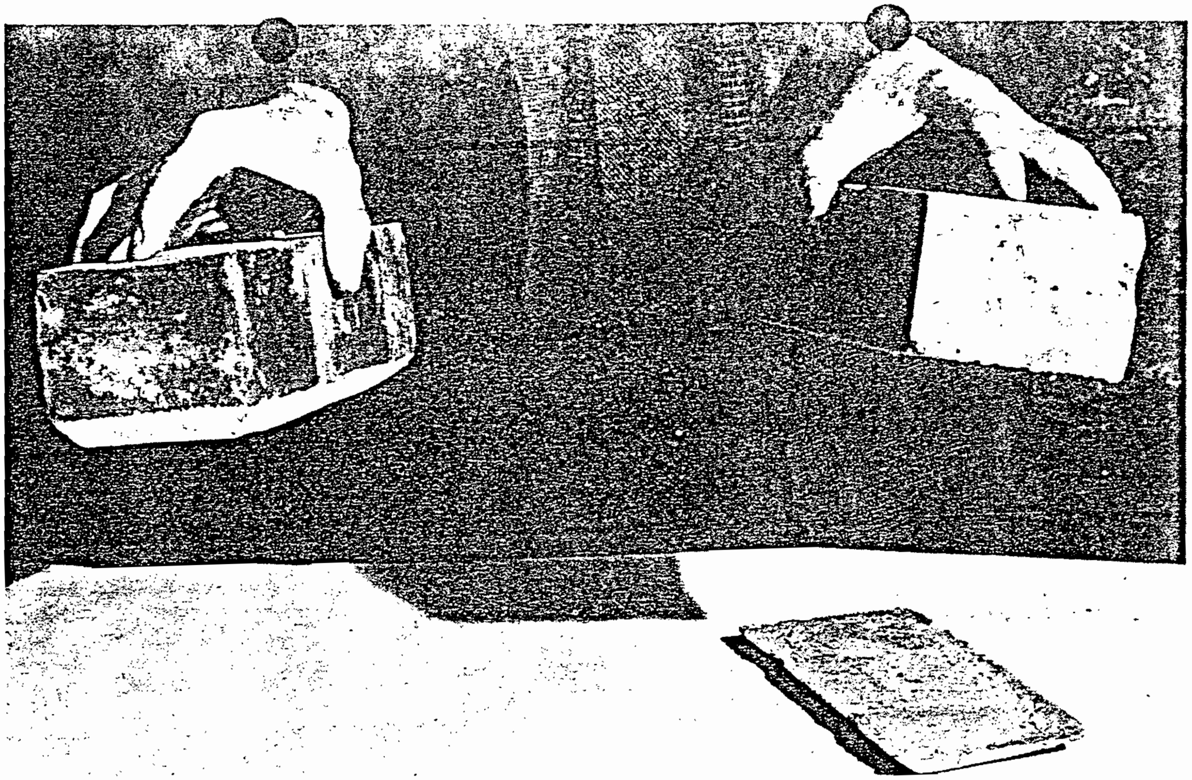
The bricks on the left were bonded with a 1 : 1 : 6 cement / lime / sand mortar; those on the right were bonded with a 1 : 3 cement / sand mortar. Note the difference in bond a few minutes after laying





The layer of mortar on the brick on the left of the picture consisted of 1 : 1 : 6 cement/lime/sand; the brick on the right had a 1 : 3 cement/sand mortar. Note the difference in adhesion. Both bricks were prepared at the same time and under identical conditions

strength may be seriously impaired if they are misused, as they tend to be.

It is, in fact, possible with plasticizers to produce workable mixes with unacceptably high sand:cement ratios, and hence very low strength. The Structural Ceramics Advisory Group for the British Ceramic Research Association took these factors into account in drawing up the model specification for load-bearing clay brickwork, and stated in a footnote that it was these reasons which led the committee to reject broadly the use of plasticizers although they recognized that air-entrained mixes have some advantages in their higher frost-resistance in early life. The specification strongly favours the use of cement/lime/sand mortars and thus confirms the claims made concerning the superior properties of lime-based mortars.

