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RILEM TECHNICAL COMMITTEES

RILEM TC 127-MS: TESTS FOR MASONRY MATERIALS AND STRUCTURES

Recommendations

Foreward:
The texts presented hereunder are drafts for general consideration. Comments should be sent to the Chairlady: Prof. Luigia Binda, Politecnico di Milano, Dipartimento di Ingegneria Strutturale, Piazza Leonardo da Vinci 32, I-20133 Milano, Italy. Fax: +39 2 23 99 4300; E-mail: binda@rachele.stru.polimi.it, by 31st July 1998.

MS-A.1 Determination of the resistance of wallettes against sulphates and chlorides

A.1.0 CONTENTS

A.1.1 SCOPE

This recommendation specifies a method of indicating the resistance of wallettes (representative samples of masonry) to damage caused by sulphates and chlorides. To ensure a representative number of mortar joints, the length of the units should not exceed 250 mm and their height should not exceed 100 mm. The test is only calibrated for solid units. It is an accelerated test because higher than normal sulphate and/or chloride concentrations are used in order to increase the stress ratios with time. A particular pattern and magnitude of stress cycles is provided in combination with moisture dynamics. The test is proposed to detect the durability (capability to prevent deterioration with time) of masonry which is exposed to moisture variations in a wall. This recommendation describes the sampling of the specimens, the conditioning before testing, the apparatus, the method of test, how to report the test results and, finally, the contents of the test report.

A.1.2 SPECIMENS (SIZE, SHAPE AND NUMBERS)

Wallettes shall be cut from larger panels or cores taken from existing masonry or made of masonry units and mortar as required for the purpose of testing. Since pointing mortars are sensitive to deterioration, the specimens shall be made as following normal site practice (composition, work and finishing). See also footnote Annex l.

Dimensions and shape

Normally, the thickness (depth) of the wallettes shall be the width of the units of which they are made. The exposed surface shall be approximately square with a minimum of 200×200 mm^2 and a maximum that is in accordance with the length of the applied masonry units, *e.g.* 250×250 mm^2. Cutting to size is allowed after the wallettes are made

and hardened. In that case, they shall contain at least two horizontal (bed joints) and one vertical joint (end joint, perpend, head joint). The four sides of the square wallette shall be plain (no mortar or plaster on the units).

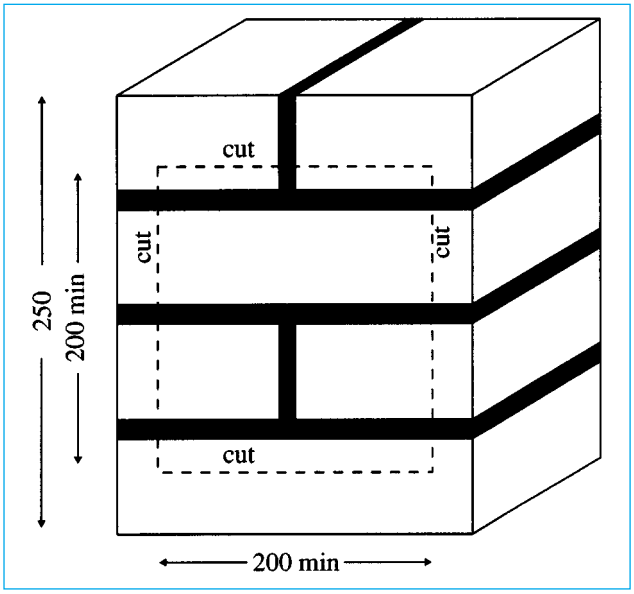


Fig. 1 – Example of a wallette (eventually cut to size).

Number of specimens

When randomly sampled, a minimum number of ten wallettes is required which contain in total at least three units (2 whole plus 2 halves cut out of one unit), *i.e.* 30 units. These randomly sampled units form a consignment which should be randomly divided into ten groups associated with ten wallettes.

In the case of selective sampling, the number depends on the purpose of the test. Generally it is preferable to sample in accordance with ISO 2859 and to interpret by the attributes method.

A.1.3 TEST LIQUIDS (water solutions)

Sodium sulphate shall be used for testing the resistance against sulphates (formation of mirabilite, decahydrate) and sodium chloride for testing the resistance against chlorides (disintegration of mortar). Both reagents shall be used at concentrations of 10% (m/m) anhydrous reagent dissolved in pure water. Other solutions in water may be used (from 0% up to saturated) if required for the purpose of the test.

A.1.4 PREPARATION OF SPECIMENS

The (hardened) wallettes shall be dried at 60 ± 5°C until constant mass has been reached. The weighing inaccuracy should be less than 0.25% of the dry mass. After cooling down to room temperature, the wallette shall be weighed again just before testing commences. This initial mass shall be recorded as M_0 [in grammes, rounded off to 10 g] .

A.1.5 APPARATUS

For each single wallette, a tank is needed made either of glass or of polymeric material, *e.g.* welded acrylic (perspex) sheet or other suitable chemically resistant materials. The tank shall be open at the top. The internal height of the container should be at least 50 mm or more than the thickness (depth) of the wallette to be tested. The bottom should be plane and square with a surface area of at least 1.7 times the surface area of a wallette. (*i.e.* the linear dimensions should be 1.3 times the dimensions of the finished wallette).

As an example, a wallette of 250 × 250 × 120 mm needs a container with approximately the following inner dimensions:

height: 120 + 50 = 170 mm
length and width: 1.3 x 250 = 325 mm

For a wallette 200 × 200 × 100 mm^2 (minimum size), the inner dimensions are 260 × 260 × 150 mm^2.

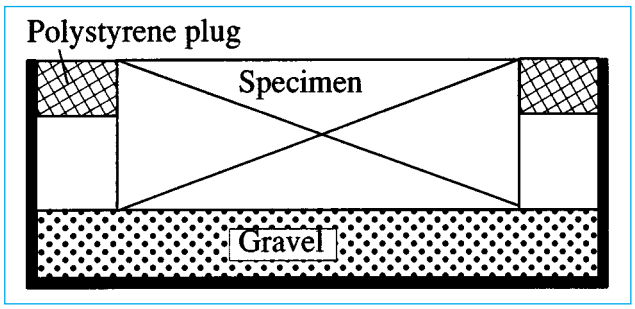


Fig.2 – Test container.

A.1.6 PROCEDURE

Each single wallette is placed onto the bottom of its container (test face up). Then, the procedure is as follows:

1. The prepared test liquid (water solution) is fed into the container over a period of one minute until a level of 20 mm up from the bottom of the wallette is achieved. This moment is labelled as time zero (t = 0 hrs).
2. At t = 4 hrs, the test liquid level shall be restored to 20 mm height.
3. At t = 8 hrs, test liquid shall be added to bring the level up to 5 mm below the upper surface of the specimen. This upper surface shall not allowed to come into contact with free liquid.
4. At t = 24 hrs, the specimen is taken out of its container. After removal of free liquid from the sides and base of the specimen, the mass shall be determined as M_w [in grammes, rounded off to 10 g].
5. The container shall be emptied and partly filled with clean and dry gravel (grain size 24 mm) to a plane level such that the remaining distance to the top of the container is equal to the thickness of the wallette which is placed on the gravel. Then, the test face of the specimen is levelled with the top of the four container sides. In addition, the specimen shall be centered with its sides parallel to the sides of the container. The remaining open spaces at the top shall be closed by hard polystyrene foam

strips with a thickness of about 30 mm. Immediately thereafter, the containers shall be placed in a closed room that is weakly ventilated at 20°C and 50% R.H.
6. After a period of 4 weeks, the exposed surface of the wallette shall be photographed and any damage described. The wallette shall be weighed (= $M_{j.1}$); loose particles shall then be brushed from the surface and photographing and describing the damage, if any, shall be repeated. After this procedure, the mass is redetermined and recorded as $M_{j.2+1}$.
7. Demineralized water shall be added to the container to a level that reaches half the height (thickness) of the specimen. Then the exposure shall be continued for a period of 4 weeks.
8. The procedure described in 6 and 7 above is repeated every 4 weeks. The mass is recorded as $M_{j.1+k}$ where k = 2, 3, 4,… Experiments have shown that it can take months before the damage comes to an end.

A.1.7 TEST RESULTS

Record the following using the record of the successive photographs for each single wallette.

From step 7 of the testing procedure onwards, after each cycle of the testing procedure the test surface of each single wallette should be photographed if there has been any significant change. Record changes as follows:

1. Mortar:

– Loose particles which can be wiped off with a bare finger.
– Flaking that can be wiped off using a soft brush.
– Detachment from the units (cracks may be observed between mortar and masonry units).
– Convex swelling or concave shrinking of joints or other observable deformation.
– Bursting of the pointing mortar shown by cracks in the proper face (formation of swelling salts).
– Any other relevant damage.

2. Units:

– Efflorescence or other defacement.
– Detachment of surface layer (blistering, flaking, pitting, chipping and delamination, powdering).
– Disintegration.
– Cracking.
– Any other relevant damage.

The above damage shall be described and, in as far as possible, quantified or classified, step by step, supported by photographs or by video recording.

If it is required to have a judgement of whether the test has resulted in a failure (FAIL or NOT FAIL), then a standard reference photograph or drawing or set of reference photographs/drawings should be prepared illustrating each failure state that is relevant to the product under test.

A.1.8 TEST REPORT

1. A reference to this method.
2. A description of the wallettes.
3. The method of sampling the units.
4. The mortar composition, preparation method, working properties and the maturing conditions.
5. Known properties of the units, *e.g.* ultrasonic characteristics, water absorption, IRA, porosity, density and technological information of manufactured ware or origin of natural ware.
6. The date of preparation of the specimens (wallettes) and the date of the test.
7. All individual values measured during the testing procedure (first to final step).
8. Evaluation of the test results.
9. A statistical interpretation of two distinguished sets of test data.
10. A data table containing the number of units that failed versus the number of cycles or time. For instance, 1 unit at cycle No. 3, 4 units at cycle No. 5, 7 units at cycle No. 6, etc. What is meant by failure (damage) must be specified. Normally, it is a criterion for rejection or discarding. The observation after each cycle is therefore: failed or not-failed. The same table is made for the mortar joints. Two techniques for statistical interpretation are given in Annex 2 based on either the Chi-squared technique or on the KAPLAN-MEIER approach. A third option, the so-called Sign Test Method, may be used.

