



## A NEW TOTAL SHRINKAGE TEST FOR MORTAR

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### ABSTRACT

Mortar plays a vital role in the overall performance of masonry walls but one of the key performance parameters is never measured nor taken account of in design - that of 'total shrinkage'. In the past it was recognised that if mortars had a high drying shrinkage they could give problems especially if used as render mixes. If render is applied to a substrate and then suffers significant shrinkage it can craze or crack leading to durability and rain penetration problems. Unfortunately the standard test only measures drying shrinkage from when the mortar is hardened sufficiently to make a rigid test bar and this omits plastic shrinkage which occurs from the moment that the mortar is applied to a substrate such as render on a wall or mortar to a masonry unit. While it is accepted that some plastic shrinkage will be allowed for in load-bearing walls by consolidation of the work (downward shrinkage) as it is built, this process can not cope with all situations and leads to underperformance of bedding and pointing mortars. This led to the development of a, visually striking, test method for total shrinkage which has been used to study its effect on durability and bond but was found to be unsatisfactory for producing reliable quantitative data. The test described in this paper is a re-engineered version which has shown to give reproduceable, repeatable and quantitative behaviour. The initial evaluation trials, using mortars made with two sands and applied to two background materials, are described.

**Key words:** mortar plastic drying shrinkage test-method bond durability rain

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## INTRODUCTION

Mortar plays a vital role in the overall performance of masonry walls but one of the key performance parameters is never measured nor taken account of in design - that of 'total shrinkage'.

In the past it was recognised that if mortars had a high drying shrinkage they could give problems especially if used as render mixes. If render is applied to a substrate and then suffers significant shrinkage it can, at best, cause microcracks to form which reduce the durability and, at worst, visible crazing or cracking of the coating which allows rain penetration - see Figure 1. Unfortunately the standard test only measures drying shrinkage from when the mortar is hardened sufficiently to make a rigid test bar and this omits plastic shrinkage which occurs from the second that the mortar is applied to a substrate such as render on a wall or mortar to a masonry unit.



Figure 1. Typical shrinkage cracking of render.

While it is accepted that some plastic shrinkage will be allowed for in load-bearing walls by consolidation of the work (downward shrinkage) as it is built, this process can not cope with all situations. In renders where the backing will largely have dimensionally stabilised by the time the render is applied and thus excessive shrinkage is likely to cause cracks or latent cracks. Typical situations where high-shrinkage mortars cause problems are:

- 1 In flat bed joints where the units have a very high suction rate or a long period suction such that differential shrinkage develops between the mortar around the periphery which dries first and that in the centre of the joint. This can lead to

cracking of the bed mortar and retraction of the centre of the mortar bed from one or other unit (see Fig 2).

- 2 In cases of exceptionally rapid drying, where vertical cracks can run from the surface of the mortar beds.
- 3 In bed joints where where the units have a very high suction rate and one unit has a frog or large perforation, ie. a larger volume of mortar. This can lead to cracking of the bed mortar at the interface between the thin outer layer and thick inner layer and significant retraction of the centre of the mortar bed (see Fig 3).
- 4 In perpend (head) joints where the geometry is determined by the plan dimensions of the building and the restraints at returns and therefore any mortar shrinkage is converted to fine pores or cracks through the wall.
- 5 When repointing both bed and head joints in existing walls which have dimensionally stabilised.



Figure 2. Shrinkage cracking of mortar within a flat bed using sand 438



Figure 3. Differential shrinkage of the larger volume of shrinkable mortar in the frog of a semi-dry pressed brick causes debonding of the central area and retraction

All these mechanisms are likely to reduce bond of the mortar to the units, the durability of the work and resistance to rain.

In the context of the knowledge that some types of sands tended to lead to high shrinkage mortars and to bond and penetration problems, the BRE, supported by the UK DETR instituted a research programme some 10 years ago and some of the results have been reported by their authors.