Further confirmation of the eminent suitability of cement/lime/sand mortars is contained in Building Research Station Digest no. 75, *Strength and stability of walls*, and Building Research Station Digest no. 58, *Mortars for pointing*. The former points out that 50% of the cement in a 1:3 cement/sand mortar can be replaced with lime and, although the mortar strength is reduced by 40%, the strength of the brickwork is reduced by only 4%. The Digest goes on to indicate the other desirable properties that the lime imparts to the finished work, such as improved resistance to cracking of the brickwork and less risk of efflorescence. Digest no. 58 also shows that lime-based mortars give brickwork with higher resistance to rain penetration than plasticized and masonry cement mortars.

Importance of bond

Mortar bond is an extremely important property and the accompanying illustrations show how tenaciously a lime-based mortar adheres to bricks compared to a cement/sand mortar.

Mortar bond was the subject of a very detailed research programme at the National Swedish Institute for Building Research. The report, published in 1967, contains a great deal of detail, but the following quotations from the conclusions are of interest:

(1) In order to obtain good adhesion to both absorbent and non-absorbent materials, a binder, consisting of hydrated lime and Portland cement, in which, to ensure satisfactory bond strength, the cement should not be less than 50% of the weight of the binder and the lime content should not be less than 25%, should be chosen.

(2) The mortar should not contain air-entraining agents which, as a rule, reduce the tensile bond strength.

There is no doubt that, for quality work with the best weather resistance that will require the minimum of maintenance, lime is an essential ingredient of mortar and cannot be replaced by plasticizers.

Other advantages

There are other important advantages of lime-based mortars which have not yet been mentioned. For example, they can be produced in a wide range of colours by the addition of suitable pigments and the ready-mixed lime/sand mortar manufacturers are finding that this has considerable appeal for the architect. The ready-mixed producers are in an ideal situation to meet this requirement; with the facilities they have for the careful control of composition they can ensure matching of colours within reasonable limits over an extended period.

As already mentioned, the strength of mortars, as determined by cube tests, does not relate at all closely to the strength of brickwork in which they are used. Further confirmation of this was contained in a most interesting paper entitled 'The effect of mortars on the strength of brick cubes' presented recently to the Second International Brick Masonry Conference by Hoath, Lee and Renton. In this paper it was shown that a 1:1:6 cement/lime/sand mortar which, as a mortar cube, gave a compressive strength at 28 days of only 680 lb/in² could be used to produce brick cubes having strengths ranging up to 2,770 lb/in² depending upon the brick used.

In all cases 1:1:6 cement/lime/sand mortar gave brick cubes of higher 7- and 28-day strengths than the plasticized and masonry cement mortars.

A British Standard has recently been published—BS 4551—on *Methods of testing for mortars and specifications for mortar testing sand*. A specification for ready-mixed lime/sand for mortars is also in an advanced stage of preparation. This indicates that knowledge in this field is advancing at a faster pace than hitherto, and the importance of mortar quality is now recognized.

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A DIALOGUE ON LIME IN MORTARS

In the December 1970 issue an article was published entitled 'The use of lime in mortars' by J. Vernon. Since then a contribution has been received from Gullhögens Bruk, a cement factory in Sweden, concerning a new type of masonry cement, with comments on the original article

Contribution from Sweden

As Mr Vernon quite rightly remarks, modern building technique requires a considerably higher working pace, and it is also correct that the durability of lime mortar is unsatisfactory. This is quite in accord with Swedish building technical opinion.

The author gives the amazing information, received from a market investigation in 1970, that in the UK cement–sand mixtures are, to a great extent, used as mortars without additives of any kind. To a Swedish building engineer it is a puzzle that English bricklayers can produce an acceptable masonry at all with such mortars. The market investigation also revealed that most architects specified cement–lime–sand mixtures as mortars, but that obviously the architects in many cases had permitted alternative materials. As a principle it is not wrong, but unfortunately the author has classified cement mortar or lime cement mortar, with addition of air-entraining agents on the site, in the same category as modern prefabricated masonry cement binding agents.

In modern masonry cement manufacture, where specific process technique and specific agents, inorganic as well as organic, are used in an extremely accurate industrial production process, binding agents are produced which give improved mortar properties and considerably lower mortar prices than earlier.

Qualities of the fresh mortars, such as water separation, workability, the ability to stick together and scouring in plastering work, and qualities of the hardened mortars such as frost resistance, strength, adhesion, water absorption diffusion through the mortar etc., can today with modern industrial techniques be directed to the level that the builder requires.