The photographs including the description, quantification or classification of damages at each cycle or moment in time shall be interpreted by comparison with relevant reference photographs or in a comparative way (other masonry with other specifications).

A.1.9 REFERENCES AND BIBLIOGRAPHY

[1] van der Klugt, L.J.A.R. and van Hees, R.P.J., 'The quality of masonry pointing', SBR/CUR-publication 299/93-03 (Annex G), Rotterdam, 1993 (in Dutch).
[2] Baronio, G., Binda, L. and Charola, A.E., 'Deterioration of bricks with and without perforations due to salt crystallization', Proc. 7th IBM^{2}AC, V1, 1985, p 223.

ANNEX MS-A.1-1 ALTERNATIVE SAMPLE FABRICATION METHOD

If the wallettes are solely used for durability testing of solid units, they can be made horizontally in a mould with their faces down. On the plane bottom of that mould, a soft sheet of foam rubber, thickness 5 mm for plane unit faces and up to 10 mm if the surface is irregular, is laid. This sheet must be immersed with a mixture of water and a cement-retarder agent. Next, the pre-wetted units are put onto the bottom with their faces down into the mould and in the pattern as desired. Then the joints are filled up by pouring the mortar, followed by some seconds of vibration. This filling and vibrating cycle is repeated until the joints are full. Very good results are achieved with a Portland cement mortar (1 part cement to 3 parts sand by volume). The wallette must be released from the mould after sufficient curing (*e.g.* 20 hours of room conditions for ceramic units), but before the retard-

ing process on the bottom (facing side) becomes inactive. This is needed for cleaning that surface by means of a brush if mortar leakage has taken place. The above wallette-making method assures a strong bond and completely filled joints with compacted and dense mortar.

ANNEX MS-A.1-2 STATISTICAL EVALUATION OF NON-PARAMETRIC DURABILITY DATA

Normal physical test methods measure quantifiable properties of materials and components, and generally it is satisfactory to assume the resultant data, measured on a sample, will have a normal distribution. This assumption allows the use of a range of standard techniques to arrive at a statistically accurate result.

Unfortunately, it is difficult to find reliable parameters with which to measure durability. Parameters such as loss of weight or area/volume of specimens can give useful information under some circumstances, but generally, whatever aspect is being used, the individual result is normally in the form of a boolean (yes/no) value. For example, failure has occured - true or false. Since durability tests are nearly always cyclic, an individual result may be in the form "fail at cycle X" and there will be a group of results from replicate tests. This type of data is termed 'non-parametric' and must be analysed using appropriate statistical techniques.

This annex describes some appropriate statistical procedures to allow objective analysis of non-parametric durability test data.

A.1-2.1 CHI-Squared (χ^2) test with the Yates correction for comparing two unpaired groups

SCOPE: This technique allows two groups of unpaired data from either (1) similar tests on different materials (*e.g.* treated and untreated) or (2) different tests on the same materials to be compared to see whether one group is performing better than the other. It is a non-parametric equivalent of the Student's t-test for parametric data. Unpaired data results from destructive tests because two successive tests cannot be carried out on the same specimen, thus there is no natural association between pairs of results.

METHOD: Carry out a durability or similar test procedure on two equal sized groups of specimens. The results should be in the form of either passes or failures after a given treatment, *e.g.* after 100 frost/defrost cycles. A correction must be applied to correct between the binomial distribution of the data and the Chi-square distribution which is continuous. The correction, due to Yates, is to reduce by 1/2 those values that exceed expectations (*i.e.* exceed the ratio pass/fail that would give the null hypothesis that the two ratios are equal) and increase by 1/2 those that fall below expectations.

The calculation is as follows after the Yates correction has been applied, where a - d are the numbers of passes and failures and e - k are totals, respectively, along rows, down columns and global (= k).

	Pass	Fail	Totals
Test group 1	a	c	e
Test group 2	b	d	f
Totals	g	h	k

then $\chi^2 = (bc - ad)^2 k / efgh$

In the sample spreadsheet given below, the resultant value of Chi squared is given in cell number B7 = (D4*E3-D3*E4)^2*F5/F3/F4/D5/E5

The result may be assessed by looking up the value of the Chi squared function in tables. If the calculated value exceeds the tabulated value for a given significance level, the result may be taken as significant.

Sample spreadsheet analysis

Spreadsheet	A	B	C	D	E	F
2		Pass (original)	Fail (original)	Pass corrected	Fail corrected	Totals
3	Group 1	20	0	19.5	0.5	20
4	Group 2	14	6	14.5	5.5	20
5	Totals	34	6	34	6	40
6						
7	Chi square	4.9	Sig. level	5%	1%	0.1%
8		Sig. value	(from table)	3.8	6.6	12
9		Significant		Yes	No	No

Row	Spreadsheet column D	Spreadsheet column E
3	= if B3/F3>B5/F5 then B3-0.5 else B3+0.5 endif	E3: = if C3/F3>C5/F5 then C3-0.5 else C3+0.5 endif
4	= if B4/F4>B5/F5 then B4-0.5 else B4+0.5 endif	E4 : = if C4/F4>C5/F5 then C4-0.5 else C4+0.5 endif

i.e. in this example, the two groups are different at a probability level of 95%, but at probability levels of 0.99 or greater the two groups have to be considered as statistically identical.

A.1-2.2 SIGN-Test for comparing two unpaired groups

The classical analogue of this test is Student's t-test for differences between observations of pairs of two independent series, X_I and X_{II}. The SIGN-Test assumes a symmetrical non-parametric distribution of the medians, X - S of the two series. If the series are equal, the null hypothesis, H_o, becomes: $X_I = X_{II}$. If series I is assumed to be better or worse than series II, the null hypothesis becomes:

$H_o : X_I >= X_{II}$, repectively $X_I <= X_{II}$

The test criterion, C, is the number of + or - within a series of size n. If H_o is correct, C follows a BINOMIAL distribution with a probability of p = 0.5 (equal 2-sided); thus:

mean value (+ or -) = P.n = 0.5 n

Standard deviation s = square root (n . p(1-p)
= 0.5 square root (n)

How to use the Table:

Example: n = 20 pairs of series $X_{I\text{-}s}$ and $X_{II\text{-}s}$. Null hypothesis H_o: $X_I = X_{II}$ (equal performance).

Observations by comparison:

3 times no difference: remaining n = 20 - 3 = 17

4 times (-), that is X_I is worse or $X_I < X_{II}$

Interpretation:

In the Table, on the line n = 17, it can be derived for C = 4 times (-) that $P_1 = 0.025$.

This means that there is a probability of 0.025 that I is worse than II ($X_I < X_{II}$) and a probability of $2P_1 = 0.05$ that H_o: $X_I = X_{II}$ is not correct. In other words, X_I and X_{II} are equal with a probability of 1 - 0.05 = 0.95 (95%). (see table with C-values next page)

A.1-2.3 KAPLAN-MEIER Procedure for a statistical interpretation of durability failures in destructive accelerated cyclic stress tests

A.1-2.3.1 Introduction

A clear and simple presentation of test data is not only practical, but also of great help for the investigation of the probabilistic model that may reflect the underlying process of deterioration and the failure mechanism. Deterioration is defined as loss of performance every time a transition takes place from a given performance state to a lower-grade state. This transition process is regarded as hazardous, and the time or the number of stress cycles between two successive transitions is a stochastic variable. Generally, the emphasis is on the stress cycle that changes a specimen from a given initial state to a lower-grade state. This means that the first, and only, detected failure counts. What is meant by failure (defective) must be specified. Normally, it is a criterion for rejection or discarding. Therefore, the observation after each cycle or series (number and/or time) is: 'failed' or 'not failed'. Observation means the use of a technique of non-destructive monitoring or relevant inspection (*e.g.* visual or tapping to detect hollow areas) which is selected to detect a change of the initial state. An example is given for measuring a change of the pulse-travel times in ultra-sonic measurements (see SUB-ANNEX A.1-1).

The aim of the KAPLAN-MEIER procedure (1958) is to present test data in the form of a curve in a double e-log grid with, on the X-axis, the number of cycles and, on the Y-axis, the integrated hazard which is directly related to the probability of surviving a change in a given performance state.

A.1-2.3.2 KAPLAN-MEIER Concept

The following survival function is valid for all integrated hazard functions, no matter what their mathematical form:

$S(t,N) = \exp\{-H(t,N)\}$ and thus $H(t,N) = \ln S(t,N)$

where:

$S(t,N)$ = probability of survival as a function of t,N

t,N = independent variable where N is the number of cycles of a prescribed duration regarded as a counting process in time continuum t

$H(t,N)$ = integrated hazard as a function of t,N.

The test results are used to obtain the empirical non-parametric survival function by means of the KAPLAN-MEIER maximum likelihood estimate:

$$S_j = \prod_{j=1}^{k}\left\{1-\left(d_j/n_j\right)\right\} \qquad \text{for } i = 1,2,3\ldots k \le n \qquad (1)$$

where:

S_j = sample estimate of the survival function after the completion of N = j cycles (N_j)

n = sample size

n_j = number of specimens at risk at cycle N_j, *i.e.* the number with no detected defects and uncensored after N_{j-1} stress cycles

d_j = number of specimens that failed at (during) stress cycle N_j.

Converted to its e-log form, the KAPLAN-MEIER formula estimates the empirical cumulative hazard function:

$$H_j = -\ln S_j = -\sum_{j=1}^{k}\ln\left\{1-\left(d_j/n_j\right)\right\} \qquad (2)$$

where:

H_j = the sample estimate of the integrated hazard function after the completion of N = j cycles (N_j).

From a statistical point of view, there is no need to continue the test until the entire sample size (n) has failed. The test can be stopped at each sufficient number of $\Sigma d_j < n$. In a standard test, the number of cycles and duration of each cycle may be prescribed, *e.g.* in a standard freeze-thaw test for masonry units and wallettes.

