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THE DEVELOPMENT OF A FREEZE THAW TEST FOR MORTAR

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Abstract
The panel freezing test is commonly used for assessing the freeze thaw resistance of clay bricks. This paper describes the use of the test to assess mortars used in panels made from frost resistant bricks. Twenty six panels in various mortars have been tested and panels on an exposure site have been monitored for two winters. The early results are consistent with our experience of use of these mortars in UK conditions.

Key Words
Freeze Thaw Testing, Mortar.

1 Introduction
A programme of work was developed to investigate the suitability of the UK accelerated freeze thaw test for clay bricks (1984, Peake et al) for assessing the durability of UK mortars and to relate performance to that on an exposure site.
The impact in the short term is the development of an industry based test method that will enable UK mortar producers to move from a prescriptive approach to freeze thaw resistance to a performance based approach. In the medium and longer term the impact will be the inclusion of the test as a requirement to satisfy the requirements of EN 998-2 the harmonised standard for Mortar for Masonry.

Background

The British Standard for Clay Bricks, BS3921 : 1985 classifies bricks into three categories in relation to their frost resistance, and the Code of Practice for the Use of Masonry gives extensive guidance on where bricks of each type may safely be used and what mortars are appropriate to use with them.
BS3921 refers to the BCRL (CERAM) Panel Freezing Test, which has been in use since 1972.

In 1979 an exposure site was established which was monitored over the next nine years and the performance of bricks during that period was compared with the performance in the Panel Freezing Test. It was concluded that for the 23 bricks tested there was a direct relationship between the performance under natural conditions and in the laboratory test (1988, Peake et al). It was concluded that bricks that withstood 100 freeze/thaw cycles in the test regime could be classified as frost resistant. The

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test requirement to distinguish between bricks of moderate and no frost resistance was not clear but it seemed that 10-15 cycles would be the appropriate one for further study (1997, P.i.T). Another study on a second site showed similar results.

In 1992 a contract was let to BCRL (CERAM) to co-ordinate a study based on tests for four procedures, namely:

a) DIN 52252 Part 1 Omni directional Freezing of Single Bricks and Part 4 Uni-directional Freezing of Test Walls.
b) BSI Draft for Public Comment : A Laboratory Test for assessing the resistance of clay bricks to freeze/thaw conditions.
c) AFNOR P13301 Hollow terracotta bricks and P13304 Facing Clay Bricks.
d) NEN 2872 Stony Building Materials – Determination of Frost Resistance – single sided freezing in a freshwater environment/NBN B 32-002 Facing Bricks.

The programme consisted of testing 16 different brick types from 8 countries in Europe and classifying them according to their frost resistance. The classification was based on that being developed in the draft European Standard the principle of which is that the manufacturer declares whether the bricks are suitable for use in severe (F2), moderate (F1) and passive (FO) environments.

The study (1997, Peake) focussed on distinguishing between frost resistant bricks ie suitable for use in a severe environment (F2) and moderately/non frost resistant products ie suitable for use in moderate and passive environments (F1/FO). The UK test was the only one to achieve 100% compliance with the manufacturers declaration and it was agreed that it should form the basis of the draft single test method. The classification system closely mirrors that in BS 3921.

2 Programme Of Work On Mortars

Brickwork panels were built in the laboratory using mortar mixes selected to cover the most typical of those currently in use in the UK. The mortar/brick combinations are given in Table 1. These were designed to be built for long term natural exposure and a smaller panel for the laboratory accelerated weathering test. It was decided not to test combinations that were unlikely to fail and those not in common use. The laboratory testing approach has been used previously for North American Mortars (1999, Edgell et al).

2.1 Test Panels

The majority of panels were ten courses, three bricks wide and built in blue engineering brick using a standard type G sand (BS 1200), however one of each of the designated cement:lime:sand mixes were repeated using a more porous soft mud solid brick. The mixes used are given in Table 1. Unfortunately, six of the original specimens (specimens 17-22 inclusive) were found to contain higher levels of retarder than in a typical mix. These have been repeated (specimens 23-28) in the laboratory and at the exposure site.

2.2 Mortars and Bricks

The samples were prepared using a standardised mixing procedure. Mortar properties tested in the laboratory included air content, flow, dropping ball and compressive strength.

The bricks were also tested in the laboratory to BS 3921:1985 for Initial Rate of suction, water absorption after a 5 hour boil and compressive strength.

2.3 Accelerated Panel freezing test

Prior to testing a panel is immersed in water for 7 days. It is then installing in the freeze/thaw apparatus, which subjects one face of the panel to repeated cycles of freezing and thawing. The remaining face and sides of the panel are insulated with 25mm thick extruded polystyrene foam board.