Mr Vernon puts forward the suggestion that masonry cement mortar could not give satisfactory adhesive strength, compressive strength and water absorption ability. This statement is not, at any rate, applicable to the Swedish masonry cement, Gullex ABCD, produced by the cement works, AB Gullhögens Bruk.

In order to illustrate the statement of the author concerning the three properties — bonding strength, compressive strength and water absorption ability — an investigation carried out at an official testing laboratory in 1967 will be described. Results from this investigation have formed the basis for the decision of the Swedish state authority concerning masonry requirements. As binding agents in this investigation partly lime and partly masonry cement Gullex ABCD, were used, the latter produced in accordance with patented methods. The English patents which concern this product are nos 1,144,024 and 1,145,239. The investigation was carried out by Mr Vithold Saretok, chief engineer at Chalmers Testing Institute in Sweden.

Experimental results

The results of the experiment are summarized in tables 1 and 2 and the photographs (figs 1–8) show water penetration through the back of the walls after a period of 6h in heavy rain at the pressure of 75mm water column.

For the investigation of the water absorption ability and the adhesion brick walls 12,5 × 50 × 100cm with full joints were erected. The walls were built with a brick quality with suction in accordance with the figures in table 1. After two months the walls were tested in a rain machine, in which they were exposed to about 0.5l of water per minute at the pressure of 75mm water column, corresponding to 6h heavy rain. The weight increase of the walls was a measurement of the water absorption. In order to better observe the water penetration, the backs of the walls were white-washed, as the photographs show.

After drying, the adhesion was determined by a bending test of the walls. The compressive strength of the mortar was determined by testing according to the Swedish norms for binding agents.

Commentary

It is important to emphasize that when choosing a mortar quality this quality has to be related strictly to the brick quality. A brick with a low water suction requires a high masonry cement quality and, vice versa, a brick with a high water suction requires a low masonry cement quality. Thus, the material components of the masonry are made to work together. This results in a masonry which has a high resistance to heavy rain, as is shown by the photographs and the

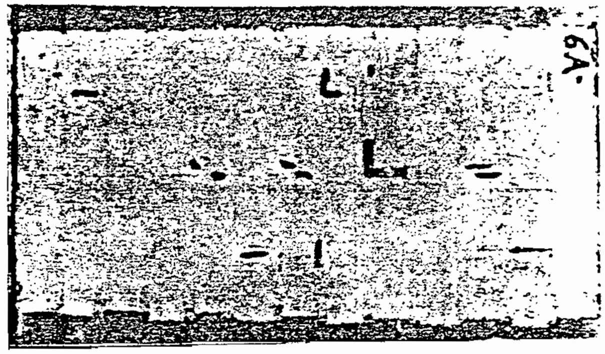

FIG. 1 Masonry cement 100/350 (*A*)

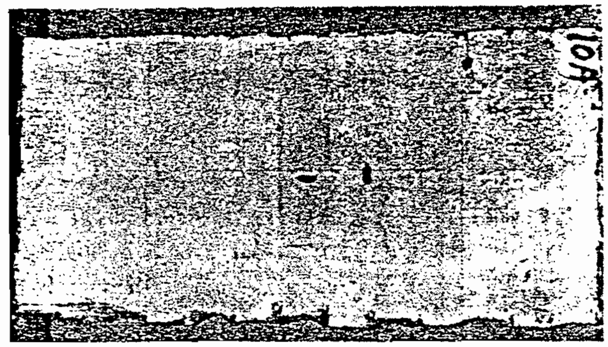

FIG. 2 Lime cement 10/90/450 (*A*)

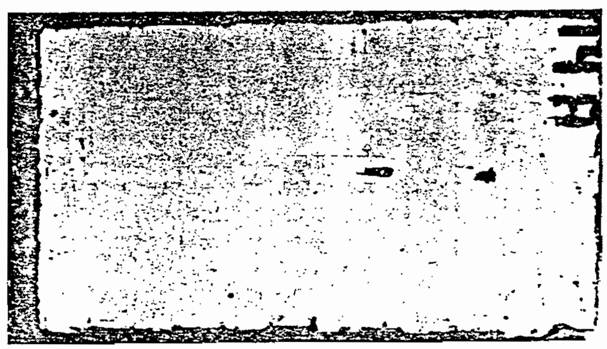

FIG. 3 Masonry cement 100/600 (*B*)