Table with C-values											
n \ P_1	0.005	0.01	0.025	0.05	0.10	n \ P_1	0.005	0.01	0.025	0.05	0.10
1	-	-	-	-	-	41	11	12	13	14	15
2	-	-	-	-	-	42	12	13	14	15	16
3	-		-	-	-	43	12	13	14	15	16
4	-	-	-	-	0	44	13	<–	15	16	17
5	-	-	-	0	<–	45	13	14	15	16	17
6	-	-	0	<–	<–	46	13	1êi	15	16	18
7	-	0	<–	<–	1	47	14	15	16	17	18
8	0	<–	<–	1	<–	48	14	15	16	17	19
9	0	<–	1	<–	2	49	15	<–	17	18	19
10	0	<–	1	<–	2	50	15	16	17	18	19
11	0	1	<–	2	<–	52	16	17	18	19	20
12	1	<–	2	<–	3	54	17	18	19	20	21
13	1	<–	2	3	<–	56	17	18	20	21	22
14	1	2	<–	3	4	58	18	19	21	22	23
15	2	<–	3	<–	4	60	19	20	21	23	24
16	2	<–	3	4	<–	62	20	21	22	24	25
17	2	3	4	<–	5	64	21	22	23	24	26
18	3	<–	4	5	<–	66	22	23	24	25	27
19	3	4	<–	5	6	68	22	23	25	26	28
20	3	4	5	<–	6)	70	23	24	26	27	29
21	4	<–	5	6	7	72	24	25	27	28	30
22	4	5	<–	6	7	74	25	26	28	29	30.
23	4	5	6	7	<–	76	26	27	28	30	31
24	5	<–	6	7	8	78	27	28	29	31	32
25	5	6	7	<–	8	80	28	29	30	32	33
26	6	<–	7	8	9	82	28	30	31	33	31
27	6	7	<–	8	9	84	29	30	32	34	32
28	6	7	8	9	10	86	30	31	33	34	33
29	7	<–	8	9	10	88	31	32	34	35	37
30	7	8	9	10	<–	90	32	33	35	36	38
31	7	8	9	10	11	92	33	34	36	37	39
32	8	<–	9	10	11	94	34	35	37	38	40
33	8	9	10	11	12	96	34	36	37	39	41
34	9	<–	10	11	12	98	35	37	38	40	42
35	9	10	11	12	13	100	36	37	39	41	43
36	9	10	11	12	13						
37	10	<–	12	13	14						
38	10	11	12	13	14						
39	11	<–	12	13	15						
40	11	12	13	14	15						

A.1-2.3.3 Presentation of data in a table

The first step is to present test data in a table with the following columns:

N_j = cycle number with j = 1, 2, 3, 4, ...
n_j = number of specimens at risk during cycle j
d_j = number of failed at (during) cycle j
d_j/n_j = empirical hazard (rate)
S_j = empirical probability of survival stress cycle j estimated with KAPLAN-MEYER formula (1)
H_j = empirical cumulative hazard at stress cycle j estimated with KAPLAN-MEIER formula (2).

Since $S_j = \exp(-H_j)$ and, thus $H_j = \ln S_j$, there is no need to use KAPLAN-MEIER formulae (1) and (2): either (1) or (2) is sufficient to estimate both S_j and H_j.

In the case of failure detection after series of cycles, the table shall contain a column with a serial number. This may also be time periods, because a number of cycles (series) times the duration of one cycle is a constant time span in a time continuum. For example, 4 cycles with a cycle time of 42 hours give time periods of one week. In that case, detection of failures, if any, occurs weekly when 4 cycles are completed. In some cases, not all cycle times within a period may be constant, but a constant number (series) of cycles takes place in regular periods of time, *e.g.* 5 cycles of 24 hours and 1 cycle of 48 hours weekly. Then, it is very practical to work with series of a constant time span.

Table – Test data and KAPLAN-MEIER estimates

Period [weeks]	Cycle [number]	Number at risk	Number failed	Empirical hazard rate	KAPLAN-MEIER survival	KAPLAN-MEIER Σ hazard
P1...6	N_j	n_j	d_j	d_j / n_j	S_j	H_j
1	4	20	0	0	1.0000	0
2	8	19	1	1/20	0.9500	0.0513
3	12	16	3	3/19	0.8000	0.2231
4	16	11	5	5/16	0.5500	0.5978
5	20	7	4	4/11	0.3500	1.0498
6	24	2	5	5/7	0.1000	2.3026

By way of example, the table above presents data and KAPLAN-MEIER estimates for:

n = 20 specimens (sample size)
N = 24 cycles, cycle time 42 hours
Series = 4 cycles per week
Period = one week with weekly observation of change in performance.

It is noted that the duration of this accelerated deterioration test was 6 weeks. After completion of N_j = 24 the total number of failed specimens was 18, thus Σd_j = 18 = < n = 20.

A.1-2.3.4 Graphical presentation

The next step is to plot the KAPLAN-MEIER estimates. In a grid S_j against H_j there will arise an empirical survival curve. Since this curve is non-parametric, a statistical analysis and interpretation is difficult. It is recommended to plot the empirical hazards, H_j, in a grid ln H(t,N) versus ln N, that is, a double e-log grid with t,N on the X-axis and H(t,N) on the Y-axis. In this way the plot is much more informative and analysable.

Often, durability test data follow a WEIBULL distribution. In that case the following integrated hazard function applies:

$$H_w(t,N) = \{T/T_\mu\}^\beta \text{ resp. } \{N/N_\mu\}^\beta$$

where:

N = number of test cycles, regarded as a continuous variable for a homogeneous counting process in time continuum t
T = stochastic variable of the inter-event times between the start of the test and the moment when the first and only failure occurs; that is, T is equal to the sum of the cycle times between a given (initial) performance state and the moment of transition to the lower-grade state defined as failure
N_μ = size parameter implying that H = 1 when N = N_μ, independent of the value of β
T_μ = size parameter, equal to the sum of the cycle times from N = 0 to N_μ, again H = 1 when T = T_μ
β = shape parameter; if β = 1, the WEIBULL integrated hazard function is identical to the EXPONENTIAL model. Normally, β ranges from 2 to 6 but its value is more commonly between 3 and 4 (dimensionless).

The e-log form of $H_w(t,N)$ is linear:

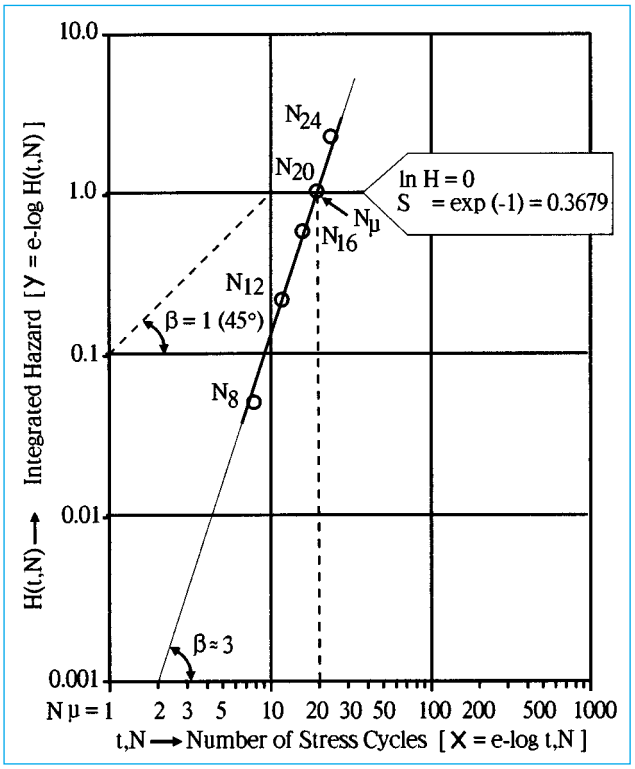
$$\ln H_w(t,N) = \beta \ln N - \beta \ln N_\mu$$

where N and N_μ may be substituted by T and T_μ which is not further considered.

A WEIBULL integrated hazard function is in a grid ln H(t,N) versus ln N represented by a straight line with slope β and two characteristic pairs of co-ordinates:

* at point N = 1 when ln N = 0 on the X-axis, and $\ln H_w(N=1) = -\beta . \ln N_\mu$ on the Y-axis;
* at point N = N_μ when H_w = 1, thus $\ln H_w(N=N_\mu) = 0$ on the Y-axis.

A typical example graph plot is shown below. It is stressed that the log-scale of the grid is one X-unit to one Y-unit such that when β = 1, the slope of a straight line through co-ordinates (H = 1, N = 10) and (N = 1, H = 0.1) is one to one, *i.e.* the angle between that line and the X- or Y-axis is 45°. The Y-scale ranges from H = 0.001 if S = exp (-.001) = 0.999 to H = 10 if S = exp (-10) = 0.0000454. The X-scale ranges from N = 1 to N = 1,000 cycles.



Test data graph based on Kaplan Meier estimates

Next the KAPLAN-MEIER estimates of H_j in the table are inserted in the grid. Obviously, the date points are on a straight line with slope β ~ 3 and N_μ ~ 20 cycles. In this case, the probability of survival as a function of given accelerated stress cycles is a single WEIBULL model.

Apart from a graphical determination of parameters β and N_μ, a computer may be employed to estimate these parameters, *e.g.* by means of linear regression or maximum likelihood programmes. Plotting of table and graph by a computer may be useful as well.

A.1-2.3.5 Interpretation of graphical results

No matter the form of the test curve, parametric or non-parametric, there will always be an intercept at H = 1. That intercept indicates the value of N_μ = N which is characteristic in every case. At that defined point, the probability of surviving the given test regime is:

$S_{N_\mu} = \exp(-1) = 0.3679 \qquad \text{for } H = 1$

Also the steepness of the curve, *e.g.* the β_S of its incremental parts, and its form are very informative. For further analysis of the underlying deterioration process see the Bibliography. Moreover, the form of the curve can easily be used to compare test results with different test regimes and/or different samples, materials, treatments or whatever.

It is noted that the failed or not criterion is focussed on the first and only change of a given performance state. Successive changes may be more severe or not. Often, deterioration damage increases progressively with time.