2.4 Exposure site testing

The exposure site panels as described in Table 1 have been constructed on steel bases in the laboratory. Each panel consisted of 12 courses of 4 bricks in half bond and was 215mm wide with a brickwork soldier coping. The first three courses of all the specimens were constructed using a 1:3 sand cement mix with blue engineering bricks as a damp proof course. The panels were left to cure for at least 28 days after which time demec points were fixed to both faces of the wall including the coping to monitor movement on site. The panels were then clamped for transportation to the exposure site. Figure 1 shows the exposure site at Dove Holes quarry, Buxton.

At the exposure site the panels were positioned about 1m apart in rows about 2m apart with their main face facing North.

In the early work on clay bricks the exposure trials related number of air frosts to the number of laboratory cycles to in each case cause failure. In this study this criterion will be used but in addition the freezing index which is based upon number of air frosts and amounts of rainfall will also be investigated as a parameter to measure the extent of frost loading. A weather station has been installed on the site to continually measure air and surface temperatures, rainfall, wind speed and wind direction.

The original 22 specimens have now been exposed to two winters at the Dove Holes site, beginning October 2001. The 6 repeated specimens were built in October 2002 and have therefore only had one winter at the exposure site.

Figure 1 : Exposure site at Doveholes

Table 1: Mortars used in the construction of panels for laboratory testing and exposure site panel testing

Morta r Mix No.	Date Made	Mortar Type	Des-ignation	Brick Type	Plasticise r Type	Sand Type	Comments
1	24/09/01	CLS	ii	Engineering		Cheadle Sand	
2	25/09/01	CLS	iii	Engineering		Cheadle Sand	
3	25/09/01	CLS	iv	Engineering		Cheadle Sand	
4	25/09/01	CLS	v	Engineering		Cheadle Sand	
5	26/09/01	CS+P	ii	Engineering	Sealomix	Cheadle Sand	
6	26/09/01	CS+P	iii	Engineering	Sealomix	Cheadle Sand	
7	28/09/01	CS+P	iv	Engineering	Sealomix	Cheadle Sand	
8	26/09/01	CS+P	v	Engineering	Sealomix	Cheadle Sand	
9	27/09/01	CLS	ii	Soft Mud		Cheadle Sand	
10	28/09/01	CLS	iii	Soft Mud		Cheadle Sand	
11	28/09/01	CLS	iv	Soft Mud		Cheadle Sand	
12	28/09/01	CLS	v	Soft Mud		Cheadle Sand	
13	10/10/01	Masonry CS	iii	Engineering		Cheadle Sand	
14	05/10/01	CLS	iv	Engineering		Yellow Sand	
15	23/10/01	CLS	iv	Engineering		Meriden Sand	
16	12/10/01	CS+P	iii	Engineering	Topair	Cheadle Sand	
17	09/10/01	Retarded CLS	iii	Engineering		Cheadle Sand	day of mixing
18	10/10/01	Retarded CLS	iii	Engineering		Cheadle Sand	24hrs after mixing
19	11/10/01	Retarded CLS	iii	Engineering		Cheadle Sand	48hrs after mixing
20	10/10/01	Retarded CLS	iv	Engineering		Cheadle Sand	day of mixing
21	11/10/01	Retarded CLS	iv	Engineering		Cheadle Sand	24hrs after mixing
22	12/10/01	Retarded CLS	iv	Engineering		Cheadle Sand	48hrs after mixing
23	20/11/02	Retarded CLS	iii	Engineering		Cheadle Sand	day of mixing
24	21/11/02	Retarded CLS	iii	Engineering		Cheadle Sand	24hrs after mixing
25	22/11/02	Retarded CLS	iii	Engineering		Cheadle Sand	48hrs after mixing
26	20/11/02	Retarded CLS	iv	Engineering		Cheadle Sand	day of mixing

27	21/11/02	Retarded CLS	iv	Engineering	Cheadle Sand	24hrs after mixing
28	22/11/02	Retarded CLS	iv	Engineering	Cheadle Sand	48hrs after mixing

NOTE: CLS – cement:lime:sand CS+P= cement:sand+plasticiser

3 Results

Table 2 gives a summary of the results where some damage occurred in the laboratory accelerated panel freezing test and Table 3 a summary of the results observed at the exposure site where some damage occurred.