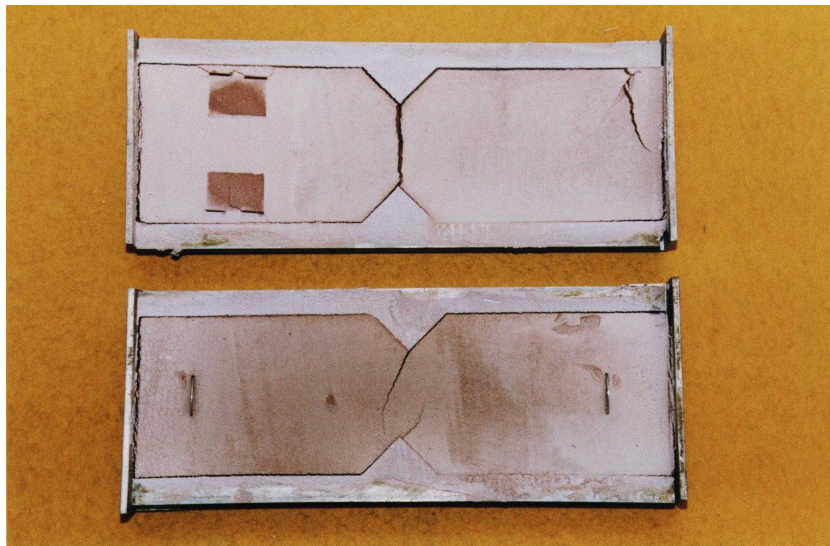


Figure 4. Trial evaluation of the rectangular mould design (with shrinkage markers)

Much work was done by teams at BRE, BCRL and Plymouth University ie. de Vekey et al (1990, 1994), and Haseltine et al (1994) to show that the bond of mortar to masonry

units was affected markedly by the type of sand used. Finer sands, especially where they had a significant clay content, appeared to result in mortars with poorer bond. More recently the work on bond was linked to work on rain penetration by de Vekey et al (1997).

As part of this programme but linked also to durability, Yool and Lees (1998) developed a prototype measuring device for total shrinkage, ie both plastic and drying shrinkage. This comprised a rectangular, open-based mould which allowed mortar to be cast in contact with a masonry unit surface. To allow easy detachment and reduced resistance to in-plane shrinkage while allowing moisture flow, two layers of surgical gauze were placed over the unit surface. To induce a measurable crack two V-shaped crack initiators were fixed either side of the middle of the mould. Further work was presented by Yool et al (1998).

This technique gave a spectacular visible indication of high shrinkage mortars, as illustrated by Figure 4, but because of a number of problems, ie. cracks forming at the end and side edges and randomly in the length of the mould and poor rigidity giving variable shape it was unsatisfactory for quantitative measurements. While most of these objections could be overcome by re-engineering this design it was felt that the concept was fundamentally flawed. This led to the idea of a much less complex specimen which would not crack but would have to be measured in some way to monitor shrinkage. The specimen chosen was a simple disk scaled to 100mm diameter to fit on a the bed face of a typical brick shaped unit. Accurately machining the disk from a very rigid material gives a very precise 'reference' starting size for the mortar specimen.

## **DESIGN AND EVALUATION OF THE NEW MOULD SHAPE**

The mould that was designed was:

- 1 circular, to encourage the drying shrinkage to occur uniformly and, hopefully, without any stress concentrations, or cracking;
- 2 100mm diameter - to allow moulds to be placed on a single European sized brick;
- 3 10mm thick - to replicate the height of a bedjoint;
- 4 made from brass - which is rigid, can be machined precisely and does not react with the mortar.
- 5 splittable in the form of two segments bolted together with locating pins to ensure accurate mating of the segments so that they be demoulded and cleaned readily.

It was conjectured that this mould would enable a better determination of the degree of shrinkage, as the sample is likely to shrink uniformly from the edge of the mould, allowing it to be measured with digital callipers as soon as it had hardened sufficiently to bear the force of the measuring process without deformation. In the early stages

several sets of measurements were taken to assure that the shrinkage was parallel, and that it would be sufficient to measure at only one set of points for each direction measured. The generation of this shrinkage crack can be seen in Figure 5.



Figure 5: A view of the new test mould complete with specimen

### **SHRINKAGE MEASUREMENT**

Having redesigned the test mould, it became necessary to reassess the method by which the shrinkage was measured.

Three methods of measurement were investigated: The use of a travelling microscope to track the movement of markers placed on the surface of a sample; The use of a camera to photograph any shrinkage and separation from the mould over a 24 hour period and/or the use of digital callipers to measure the diameter of the hardened mortar.

To aid the accuracy of the photographic record, two lines 140 mm apart were engraved on the surface of each of the moulds, to give a reference scale that would be visible when the photographic record was examined and make it possible to calculate the precise degree of enlargement (see Figure 5). This enabled an accurate determination of the mortar shrinkage to be made after the test from the photographs. To increase the accuracy of these measurements, all photographs were taken with slide film, allowing the slides to be projected and the tablets re-measured at any later date. Digital callipers used to measure the hardened mortar were accurate to 0.01mm.