A.1-2.3.6 References and bibliography

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Swinkels, M.M.J. and Van der Ven, M.L.J.M., 'Freeze/Thaw Experiments with Ceramic (soft-mud moulded) Bricks', B.Sc - thesis work conducted by Bekker, P. and Daams, C., Eindhoven University of Technology, Adamczyk, T. and Coremans, P., Eindhoven Polytechnic, Department of Engineering Physics, Eindhoven, Netherlands, 1989.

SUB-ANNEX MS-A.1-1 – TEST USING UPV DATA TO ASSESS STATE CHANGE

1. Measure the initial pulse travel time of each unit in the moisture condition as prescribed for testing.

2. Measure the pulse travel time of each unit after each cycle and compare the result with the initial (reference) value. An increase of the initial value can be an indication for a defect that comes into existence (propagation of initial cracks and flaws). Generally, there is a probability of 50% that the pulse travel time after each stress cycle is longer or shorter than the initial value. Therefore, the standard error due to measuring inaccuracies must be taken into account for the interpretation of the cycle when deterioration came into effect. Thus, the first increase of the pulse travel time is not yet decisive. When the first increase is followed by a second and a third increase, the increasing trend reflects deterioration with the subsequent number of stress cycles. Some examples from a set of deterioration curves are given in Fig. 1.

3. The duration of the test is determined by the number of stress cycles and the duration of each cycle which are both prescribed in a standard test. At the end of the test we have: - no failures, or - failures with the associated cycle at which the durability defect came into existence.

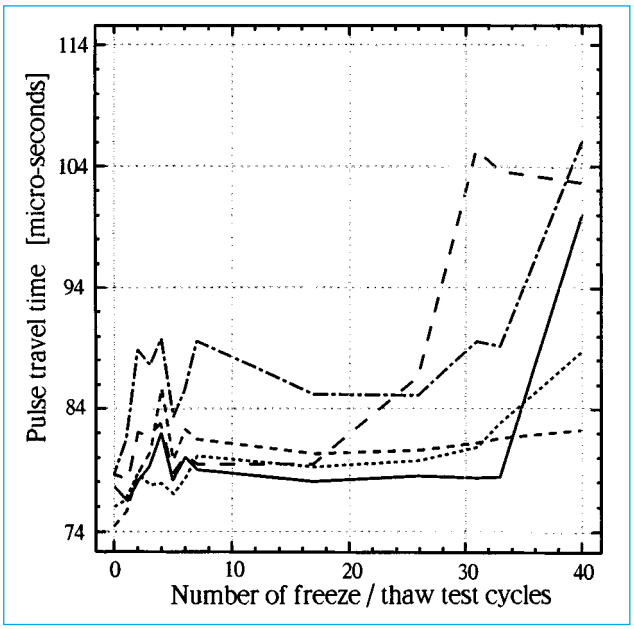

Fig. 1 – Some example test curves.

MS-A.2 Uni-directional salt crystallization test for masonry units

A.2.0 CONTENTS

A.2.1 SCOPE

This recommendation specifies a method of indicating the resistance of individual masonry units to damage caused by sub-surface crystallization of water-soluble salts (crypto efflorescence). This is an accelerated test, as higher than normal salt concentrations are used. The test generates short stress cycles and is proposed to detect the durability of masonry unit surfaces which are exposed to moisture dynamics in a wall. It describes the sampling of the specimens, the conditioning required before testing, the apparatus, the method of test, how to report the results, how to interpret the results, the contents of the test report, and, in section 8, the background and theoretical aspects.

A.2.2 SPECIMENS (Size, shape and numbers)

Specimens should be normal whole units randomly or selectively sampled. Larger specimens, especially low porosity materials, may be cut to reduce the path length between the absorption face and the test face. It is preferable to sample in accordance with ISO 2859 and interpret by the attributes method.

A.2.3 TREATMENT AND PREPARATION (CONDITIONING) OF SPECIMENS

CHOICE OF TEST FACE: The test face must be one which would be exposed in normal masonry work. For most units, this can be the stretcher face or the header face. It is recommended that the faces be chosen such that the path length between the absorption face and the test face is 120 mm or less. Larger units may be cut to reduce one of the path lengths to less than 120 mm. Units should be cut before drying. Fig. 1 shows a possible cutting plane for units exceeding 120 mm.

DRYING: Ceramic material samples should be dried in an oven at a temperature of 105 ± 5°C and samples of other materials, *e.g.* concrete, aerated concrete, stone etc., at 60 ± 5°C to a constant mass. This shall be taken to be when the difference in mass between two weighings 24 hours apart is less than 0.1%. Note the mass of the sample as M_d if dried at 105 ± 5°C and M_{60} if dried at 60 ± 5°C.

SPECIMENS TESTED UNTREATED: Use only one group and wrap with rubber sheet so that evaporation is prevented on four sides as illustrated in Fig. 1.

EVALUATION OF SURFACE TREATMENTS (CONSOLIDENTS): Divide the sample batch into two equal groups (T and U) by random selection. The first (T) group should be subjected to the specified surface treatment on the smaller (factory-made) face (usually the header). The (U) group should be left as dried. All the specimens should be wrapped tightly with rubber sheeting so evaporation is prevented on four sides as shown in Fig. 1. The treated surface, or the equivalent face on the untreated units, and the opposite face are left exposed, one for water absorption and the opposite one for surface testing.

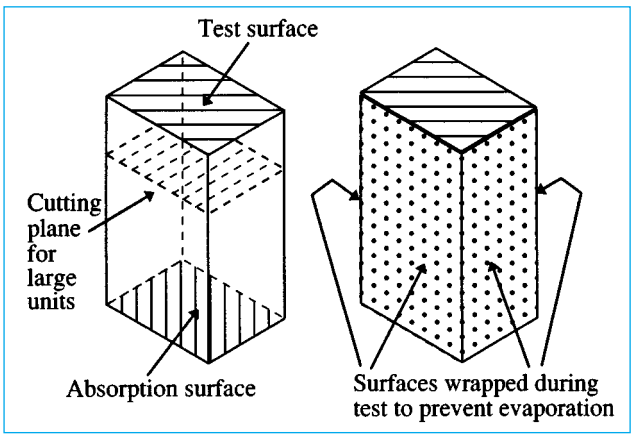

Fig. 1 – Specimen geometry.

A.2.4 APPARATUS

A large capacity tank with a wire mesh shelf at the bottom for immersion. Either a constant temperature/humidity room or cabinet for the drying face.

A.2.5 PROCEDURE

After preparation, the test cycling should commence. The units are placed on the wire mesh with the absorption surface in contact with the mesh and immersed to a depth of 2 mm in a saturated solution of sodium sulphate (Na_2SO_4) for 2 hours. If cut units are used, the cut surface shall be used as the absorption surface and the factory-made surface shall be used as the test surface. The units are then dried for a period of 4 hours at a tempera-

ture of 20°C and a R.H. of 50% in a climatic chamber. The relative humidity and temperature have been selected such that the thermodynamic conditions, due to the rate of evaporation, create a zone under the surface where the conditions necessary to the formation of mirabilite (decahydrate) are realized. In fact, at the liquid-vapour interface the R.H. is near to 100%. The cycle is repeated up to the first damage of the unit, and then continued as far as required for the purpose of testing if the behaviour of the subsequent surface layers should be investigated.

A.2.6 TEST RESULTS

Record the number of cycles and any damage following the description guidelines below. After each cycle of the testing procedure, the test surface of each single unit should be photographed if there has been any significant change. Record changes as follows:
– Efflorescence, staining or other aesthetic damage
– Detachment of surface layer (blistering, flaking, pitting, chipping and delamination, powdering)
– Cracking of the body
– Disintegration
– Any other relevant damage.

The above damage shall be described and, as far as possible, quantified or classified, step by step, supported by photographs or by video recording.

If it is required to have a judgement of whether the test has resulted in a failure (FAIL or NOT FAIL), then a standard reference photograph or drawing or set of reference photographs/drawings should be prepared illustrating each failure state that is relevant to the product under test.

A.2.7 TEST REPORT

1. A reference to this method.
2. A description of the units including their overall size and shape.
3. The method of sampling of the units.
4. The other known properties of the units, including ultrasonic characteristics, strength, water absorption, IRA, porosity, density and the manufacturer's data and reference name/number for new products, the origin of naturally occurring (*e.g.* quarried) materials or the site of origin of materials removed from existing structures.
5. The date of conditioning of the specimens and the date of the test.
6. The number of cycles to failure of each individual specimen or the number of cycles at which the test was terminated without damage.
7. Failure characteristics of each specimen, *i.e.* cracking, delamination, spalling, disintegration etc.
8. Evaluation of the test results.
9. A statistical interpretation of the test results, *e.g.* as given by Annex 2 of MS.A.1 [7].

A.2.8 BACKGROUND AND BIBLIOGRAPHY

[1] Binda, L. and Baronio, G., 'Mechanism of masonry decay due to salt crystallization', in 'Durability of Building Materials', no. 4 (Elsevier, Amsterdam, 1987) 227-240.
[2] Binda, L., Baronio, G., Anti, L. and Anzani, A., 'Measurement of the rate of deterioration of masonry materials and of conservation treatments', Proc. Br. Masonry Soc., M4, 1990, 5-9.
[3] Binda, L., Baronio, G. and Squarcina, T., 'Evaluation of the durability of bricks and stones and preservation treatments', 7th Intl. Congr. of Deterioration and Conservation of Stone, V2, Lisbon, 1992, 753-761.
[4] Binda, L. and Molina, C., 'Building materials durability; Semimarkov approach', *J. of Materials in Civil Engineering, ASCE* **12** (4) (1990) 223-239.
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[6] 'Crystallization test by partial immersion - Test No.V.2', Recommended tests to measure the deterioration of stone and to assess the effectiveness of treatment methods, RILEM TC 25-PEM, Protection and Erosion of Monuments (Bordas-Dunod, 1980).
[7] Annex 2 of MS-A.1, Statistical evaluation of non-parametric durability data, *Mater. Struct.* **31** (205) (1998) 4-8.