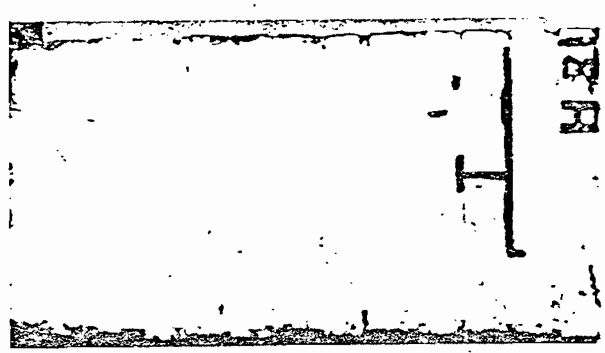

FIG. 4 Lime cement 35/65/550 (*B*)

FIG. 5 Masonry cement 100/900 (*C*)

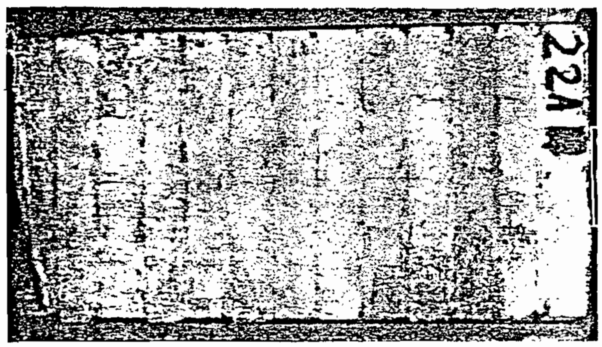

FIG. 6 Lime cement 50/50/650 (*C*)

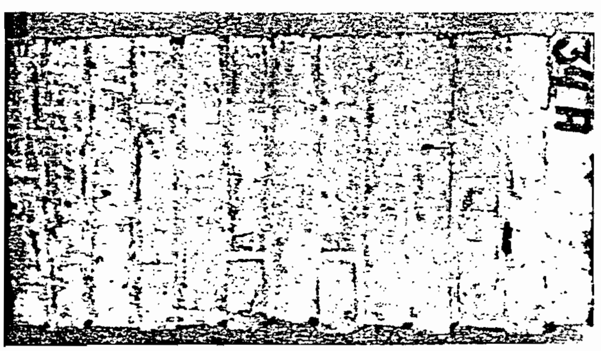

FIG. 7 Masonry cement 100/1,100 (*D*)

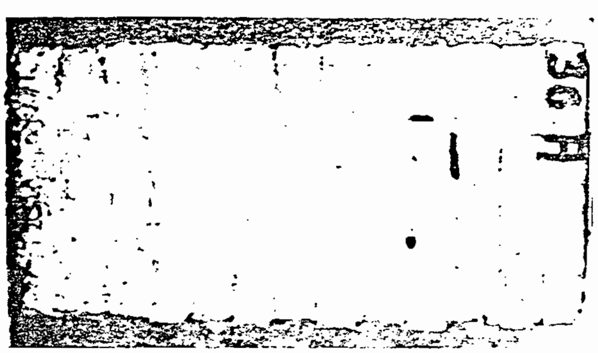

FIG. 8 Lime cement 50/50/950 (*D*)

TABLE 1 Extract from the results of an official Swedish testing laboratory

Brick suction, g water/min	*Mortar quality* (Swedish nomenclature)	*Mortar mixture,* kg	*Consistency,* Mo	*Air content,* %
12	A	Gullex ABCD 100/300	20	19
12	A	Gx 100/350	20	24
12	A	KC 10/90/450	20	14
51	B	Gx 100/600	19	27
51	B	KC 35/65/550	20	17
139	C	KC 50/50/650	20	18
139	C	Gx 100/900	19	24
139	D	KC 50/50/950	20	20
139	D	Gx 100/1,100	19	23

TABLE 2 Extract from a report of an official Swedish testing laboratory

Relation of water-binding agent	*Water separation*	*Bond stressing,* kp/cm²	*Compressive strength,* 28 days,kp/cm²	*Water absorption of masonry,* kg water
0·47	1·4	10·2	226	1·4
0·51	0·5	7·8	147	1·7
0·65	2·3	10·8	196	3·0
0·73	1·3	1·3	72	13·7
0·84	2·1	2·1	81	12·4
0·96	1·6	1·4	44	17·2
1·01	1·7	0·5	49	18·8
1·28	1·8	1·7	21	17·7
1·27	2·2	2·0	36	19·4

measured water absorption ability. No difference exists in quality, in this respect, between a masonry cement and a lime cement mortar.