### **EXPERIMENTAL ASSESSMENT OF THE NEW MOULD DESIGN**

All the tests were carried out with a designation (iii) 1:1:6 cement: lime: sand mix mortar, without any plasticising additives, mixed to a constant water to cement ratio of 2.5 :1 .

Two sands previously tested – and with known characteristics – were chosen for the tests. These sands were selected as a result of earlier unpublished work carried out at the BRE. The first sand – number 438 - had been shown to produce a mortar with a very high shrinkage rate; the second – number 431 – had been shown to produce a mortar with a low shrinkage rate. The grading curves and other characteristics are given in Table 1. The dry sieving method is a straightforward process on the oven-dried material as received. It tends to underestimate the fines content because much of the finer material, especially clays, tends to form larger-sized aggregates. The wet method overcomes this by first disseminating the sand in water and washing out the finest fraction followed by a wet or dry sieving of the remainder. The MBV measures the content of the more deleterious clay fractions by a dye-adsorption technique see Yool et al (1998).

For this initial evaluation two brick types were used. These were an extruded clay brick and a calcium silicate brick. For experimental convenience they each had at least one flat bed face. All the bricks used in the tests were oven dried at 80°C for 24 hours prior to testing so as to give all bricks a uniform moisture content at the start of each series of tests, but had been allowed to cool to room temperature before testing took place. Prior to the testing, all the bricks to be used in the test programme had their initial rate of suction measured, following the requirements of BS 3921. This allowed the bricks to be ranked by suction rate, and permitted matched sets of four bricks to be created - comprising of the same type of brick with similar initial rates of suction. The test programme was then carried out on these matched sets. The suction rate values are shown in Table 2, and ranged from 0.60 kg/m<sup>2</sup>/min to 1.6 kg/m<sup>2</sup>/min.

The technique used in making the specimens was essentially the same as use by Yool and Lees (1998). Two single layers of surgical gauze were tensioned lightly over the flat bed face of the brick and the moulds were laid on top (see Figure 6). A zero suction test could also be carried out by interposing a polythene sheet between the gauze and the brick surface (see Figure 7). The purpose of the gauze was to reduce the shear bond of the mortar to the surface thus allowing it to shrink with the minimum restraint, to allow a near normal moisture interaction between the mortar and the surface and to facilitate demoulding of the specimens for subsequent evaluation of long-term drying shrinkage.