MS-A.4 Determination of the durability of hardened mortar

A.4.0. CONTENTS

A.4.1. SCOPE

This recommendation specifies a laboratory method of testing for determining the durability of masonry mortars containing mineral binders and normal, as well as lightweight, aggregates to either freeze/thaw action or sulphate attack or a combination of both. The standard method covers specimens of mortars prepared in the laboratory or sampled from fresh batches placed between standard substrates with negligible suction (the most

onerous condition), but other types of unit may be specified. The method may also be applicable to mortar beds taken from existing structures. Visual assessment is used at the end of the test to determine the degree of damage suffered by the specimen.

A.4.2. SPECIMENS (Size, shape, numbers)

A.4.2.1 Laboratory made specimens

A total of eight tablet specimens 55 ± 1mm long × 33 ± 1mm wide × 10 ± 1mm high (the thickness of the bed joint) are cut from two hardened mortar beds removed from between pairs of units. The units should be in a moisture state as specified, but should be water saturated (with negligible suction properties) to give the worst case durability. To avoid contamination of the freezing-only specimens, the units should contain less than 0.05% of sulphate (m/m).

A.4.2.2 Site specimens

Eight specimens should be cut from existing work from a position similar to that shown in Fig. 3(A).

A.4.3. PREPARATION OF LABORATORY SPECIMENS

Samples of fresh mortar having a minimum volume of 1.5 litres shall be prepared as specified or sampled randomly from a larger pre-existing batch. The maximum consignment size to which the samples relates shall be in accordance with the relevant product specifications. The consistence of the mortar as used shall be measured using a standard method (*e.g.* CEN EN1015-4 or ASTM C780) and reported.

Ready-to-use mortars (factory-made wet mortars which are retarded) shall be made into specimens within their specified workable (pot) life. Other mortars gauged with hydraulic binders shall be made into specimens not less than 10 min, and not more than 30 min, after completion of mixing, unless otherwise instructed by the manufacturer. Before using, the batch shall be gently stirred by hand, using a trowel in 5 - 10 seconds to counteract any false setting, but without any additional mixing of the batch.

The length of the mixing period shall be measured from the moment all constituents are introduced into the mixer.

Any deviation from the mixing procedure prescribed shall be noted.

Prepare two mortar beds between two pairs of wet units. The latter are prepared by immersing the units in water for 16 hours followed by a 5 minute drain at 20°C + 5°C, unless otherwise specified.

Cut two layers of surgical gauze 50 mm wider than a unit. Place one layer on the surface of the lower unit of the couplet which will be in contact with the laid mortar so that an overlay of approximately 25 mm each side of the unit occurs and smooth firmly to the wet surface This is to facilitate later removal of the bed. Tape the other layer of gauze to the sides of the upper unit such that it is tensioned over the bedding face.

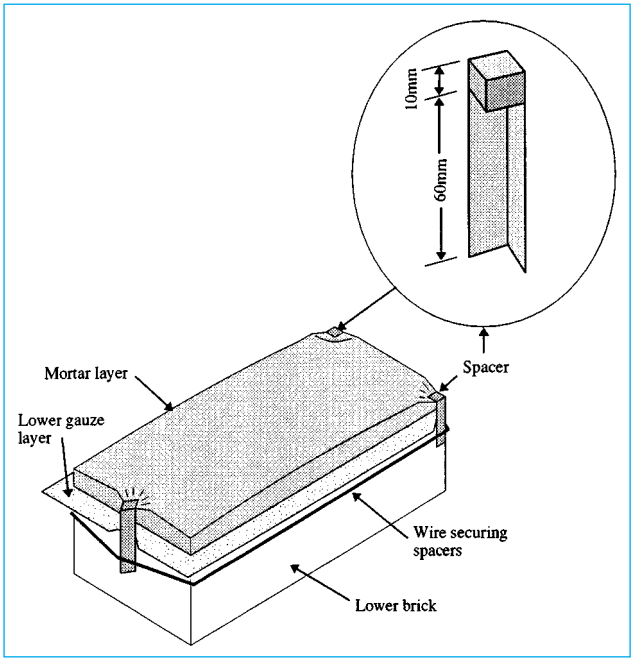

Fig. 1 – The mortar bed specimen in preparation with the spacers in place over the lower gauze layer and the fresh mortar layer trowelled on.

Position spacers on the bottom unit (*i.e.* the one on which the mortar will be laid) over the gauze and secure with a length of wire or adhesive tape around the unit. Lay the mortar on the bottom unit a little proud of the top of the spacers. The spacer and the specimen with the mortar bed in-place are shown in Fig. 1. Place the other unit with gauze in position on top and gently tap down until contact with the spacers is made. Scrape off excess mortar and finish by tooling both struck faces with the perspex tube. Repeat for the second couplet. Carefully remove the spacers after completion of the initial set.

A.4.4 CONDITIONING OF SPECIMENS

Cure the couplets at a temperature of 20°C ± 2°C and a relative humidity of 95% ± 5% for a period given in Table 1. After this period separate the mortar beds from the units. If any sticking occurs, gentle tapping around the units may secure removal. Remove the gauze.

For hydraulic cement mortars, place the beds over, but not in contact with, water in a closed container at 20°C + 5°C in which a CO_2 - free moist air atmosphere is maintained with "carbosorb". Store till age 28 days after casting. At approximately 21 days, the beds are cut as shown in Fig. 2 to provide the test specimens, labelled as required and returned to the container.

Table 1 – Storage time of couplets before separating the mortar beds from units		
Type of mortar	Content of hydraulic cement in total mass of binder	Time before separating mortar beds from units
	%	days
Air - Lime mortar	0%	28
Lime / hydraulic cement mortars	<50%	5
Lime / hydraulic cement mortars	>50%	2
Mortar with other hydraulic binders	(as required)	2
Retarded mortars	(as required)	2 days after end of workable life

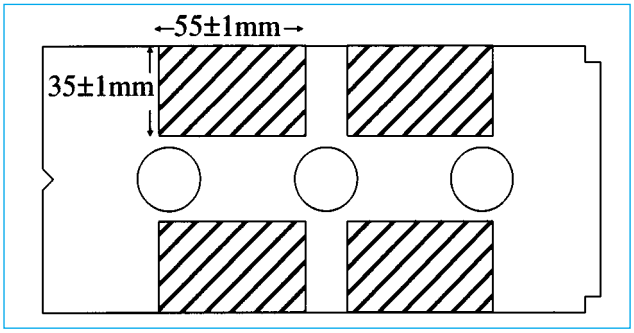

Fig. 2 – Typical cutting plan for obtaining four specimens from the mortar bed.

NOTE 1: If the specimens appear to be noticeably wet, as they may be if wet-cutting has been employed, then pre-drying in the desiccator over "Carbosorb " may be advisable.

For air-lime mortars, store in air at 20 ± 10°C and 50% ± 10% r.h. for a further 90 days. Ensure that these specimens are ventilated with atmospheric air containing CO_2.

After completion of the curing period, remove the specimens from the storage container and dry for 24 hours over saturated calcium chloride solution (r.h. = 32% ± 2%) in an oven, fitted with a fan, and maintained at 20°C ± 2°C.

A.4.5 APPARATUS (list in alphabetical order)

Armaflex sheet insulation, 1 face sealed, 1 face open, nominally 9 mm thick; Calcium chloride; "Carbosorb" or other CO_2 absorbent; Commercially available, low sulphate units with one flat unperforated bed face which are saturated with water to give negligible suction; Deep freeze cabinet, to maintain temperature below - 15°C; Desiccator; Expanded polyethylene strip nominally 35 mm wide and 10 mm thick; Diamond saw or other suitable cutting equipment for preparing specimens; Fan assisted drying cabinet/oven capable of maintaining a temperature of 25°C ± 2°C; Flexible wrapping film (*e.g.* Cling film); Foamed - polystyrene box with recesses; Hygrometer; Large plastic trays bearing glass plates on supports; Low power optical microscope (5-10 magnification); Perspex tube, 25 mm diameter; Plastic boxes approximately 70 × 50 × 35 mm; Potassium sulphate solution 36,25 g/l (2% SO_4); Spacers to gauge mortar bed thickness 10 mm high; Surgical gauze.

A.4.6 TEST PROCEDURE

Place the specimens tooled face uppermost on horizontal glass plates, Fig. 3B, which rest on supports in large plastic trays. Specimens 1 and 2 are stood on a plate drip fed with the sulphate solution and specimen 3 on a plate drip fed with water. The surface tension forces should maintain a solution depth of about 1 mm on the glass plate. Fig. 3A shows the flow patterns for the equivalent piece of mortar in a wall.

After approximately 20 minutes solution uptake, remove the specimens and pack each one tightly, surrounded by insulant, into a plastic box, Fig. 3C, so that only the tooled face is exposed. 5 ml of tap water are added to each box before packing to enable saturation of the specimen to reach a level that will cause failure of a frost vulnerable material.

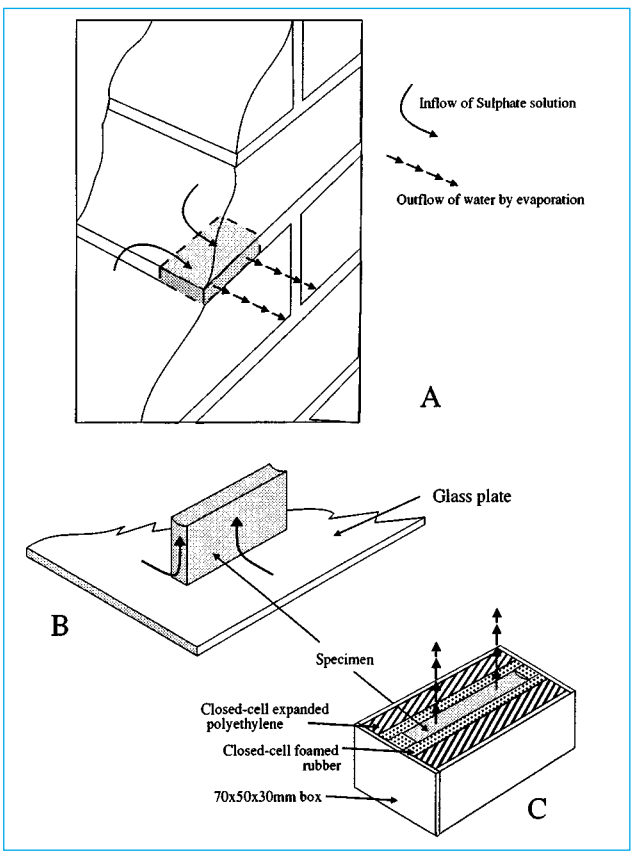

Fig. 3 – The specimen (A) as it would be in a wall, (B) during the liquid uptake phase on the glass plate, and (C) in the insulated box for the freezing, evaporation and drying phases.