As regards the compressive strength, there is no difference for high-quality mortars, while for mortar quality *C* and *D* a masonry cement mortar gives a higher compressive strength and, therefore, should take higher loads. Mortar quality *C* is in Sweden, and probably in England too, the most common mortar quality.

Regarding the adhesive strength, it can be noted that, in the highest mortar class with low-soaking brick, adhesive strengths are obtained to the extent of 8–10kp/cm², while in the remaining classes, *B*, *C* and *D*, it becomes 1–2kp/cm². No difference between a masonry cement mortar and a lime cement mortar can be found. At an adhesion of 1–2kp, it can be seen from the photographs that the masonries are waterproof in spite of the considerable heavy rain during the investigation.

If higher adhesive strengths are required, such as 20–25kp/cm², together with a high brick quality — which can be the case when producing brick elements with a span width of 5–6m — this is no problem either when using a modern masonry cement.

The report from the National Swedish Institute for Building Research, referred to by Mr Vernon, has been criticized in written form by research scientists at AB Gullhögens Bruk, for two main reasons. First, this report does not show any balance at all between the number of experiments on lime and lime cement on the one hand and masonry cement on the other. Only a few tests concern masonry cement, and the small number of tests shows no unmistakeable trend of inferior results as compared to lime cement. Secondly, the conclusion is incorrect that the air content in a mortar necessarily must give too low an adhesive strength; compare table 1, mortar class *A*, with 20% air in the mortars and an adhesive strength of about 10kp/cm². It is commercially important to note the possibility of mixing the masonry cement with larger quantities of sand than when using lime cement.

The most common mortar class *KC* 50/50/650kg (volume of binding agent/sand 1 : 4) is classified in the same category as Gullex 100/900kg (volume 1 : 7). As 100kg lime cement, containing 50kg lime and 50kg cement, is probably more expensive than 100kg of masonry cement, the price of the masonry cement to the builder will be considerably lower and will also be a lot better from the mason's point of view.

Reply from Mr J. Vernon

The discussion on my article, submitted by Gullhögens of Sweden, is most interesting.

As indicated in the original article, we were surprised to find that so much cement–sand mortar without lime or other plasticizing agent is used in this country. Gullhögens emphasize the matter by saying that they are puzzled that acceptable masonry can be made with such mortars.

We would agree that masonry cements are less prone to misuse than liquid plasticizers added on site. Nevertheless, it should always be remembered that masonry cements do contain substantial quantities of inert filler which, apart from the advantage of improving the plastic properties of the mortar to some extent, plays no further part in the hardening of the mortar. With lime in the mix, a chemical reaction takes place between this and the carbon dioxide in the atmosphere which gives increasing strength to the mortar and helps to ensure a satisfactory, weather-resistant and enduring bond between the masonry units.

It was not stated in the original article that masonry cement could not give satisfactory adhesive strength etc. However, it was pointed out that the Building Research Station in this country have indicated in Digest no. 58 that mortars containing masonry cement give less resistance to rain penetration than mortars containing lime. We also quoted from the report of National Swedish Institute for Building Research which gave limits for the proportions of cement and hydrated lime in mortars in order to obtain the best adhesive properties. The same report indicated that air-entraining agents, which are included in masonry cements, should not be added to the mortar since they generally reduce tensile bond strength. We note that Gullhögens have been critical of this report but, as a national research institute, we considered their conclusions worth mentioning.

Gullhögens conclude from the compressive strength tests they have quoted that higher loads ought to be accepted when using masonry cement. We would have to question this if the compressive test results on which they are basing the conclusion were carried out on mortar cubes. In fact, the paper by Hoath, Lee and Renton, referred to in the original article, showed quite clearly that, although mortar cubes made from 1 part masonry cement and 4½ parts sand, by volume, had significantly higher strengths than cubes made from 1 : 1 : 6 cement : lime : sand, by volume, the position was reversed when brick cubes containing the mortars were tested. The difficulty here is that it is almost impossible to develop a laboratory test for mortar cube tests that will relate closely to practical conditions and the testing of brick cubes or pillars containing the different mortars would seem to be more relevant.

LETTER TO EDITOR

LIME IN MORTARS

Sir,—The discussion in your June 1971 issue concerning lime in mortars mentions the paper produced following a programme carried out at my company's R&D laboratory at Gerrards Cross, which we presented at the Second International Brick Masonry Conference at Keele University in April 1970, and it may be of further interest for me to explain our work.