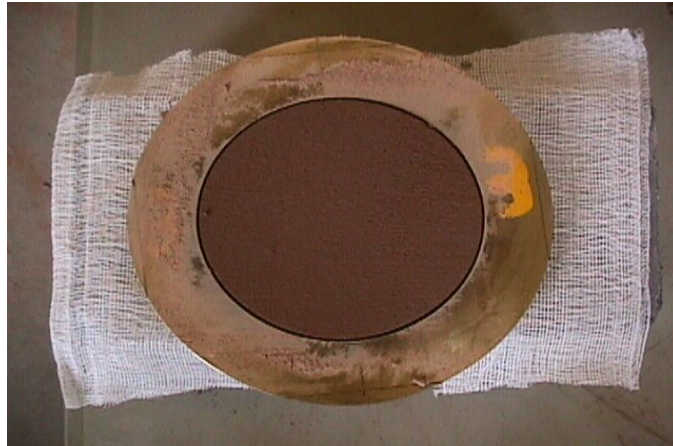


Figure 6: Test mould in place after filling with mortar

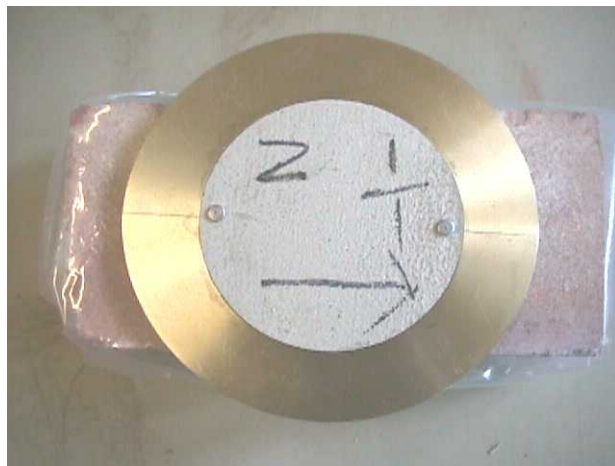


Figure 7: Demec pips in place on mortar to act as markers

The mortar was then placed in the mould and trowelled off flush with the top surface. The markers were placed on the surface of the mortar and the initial distance between the markers determined with a travelling microscope, as can be seen in Figure 7. Standard Demec measuring pips were used as markers, as they were readily available and the centre punched dot was a convenient point on which to align the travelling microscope's cross hairs. A photographic record was started simultaneously with these initial readings and photographs were taken at the following intervals: 5, 10, 15, 30 minutes, and 1, 2, 3, 4 and 24 hours. The photographic technique allows four replicates to be recorded at any one time, as opposed to just one with the microscope method.

Using the photographs, it is relatively simple to see if - and, if so, when - the sample has separated from the mould and by how much. This qualitative assessment can be cross-



checked quantitatively once the mortar is hard, by measuring the diameter of the circular specimens with the callipers to an accuracy of 0.01 mm.

## **RESULTS**

Each mortar specimen was removed from the mould after 24 hours and then measured in two directions, at 90° to each other. The average of these two readings was then calculated. The data can be seen in Table 2. Since the along versus across brick ratio may be significant, due to slight variations in orthotropic brick absorption properties, the difference has been calculated. This indicates that there are positive and negative differences for both sand types and brick types except the extruded brick with sand 431 suggesting that there is no bias. In addition, despite using mortars with a high shrinkage, none of the mortars showed any additional shrinkage cracks other than those at the edge of the mould.

In order to evaluate the results a three way analysis of variance was carried out using three variables each in two states and using the four brick samples as replicates: direction of measurement (along and across); brick type (CS and EC); sand type (431 and 438). The result, in Table 3, shows clearly that there is statistically no effect of direction of measurement but a clear effect of brick type and sand type and an interaction between them. A second three way analysis of variance was carried out but this time using the two measuring directions as replicates. In this analysis the four brick specimens were treated as a further variable with four states. This result indicates that despite the selection of bricks and near matching of the absorption characteristics, the individual bricks were significantly more different in behaviour than the two types. The sand again had a very clear effect .

As a result, it was concluded that the new mould had performed well and was very sensitive to the sand type which was the objective of the work. The measurements showed that the mortar shrinkage occurred predominantly within the first 24 hours - and in some cases within the first 8 hours - of a test.

The values of the specimen shrinkage obtained using the photographic technique, the travelling microscope and the callipers were found to be in very close agreement. However, the speed and ease of measurement was low with the microscope.

One possible criticism of the test is that the air surface, while completely appropriate to tests on rendering mortars, is much greater than that in a real mortar joint and that convective drying from this surface may have an undue influence on the result. Two possible ways suggest themselves for getting around this problem:

- make the joint only 5mm thick and place a layer of poly-ethylene sheet over the top such that the only drying will be via the brick pores and this models half a joint from its centre to the brick surface
- place the specimens in a 100% humidity chamber immediately after striking off so that moisture loss from the specimen surface is inhibited.

These techniques need evaluation in a future programme of optimisation of this test.

## CONCLUSIONS

- The mortar shrinkage test frames used by Yool and Lees, while allowing the degree of shrinkage to be easily assessed on a qualitative basis, made it difficult to obtain accurate quantitative results. As a result, a new circular brass mould was designed at BRE for trial use in the assessment of mortar shrinkage.
- Initial results reported here indicate that the test is capable of giving a reliable quantitative value for shrinkage of mortar both during the plastic stage and the subsequent drying stage timed from the point of contact between mortar and substrate.
- The use of the combination of a photographic record and measurements taken at 24 hours and subsequently with callipers was found to give an accurate assessment and be the most practical measuring technique for hydraulic cement mortars. The photographic method has the added advantage of automatically providing a permanent record of all the work carried out and would be very straightforward using a high resolution digital camera.
- The travelling microscope was equally accurate but too cumbersome and slow to keep pace with the test.
- Due to the simple nature of the test method and the high degree of reproducibility, this test may be suitable as a tool for assessing the suitability of repointing mortars and as a general test for initial shrinkage and dimensional stability of mortars and plasters.
- If it could be linked by a calibration programme it might also be a useful method for screening mortar-substrate combinations for bond behaviour.