Place the boxed specimen in polystyrene trays and wrap the trays in cling film to prevent loss of moisture from the mortar face. Specimens 2 and 3 may be placed in the same tray, specimen 1 should be placed in a separate tray. Store the wrapped trays in the laboratory for 2 or 3 days.

NOTE 2. Continuous cycling will require that specimens exposed to solution on a Friday will have to be stored for three days rather than two days. If cycling has to be interrupted, *e.g.* by holidays, specimens should be stored after drying, packed in dry boxes and wrapped in cling film until cycling can be recommenced.

For the final 5 hours of this period, place the trays containing specimens 2 and 3 in a deep freeze cabinet below - 15°C for five hours, then remove them and allow to thaw at room temperature. (During this time the tray containing specimen 1 remains at room temperature.) Subsequently, remove all specimens from their boxes and repack (also with insulant) into a second set of dry boxes and place in the drying oven for 24 hours. A timetable for the above procedure is set out in Annex MS-A.4-1.

A.4.7. TEST RESULTS

The performance of the mortar specimens after each cycle of sulphate addition and freezing must be monitored by visual inspection, and the use of a low power microscope is recommended to detect cracking. After 25 cycles, each specimen is given a visual assessment rating (VAR) ranging from 1 (50% loss in area) to 10 (unaffected). This is determined by placing it on a template, Figs. 4 and 5, which most nearly matches its condition. If a specimen looses 50% of its area before completing 25 cycles, it is removed from the test when this occurs and the number of cycles which have been completed noted.

The most common forms of failure are loss of corners or progressive crumbling of the exposed faces of the specimens.

Assessing specimens which are cracked but still holding together is more difficult and involves a subjective judgement. Assume the crack will progress in the direction it has started and that it will ultimately cause the detachment of a portion of the specimen. Match the consequent residual shape to the nearest template in Figs. 4 or 5 and estimate the present progress of the crack as a portion of the % loss of mortar shown against the template. Record the nearest equivalent VAR to this reduced % loss of mortar.

Report the overall performance of the sample as either good, marginal or poor as illustrated in Figs. 4 and 5.

Report the type of failure as being either due to sulphate attack, frost failure or a combination of both types, see Notes 3, 4 and 5.

NOTE 3: Frost failure tends to occur at the "tooled " edge or corners, which are uppermost when the specimens are placed on the glass plate and in the insulated boxes.

NOTE 4: Sulphate failure tends to show at the lower edge or corners, where the sulphate first enters by capillary rise from the glass plate.

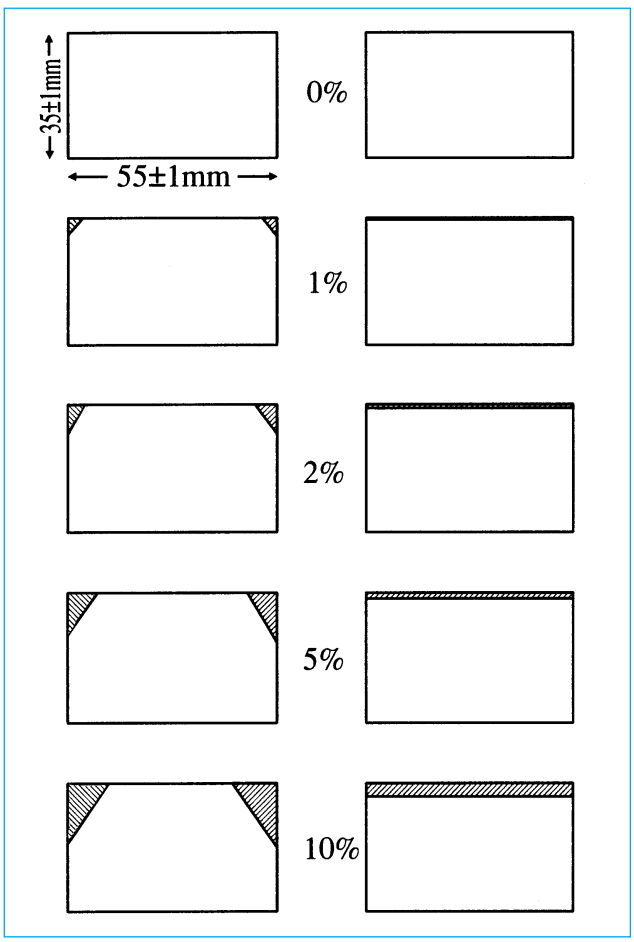

Fig. 4 – Templates for judging the Visual Assessment Rating (0-10%).

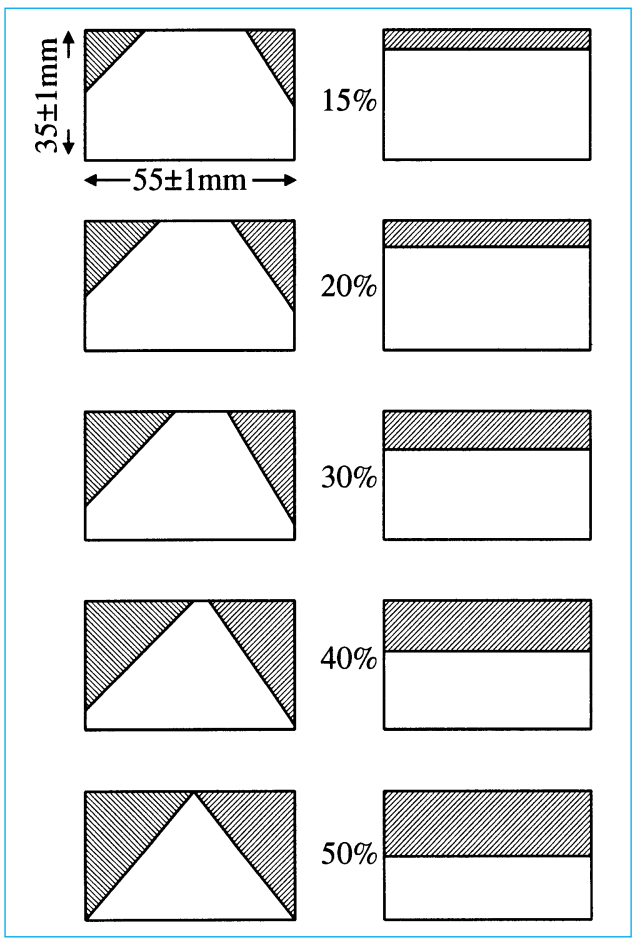

Fig. 5 – Templates for judging the Visual Assessment Rating (15-50%).

NOTE 5: The more destructive combination of frost and sulphate usually produces an accelerated type of frost failure.

A.4.8 TEST REPORT

The test report shall include the following information, if relevant:

1. A reference to this test method.
2. The method of sampling of mortar or of hardened specimens from existing structures and by which organisation.
3. Identification of mortar samples including (where known) type, origin and designation of the mortar, the specification of any constituents including binder, sand, lime, plasticisers, etc.
4. Preparation (mixing, casting) and storage (curing) conditions.
5. The date and time of preparing samples for test (*i.e.* date and timing of any mixing, casting, moulding or demoulding procedure (if appropriate).
6. Type and description of any substrate, including suction properties, or any suction pretreatment used when preparing samples for test; degree of saturation of porous units.
7. Consistence of test mortar and any control mix.
8. Age of mortar when tested.
9. Total mass of each individual test sample.
10. Test method used (reference method or alternative method, if appropriate), and details of test specimens including number, dimensions, mass and date of test, etc. if appropriate;
11. Test results (Visual assessment rating), overall performance of the sample, type of failure, etc.

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[7] ASTM C780-91, 'Test method for preconstruction and construction evaluation of mortars for plain and reinforced unit masonry, Annex A1: Consistence by cone penetration test method'.

[8] EN 1015-4, 'Methods of test for mortar for masonry - Determination of consistence of fresh mortar (by plunger penetration)'.

ANNEX MS-A.4-1

TIMETABLE FOR SPECIMEN TESTING BASED ON 25 CYCLES AT 2 CYCLES PER WEEK

Cycling of specimens can start on a Tuesday or a Friday.

Minimum number of specimens for durability test is 3:

Specimen 1 - Sulphate only
Specimen 2 - Sulphate + Frost
Specimen 3 - Frost only.

DAY POINT	ACTIONS
TUESDAY (PM)	Take all specimens out of drying cabinet. Place Nos. 1 and 2 on sulphate plate for 20 minutes.
	Place No. 3 on water plate for 20 minutes.
	Place specimens in boxes with 5ml of water. Cover with cling film and store in the laboratory.
WEDNESDAY	No action required.
THURSDAY (AM)	Put the boxes containing Nos. 2 and 3 into the freezer.
THURSDAY (PM)	After 5 hours, remove the boxes and allow to thaw for about 30 minutes in air at ambient laboratory temperature.
	Remove all three specimens from their respective boxes, inspect and record any damage using the templates if necessary.
	Place the specimens in dry boxes and place in a drying oven for 24 hours.
FRIDAY (PM)	Take all specimens out of the drying cabinet. Place Nos. I and 2 on sulphate plate for 20 minutes.
	Place No. 3 on water plate for 20 minutes.
	Place specimens in boxes with 5 mls. of water. Cover with Clingfilm and store in the laboratory.
SATURDAY	No action required.
SUNDAY	No action required.
MONDAY (AM)	Put the boxes containing Nos. 2 and 3 into the freezer.
MONDAY (PM)	After 5 hours, remove the boxes and allow to thaw for about 30 minutes in air at ambient laboratory temperature.
	Remove all three specimens from their respective boxes, inspect and record any damage using the templates if necessary.
	Place the specimens in dry boxes and place in a drying oven for 24 hours.
TUESDAY (PM)	Restart cycle.