Table 2: Results of Laboratory Tests of mortars

N.D = No damage

Mortar Mix No.	Lab pre-50 cycles	Lab 50 cycles	Lab 100 cycles	Lab 150 cycles	Lab 200 cycles
3	Deep widespread damage (30 cycles)	More damage, panel unstable, test stopped			
4	Widespread damage (10 cycles), severe damage (30 cycles)	More damage, panel unstable, test stopped			
11	Light surface damage (35 cycles)	4-5 perpends with light surface damage	Little change, test stopped		
12	Light surface damage (15 cycles)	Widespread surface damage concentrated at bottom of panel	Little change, test stopped		
14	Light surface damage (20 cycles), widespread damage (30 cycles), severe damage (40 cycles)	More damage, panel unstable, test stopped			
15	No Damage after 40 cycles	2 perpends flaking	Light surface damage	Little change test stopped	
16	ND	ND	I perpend showing surface loss	Damage to perpend deepening, light damage to other perpends	As 150 cycles
21	Light surface damage (10 cycles)	Widespread light surface damage	Widespread light surface damage	Little change test stopped	
22	Light surface	More damage, panel			

Mortar Mix No.	Lab pre-50 cycles	Lab 50 cycles	Lab 100 cycles	Lab 150 cycles	Lab 200 cycles
	damage (10 cycles) severe damage (35 cycles)	unstable, test stopped			

Table 3: Results of Exposure Site Panel tests on mortars

Mortar Mix No.	Field after 1 winter	Field after 2 winters
11	ND	ND
12	First signs of spalling on 2 perpend joints (N face)	No worsening of spalling
14	ND	Light surface damage
22	Widespread surface spalling on left hand side of north pace perpends, first signs of light spalling on coping and south face	slight deterioration
28	ND	ND

Table 4 provides a summary of the laboratory tests carried out on the mortars as mixed and used in the panel tests. Table 5 gives details of the results of the tests carried out on the two different types of bricks.

Table 4: Results of Laboratory Mortar Test Work

Mix No.	Date sampled	Air content (%)	Ball Drop	Flow	Cube Strength (N/mm²)
1	25/09/01	7.0	11.6	135	5.07
2	26/09/01	5.3	9.5	133	2.91
3	26/09/01	5.2	10.8	134	1.01
4	26/09/01	5.1	10.2	137	0.51
5	27/09/01	19.5	9.5	126	9.58
6	27/09/01	17.0	11.4	128	3.78
7	27/09/01	17.0	12.5	135	1.79
8	27/09/01	17.0	12.1	132	1.88
9	28/09/01	7.7	12.4	137	4.62
10	29/09/01	3.5	14.0	138	3.23
11	29/09/01	5.4	13.2	137	1.08
12	29/09/01	5.1	12.4	135	0.57
13	01/10/01	12.5	9.6	136	4.89
14	05/10/01	5.2	9.6	126	1.38
15	23/10/01	7.8	10.0	130	1.93
16	12/10/01	25.0	10.7	125	1.76
17	09/10/01	21.5	9.7	125	5.18
18	10/10/01	18.0	9.8	124	3.91
19	11/10/01	16.5	10.4	126	1.57
20	10/10/01	19.0	9.0	124	1.85
21	11/10/01	15.5	9.8	125	0.36
22	12/01/01	12.0	9.5	127	0.19

Table 5: Results of Laboratory Brick Test Work

Brick Type	Initial Rate of Suction (kg/m^2/min)	Water Absorption 5 hr Boil (%)	Compressive Strength (N/mm^2)
Blue Solid Engineering	0.11	4.8	104.1
Soft Mud	1.47	19.6	28.6

4 Comments

4.1 Laboratory Panels

All laboratory tests have now been completed.
Designation ii and iii cement:lime:sand mixes in blue engineering bricks were found to be fully frost resistant to 200 cycles. However the weaker mixes, designation iv and v showed significant failure after 30 cycles. The equivalent mixes in soft mud bricks also only showed failure in the weaker designations but this occurred much later in the freeze thaw regime i.e. minor failure at 50 cycles and more widespread failure after 100 cycles. The samples prepared using cement:sand and plasticiser were all found to be fully frost resistant to 200 cycles. However the designation iii mortar using a different plasticiser showed slight damage after 100 freeze-thaw cycles. The samples using the alternative sands at designation iv both showed significant progressive failure after 50 cycles. The masonry cement designation iii was found to be fully frost resistant.

4.2 Exposure Site Panels

The exposure site at Dove Holes is examined on a monthly basis and after one winter (October 2001 – March 2002) damage was only recorded on two of the 22 panels. Light spalling was noted on the designation iv cement:lime:sand mortar with soft mud brick. This was mainly on the North face and on perpend joints.