This new technique offers the possibility of a new performance test for total shrinkage behaviour of mortars which is simple, rapid, economical and can take into account the characteristics of the mortar, the type of substrate and the air temperature / humidity condition for surface layers (eg. renders). If shown to be more representative, the test for masonry mortars could be carried out using a half-bed thickness layer and a moisture barrier over the top surface to emulate the middle of the joint.

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Table 1. Sieve analysis, methylene blue value (MBV) and bulk density of the test sands

Sieve	Sand 431		Sand 438	
	Dry method	Wet method	Dry method	Wet method
5mm	100	100	100	100
4mm	100	100	98	100
2.8mm	99	100	96	100
2.36mm	99	100	95	100
2mm	98	99	94	100
1.4mm	97	99	92	99
1.18mm	96	98	92	99
1mm	95	98	91	99
600µm	92	95	85	99
500µm	89	93	78	99
300µm	66	75	52	84
250µm	50	59	42	75
150µm	11	17	12	33
125µm	6	12	7	25
75µm	1	3.3	0.9	9
63µm	0.7	2.9	0.7	7.4
MBV	2.39		4.96	
Dry bulk density	1480		1320	

Table 2. Mean results of brick suction and mortar behaviour in the new ring test

Mould No.	Brick Type	Brick IRS kg/m <sup>2</sup> /min	Sand Shrink-age Level	Diameter after shrinkage - mm and % of start dia.		Average shrinkage		Difference between along and across value	
				Along †	Across ‡	mm &%	CV%	mm	%
1	CS	0.63	High	98.15	97.97	1.94	6.19	+0.18	9.28
2	CS	0.72	High	97.91	97.94	2.08	0.96	-0.03	-1.45
3	CS	0.70	High	98.60	98.00	1.70	24.7	+0.6	35.29
4	CS	0.67	High	98.17	97.93	1.95	8.21	+0.24	12.31
1	EC	1.53	High	97.45	97.37	2.59	1.93	+0.08	3.09
2	EC	1.56	High	98.29	98.27	1.72	0.58	+0.02	1.16
3	EC	1.60	High	97.15	97.58	2.63	11.39	-0.43	-16.32
4	EC	1.50	High	97.82	97.70	2.24	7.31	+0.12	5.36
Average values for high shrinkage sand				97.94	97.85	2.11	-	+0.10	+4.63
1	CS	0.63	Low	98.72	98.80	1.24	4.03	-0.08	-6.45
2	CS	0.72	Low	99.05	99.03	0.96	1.04	+0.02	2.08
3	CS	0.70	Low	98.92	98.75	1.16	10.30	+0.17	14.59
4	CS	0.67	Low	98.86	99.09	1.03	15.61	-0.23	-22.44
1	EC	1.53	Low	99.14	99.19	0.84	4.79	-0.05	-5.99
2	EC	1.56	Low	99.30	99.42	0.64	12.50	-0.12	-18.75
3	EC	1.60	Low	99.20	99.28	0.76	7.89	-0.08	-10.53
4	EC	1.50	Low	99.21	99.28	0.75	6.62	-0.07	-9.27
Average values for low shrinkage sand				99.05	99.10	0.92	-	-0.05	-5.96
Average values for both sand types						1.51		+0.02	+1.40

† Diameter measured parallel with the long face of the brick ‡ Diameter measured normal to the long face of the brick

Table 3. Results of analysis of variance for two main variables and measuring direction

Variable	F/ratio	Degrees of freedom	F crit.	Significance @ probability
Direction	0.088	1/24	4.26	Not significant
Brick type	8.98	1/24	4.26	Significant @ 99%
Sand type	162.6	1/24	4.26	Significant @ 99%
Direction v brick type	0.77	1/24	4.26	Not significant
Direction v sand type	0.8	1/24	4.26	Not significant
Brick v sand type	15.1	1/24	4.26	Significant @ 99.9%
Three way interaction	0.37	1/24	4.26	Not significant
Residual	15.1			

Table 4. Results of analysis of variance for two main variables and brick samples

Variable	F/ratio	Deg. of freedom	F crit	Significance @ probability
Sand type	439.4	1/16	4.26	Significant @ 99.9%
Individual brick	5.27	3/16	4.26	Significant @ 97.5%
Brick type	0.024	1/16	4.26	Not significant
Sand type v individual brick	0.26	1/16	4.26	Not significant
Sand v brick type	40.8	1/16	4.26	Significant @ 99.9%
Brick type v individual brick	5.25	3/16	4.26	Significant @ 97.5%
Three way interaction	7.33	1/16	4.26	Significant @ 99.9%
Residual				