MS-B.1 Freeze/thaw test of masonry panels

B.1.0 CONTENTS

B.1.1 SCOPE

This recommendation specifies a method of determining the freeze/thaw resistance of unit masonry in the form of small walls. Guidance is given on the preparation of the specimens, the conditioning required before testing, the apparatus, the method of test, the recording of the results, the method of interpretation of the results and the contents of the test report. Additional background information is given in B.1.10.

B.1.2 SPECIMENS (Size, shape and numbers)

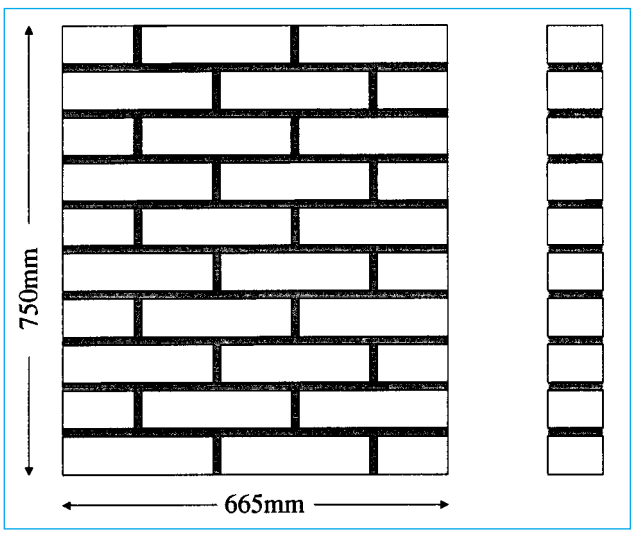

Fig. 1 – Recommended panel size (example units have a face size of 225 × 65 mm).

The method is designed to test panels of masonry consisting of panels 750 mm high by 665 mm wide. The apparatus described will accommodate two 750 mm × 665 mm panels placed side by side or other sizes if provided with a masking plate. Sufficient units should be sampled to allow the construction of one or more panels and provide 25 for additional tests as required. Ten of the additional units should be randomly selected for a water absorption test in accordance with LUM A.4. There is normally adequate replication of units and joints in a single panel.

B.1.3 PREPARATION AND CURE

The specimen shall be constructed on steel channel bases with the sides at right angles to the base and the top parallel to the base (checked with a spirit level). The construction should, where possible, be carried out with the units in the same attitude as they will be in the masonry. All joints shall be of uniform thickness and full of mortar. Frogs should not be exposed at the end of a specimen. Perforations should not be filled. Any acceptable masonry mortar may be used or a 1:4.5 HAC:sand mix may be used for rapid testing. The mortar joints in the panel should normally have a flush finish.

B.1.4 CONDITIONING OF SPECIMENS

The OPC specimens shall be stored for 28 days in the laboratory at a temperature of between 10°C and 30°C. High Alumina Cement mortar panels should be cured for at least 3 days. Excessive evaporation of water should be prevented, *e.g.* by use of plastic sheet. Temperature and humidity of the laboratory should be recorded continuously.

B.1.5 APPARATUS

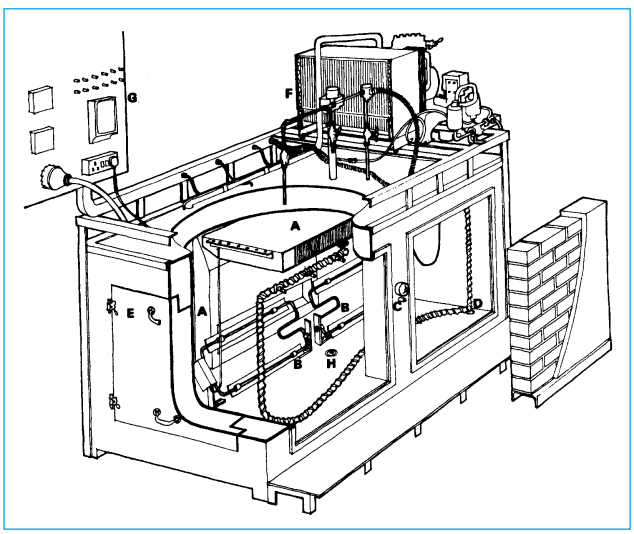

Fig. 2 – Cut-away diagram of the freezing test apparatus.

Fig. 2 gives a general view of the equipment and the arrangement of the various components in the cabinet. The cabinet is of double-skin galvanized sheet-metal construction with internal measurements of 1 m deep × 1.7 m long. The space between the skins is filled with

150 mm of polyurethane foam. The two openings at the front of the cabinet are 640 mm wide × 680 mm high, and are closed by the test panels which are sealed to the outside of the cabinet by a foam rubber gasket. A 1 kW radiant heater (B) is located 70 cm from the face of each panel. Each heater consists of a loop of mineral-filled element (180 cm long) fitted with a polished aluminium reflector. At the appropriate part of the cycle, water may be applied to the face of the masonry at a rate of 2 litres/min from three jets (D) directed at the top of each panel. The rate of application is sufficient to give a continuous film of water running down over the face of the test panel during the spray period, and this water is subsequently drained through a hole in the base of the cabinet. The spray system is protected from frost-damage by draining it (H), immediately after spraying, through a system of solenoid-operated valves. The exposed pipework is wrapped with soil-heating cable to provide additional protection against freezing. The cabinet is mounted in a steel frame which provides a platform for the refrigeration unit (F). ***This unit is a Frigidaire AP5 (now known as a Porter Lancastrian PLA5) driven by a 2 hp motor and operating two 'Searle-Bush' evaporators (A) mounted inside the cabinet.*** The fans in the two evaporators run continuously throughout the cycle to provide air circulation within the cabinet. Air temperatures in the cabinet during the freeze/thaw cycle are controlled by platinum resistance thermometers (C). The temperature during the freezing part of the cycle is controlled by regulating the flow of pumped coolant via a magnetic valve and the heat input during thawing is controlled by on-off switching of the electrical heaters. The automatic sequencing of events during a freeze/thaw cycle is performed by a series of electro-mechanical timers mounted in a separate control panel (G). The interior may be inspected, if necessary, via the panel (E).

B.1.6 PROCEDURE

Totally immerse the panel in water at a temperature of 10-20°C for 7-8 days, then remove and allow it to drain for between 10 and 20 minutes. Expose one face to repeated cycles of freezing and thawing. Enclose the other face and the top and the sides of the panel in a close fitting jacket of 25 mm thick expanded polystyrene. Subject the wall to a cycle of freezing and thawing, consisting of:
(1) 132 ± 1 minutes freezing at an air temperature of -15 ± 3°C;
(2) 22 ± 0.5 minutes thawing with radiant heaters to a maximum air temperature of 25 ± 1°C;
(3) During the last 2 minutes of the thawing period spray with water at a temperature of 10-20°C at 2 l/min. to replace that lost by evaporation; and
(4) 3 minutes dwell to drain away the water in the system.

B.1.7 TEST RESULTS FAILURE CRITERIA

The panels are examined daily at the end of the thaw part of the cycle for obvious signs of damage. The condition should be assessed and recorded in detail at the end of the 10th cycle, at the end of the 100th cycle, and at any intermediate stage if the damage has reached a level which may be deemed to be a failure. The period of interruption of cycling for examinations should be the minimum required. After the completion of 100 cycles (or less) the panel is removed and dismantled. Each unit and all mortar joints are carefully examined for surface damage and any incipient separation of the surface layers. Fig. 3a shows typical damage at the end of a test.

CLASSIFICATION OF DAMAGE

Condition should be assessed in terms of the classification below and recorded before the start of the test and subsequently as given above. Damage shall be classified (see Fig. 3b) as:

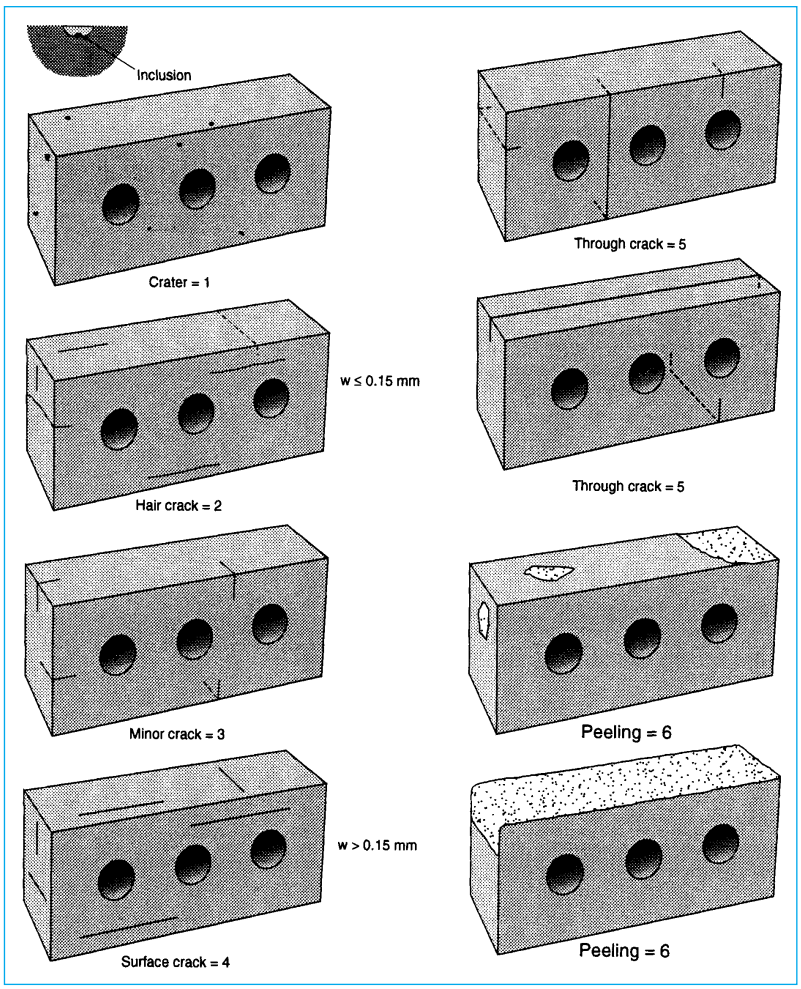

Fig. 3a – Illustration of some types of damage which may/may not be indicative of failure.