More widespread damage was noted on the retarded ready-mix designation v mortar with retempering after 48 hours. However, this mix was found to contain too much retarder. The repeat mix was not put on site until the following winter.

After two winters (to March 2003) no worsening of damage to the designation iv cement:lime:sand mortar with soft mud brick was found, and the repeated retarded ready-mix designation v mortar with retempering after 48 hours was found to have suffered no damage (after one complete winter), although the original specimen continued to deteriorate.

In addition, the panel made in designation iii cement:lime:sand in blue engineering brick had blown over in strong winds and was irreparable. Light surface damage was noted on the designation iv mix using the Yellow sand, although no damage was noted on the Meriden sand.

Demec results continue to be monitored but are currently inconclusive.

4.3 Mortars and bricks

The original intention was that all of the samples would be mixed to a standard consistence using the dropping ball method. However as is clear from Table 4 the

range in dropping ball value does vary in order to produce mixes that for the varying constituents and designations were easy to use.

The designation ii mortars were found to have the highest cube strength of approx 5 N/mm^2 for the cement:lime:sand mixes, and 9.62 N/mm^2 for the cement:sand + plasticiser. The air content was also much higher in the plasticised mix at 19.5% as opposed to 7.5% for the other mixes. This in turn led to a much lower flow rate of 126 compared to 136.

The designation iii mixes all had cube strengths of approx 3 N/mm^2 apart from the masonry cement mix which had a strength of 5 N/mm^2. The plasticised mixes also had higher air contents and lower flow. As expected, the retarded mixes had lower cube strengths the longer they were retempered.

Designation iv mixes all had low cube strengths of around 1 N/mm^2 and there was no appreciable difference between the retarded mixes. The plasticised mixes again had the highest air content but the retarded mixes had the lowest flow.

Designation v mixes had compressive cube strengths of lower than 1 N/mm^2 apart from the mix containing plasticiser which had a strength of 1.88 N/mm^2 and an air content of 17% compared to 5% for the cement:lime:sand mixes.

4.4 Weather Station

The purpose of the weather information is to assess the severity of the conditions of the exposure site. Winters 2001-2002 and 2002-2003 have been found to be milder than usual over the last 50 years but Buxton does have particularly extreme weather, with much wetter and colder winters than the majority of Britain. Only the extreme North of Scotland appears to have more severe winter conditions.

5 Summary And Further Work

Table 6 provides a summary of the specimens which were deemed to have suffered some form of failure either in the laboratory or at the exposure site.

Table 6: Summary of mortar failures

Mortar Mix No.	Designation	Lab pre-50 cycles	Lab 50 cycles	Lab 100 cycles	Field after 1 winter	Field after 2 winters
3	iv	Deep widespread damage (30 cycles)	More damage, panel unstable, test stopped			
4	v	Widespread damage (10 cycles), severe damage (30 cycles)	More damage, panel unstable, test stopped			
11	iv	Light surface damage (35 cycles)	4-5 perpends with light	Little change, test stopped		

Mortar Mix No.	Designation	Lab pre-50 cycles	Lab 50 cycles	Lab 100 cycles	Field after 1 winter	Field after 2 winters
			surface damage			
12	v	Light surface damage (15 cycles)	Widespread surface damage concentrated at bottom of panel	Little change, test stopped	First signs of spalling on 2 perpend joints (N face)	No worsening of spalling
14	iv	Light surface damage (20 cycles), widespread damage (30 cycles), severe damage (40 cycles)	More damage, panel unstable, test stopped			Light surface damage
15	iv	No damage after 40 cycles	2 perpends flaking	Light surface damage		
21	iv	Light surface damage (10 cycles)	Widespread light surface damage	Widespread light surface damage		
22	iv	Light surface damage (10 cycles) on several perpends, severe damage (35 cycles)	More damage, panel unstable, test stopped		Widespread surface spalling on left hand side of north pace perpends, first signs of light spalling on coping and south face	slight deterioration

The accelerated panel freezing tests appears to have identified the weaker mix designations as being those most likely to fail. Also those samples made with the alternative sands were also found to fail the test. Designation ii and iii mortars are much less likely to fail.

The exposure site test is not currently showing any significant difference between the mortar mixes. However, the panels have only been subjected to 2 winters which were not particularly harsh in comparison to previous winters.

It seems evident that the exposure site needs to be monitored for many more years to assess whether the accelerated laboratory test identified the true susceptibility of the mortars under natural conditions.

The initial indications are that the panel freezing test as described in prEN 772-22 (1999, CEN) could form the basis of the test suitable for distinguishing between mortars which are suitable for UK conditions and those which are less so.

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