I requested the programme originally as I could not accept the principle of crushing cubes of mortar as a test of brickwork performance, which was being advanced by a committee of the British Standards Institution. If this principle were to be pursued we should end up with all our bricks laid in strong cement-sand mortars which can very easily be shown to give defective walls, particularly if calcium silicate bricks are used.

The programme only dealt with 9in cubes of bricks and mortar, tested in conjunction with 4in cubes of mortar, and covering mortars of various compositions including the ones now under discussion. We are at present negotiating with the Brick Development Association and the British Ceramic Research Association to extend the programme to 6ft and 8ft wall sections in order to make our earlier results quite conclusive. Before putting forward my opinions on the reasons for our results, I should like to give two tables extracted from our paper, to illustrate what we discovered.

Clay bricks having an average compressive strength of 4,750 lbf/in²

Mortar grade	*Mortar mix by volume* (C:L:S)	*Mortar compressive strength (lbf/in²)* 7-day	28-day	*Cube compressive strength (lbf/in²)* 7-day	28-day
I	1:¼:3	2,220	2,590	1,100	1,290
II	1:½:4½	955	1,570	1,015	1,345
III	1:1:6	440	680	*1,060*	*1,235*
	1:1:6 plus plasticizer	450	645	855	950
	1:0:6 plus plasticizer	645	950	385	1,110
	1:0:4½ masonry cement	770	875	740	945
IV	1:2:9	180	245	635	660

Calcium silicate bricks of an average compressive strength of 4,420 lbf/in²

Mortar grade	*Mortar mix by volume* (C:L:S)	*Mortar compressive strength (lbf/in²)* 7-day	28-day	*Cube compressive strength (lbf/in²)* 7-day	28-day
I	1:¼:3	2,370	2,830	1,980	2,230
II	1:½:4½	800	2,100	1,615	1,726
III	1:1:6	410	920	*1,935*	*1,980*
	1:1:6 plus plasticizer	400	750	1,350	1,410
	1:0:6 plus plasticizer	645	1,265	1,320	1,360
	1:0:4½ masonry cement	760	1,465	1,435	1,420
IV	1: 2: 9	180	325	*1,585*	*1,730*

It will not escape the eye of the interested technician that an addition of lime causes a beneficial effect which completely upsets the rather inexpert costing hinted at in the penultimate paragraph of the Swedish article. On this point I would suggest that the proportionately insignificant cost of mortar in any building precludes price variations being worthy of consideration when the questions of durability and performance are concerned. I am sure that the arguments of economy put forward at one time by plasticizer manufacturers in the UK have now been found so misleading as to cause them to be discontinued.

The reasons I think that cause the not altogether unexpected results arise from two factors:

(i) Friction (ii) Adhesion

A good lime putty allows a well graded sand to be used without loss of workability. With any amount of air entrainment (and too much of this can be detrimental), a soft small particle sized sand is a necessity to make a workable mortar with cement. Such a sand has little or no friction effect on the brick. We invariably use coarse sands probably conforming to BS 1199, which have a considerable friction effect in addition to certain other desirable qualities not immediately concerned with this discussion.

Lime, by reason of its water retentivity properties, provides a degree of adhesion unobtainable in cement mortars, which can very easily be shown in a simple experiment using two dry bricks and a mortar joint between them, as illustrated in the article by J. Vernon in your December 1970 issue.

From observation, particularly of wall sections, it is quite clear that the first action in brickwork failure is a lateral movement of one or more bricks, followed by spalling of the displaced units and then collapse. This friction effect, together with the mortar adhesion, resists lateral movement thereby giving the enhanced values. It has been exactly determined that the method of failure is as I have described it, but whilst various types of bricks have been tested with a standard mortar, I can find no report of a standard brick being tested with different mortars in a scientifically controlled programme. This is what I now propose to do.

This is, I think all I can add to the discussion at present, but I hope it will be sufficient to provoke the idea that mortar is entirely different from concrete in its function, subject to different influences and requiring different properties. Of these, strength and economy are to a degree less vital than workability, elasticity and durability. The discussion in your journal will have served an extremely useful purpose if these points are noted by even a small proportion of the people responsible for decisions on the type of mortar to be used in the construction industry.

Yours etc.,

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