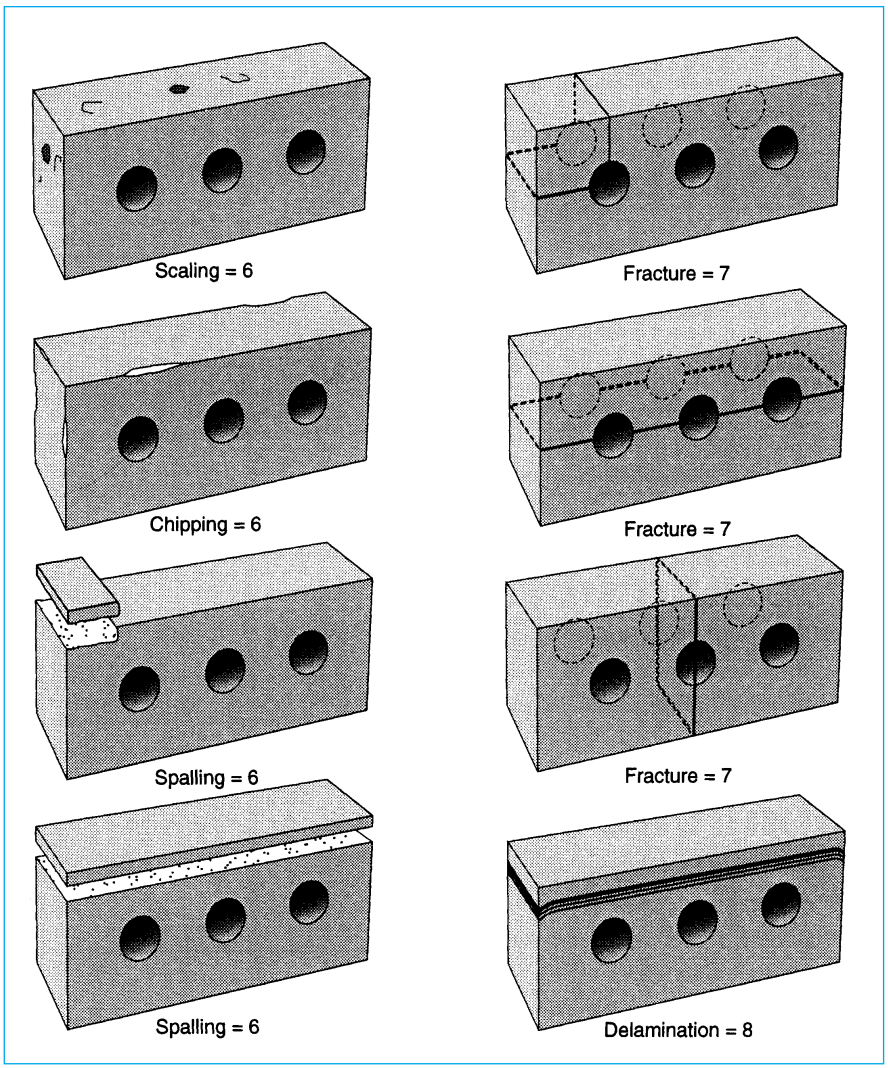

Fig. 3b – Illustration of the types of damage possible in the Freeze-Thaw test.

Flaking: (= peeling, scaling and chipping) The loss of laminar material from the exposed face not exceeding 10 mm in either face dimension. This damage is not considered significant unless it causes visible alteration to the colour or texture of the unit viewed with the naked eye from a distance of 3 m.

Spalling: The loss of laminar material from the exposed face exceeding 10mm in either face dimension.

Crumbling: The loss of particulate material from the exposed face resulting in areas of damage exceeding 10mm in either face dimension (alternative to spalling).

Cracking: The formation of cracks readily visible to the naked eye in the exposed face.

Incipient lamination (hollowness): Cracks forming parallel to the surface detected by tapping with a small metal rod but not visible. Such damage should be noted but only reported at the end of the test if confirmed by checking the units after removal.

Delamination: Cracks in the face of any unit which have formed during the test but which are only apparent after dismantling the panel. They are usually within 20 mm of the face of the unit. Cracking of webs between perforations is a special case of delamination.

Fracture: This is an unlikely mode of failure for a mortared panel test, due to the restraint of adjacent units, but may occur for individual unit tests.

If the units, when classified by this method, show no signs of failure after 100 cycles, they would be expected to be durable under all conditions of exposure normally found in practice. Units showing no signs of failure after 10 cycles, but having failed after 11 - 100 cycles, would be expected to be durable under most conditions of exposure, but some failure could occur if they were used in a situation where repeated freeze/thaw cycling occurred when the units were saturated with water. Units which fail in less than 10 cycles are considered to be suitable for internal use only. Mortar, if of interest, should be classified in a similar way.

B.1.8 TEST REPORT

1. A reference to this method.
2. A description of the specimens including their overall size and shape, bonding and joint thickness.
3. The method of sampling of the units.
4. The properties of the units including strength and, where appropriate,water absorption, IRS, density.
5. The composition and strength of the mortar used.
6. The date of preparation of the specimens and the date of the test.
7. The conditions of storage.
8. The condition of the panels, the mortar joints and of all the individual units after each of 10, 50 and 100 freezing cycles.
9. Failure characteristics of the units, *e.g.* corners spalling, face spalling, loss of surface finish only, crumbling, powdering, hollowness, perforations exposed, etc.
10. Failure characteristics of the mortar if required.
11. Photographs or accurate drawings of visible failure states.

B.1.9 BIBLIOGRAPHY

1) West, H.W.H., Ford, R.W. and Peake, F., 'A panel freezing test for brickwork', *Br. Ceram. Trans, J.* **83** (1984) 112-115.
2) Butterworth, B., 'Frost resistance of bricks and tiles: A review', *Br. Ceram. Trans, J.* **1** (1964) 203.
3) Stupart, A.W., 'A survey of literature relating to frost damage in bricks', *Masonry International* **3** (2) (1990) 42-50.

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B.1.10 BACKGROUND

Joint finish: In practice, the type of joint finish is considered to have a marked influence on the durability of exposed masonry, mainly due to the influence that it has on the penetration of water into the face. In the present test, the masonry is saturated by complete immersion, thus the type of joint finish is unimportant. Care should be taken to ensure that the units are in a moisture state appropriate to the objectives of the test and that the consistence of the mortar is properly adjusted to the state of the units.

Rate of heat transfer to the panel: In order to ensure that the freeze/thaw conditions can be replicated by other laboratories if similar equipment is constructed, the rates of heating and cooling of a pair of reference panels were determined. Two concrete panels, each measuring 762 × 686 × 114 mm, were cast from a cement/sand/aggregate mix (1:1:3 ratio by volume). Thermocouples were installed during casting to measure temperatures at nine points across the face of each panel at a depth of 10 mm, measured from the surface exposed during the test. The nine points were distributed uniformly over the area of the panel. After an extended period of curing and drying, the panels were weighed and the density determined (2300 kg/m). The panels were installed in the freeze/thaw apparatus and fitted with 25 mm expanded polystyrene insulation jackets as for a normal test. The air temperature in the cabinet was reduced to - 15 ± 2°C as quickly as possible (approximately 10 min) and controlled at this level. The time required for the temperature at the centre point of each panel at 10 mm depth to fall from + 10°C to 0°C was 80 min. The panels were then subjected to repeated heating and cooling cycles using the same conditions as those in the normal procedure (132 min cooling and 20 min heating) but omitting the 2 min spraying with water. When temperatures measured within the panels indicated that consecutive cyclic conditions were the same (after about 8 cycles), the mean minimum temperature attained at the nine measurement positions was determined over a number of cycles. This mean value was - 8± l°C. The range of minimum temperatures measured over the area of the panel (9 readings) was ± 3°C from the mean. After repeated cycling, the maximum temperature attained at a depth of 10 mm at the middle position of the panel was -1°C (± 0.5°C).

Mechanism: During the first few cycles, the freezing zone extends progressively towards the rear face of the panel, so that after about 8 cycles the water contained in the masonry remains permanently frozen except for that contained in the zone extending approximately 12 mm from the face, which is exposed to cyclic freeze/thaw conditions. As this zone is re-frozen subsequent to thawing, a layer of water is trapped between two layers of ice. This condition is considered to impose greater stresses in the unit than if the liquid water were free to move away from the advancing freezing zone. Fig. 4 shows the temperature distribution across the thickness of the panel during typical cycle.

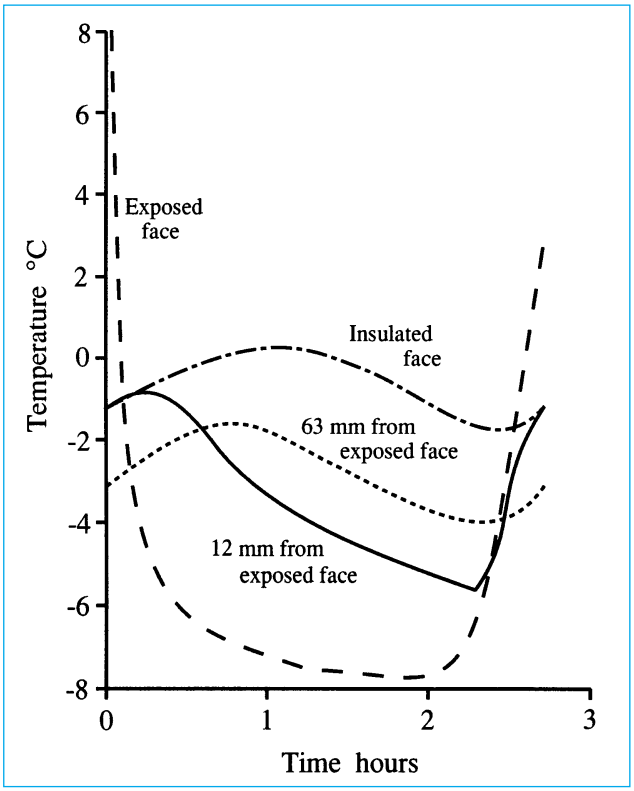

Fig. 4 – Temperature distribution during a typical cycle.