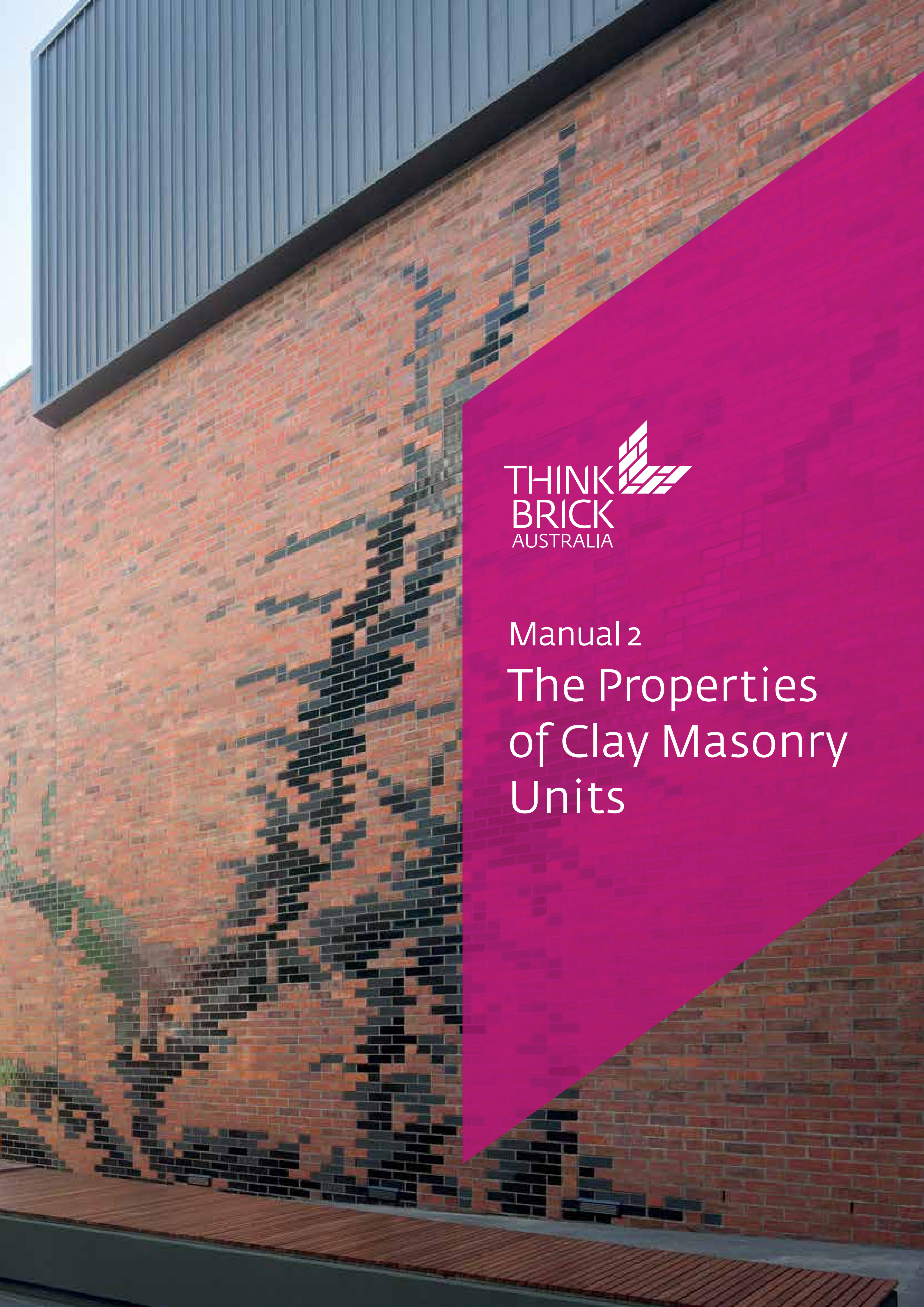

THINK BRICK AUSTRALIA

Manual 2

# The Properties of Clay Masonry Units

Cover: The multi-residential development, **87 Chapel Street**, developed for PPHA (Port Phillip Housing Association) consists of two, four-storey apartment buildings and a feature wall that is centrally located in a courtyard. The art wall has been created with two different types of brick: oil-pressed clay bricks provide the background for a large "creeper vine", which has been recessed into the background with glazed bricks in three different colours. Construction by Hacer Group, bricklaying by Matt Vaughan Pty Ltd.

Architect: MGS Architects
Artist: Sue Buchanan
Photography: John Gollings

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THINK BRICK AUSTRALIA

PO Box 275, St Leonards NSW 1590 Australia
Suite 7.01, Level 7, 154 Pacific Highway, St Leonards NSW 2065 Australia
Telephone +61 2 8448 5500
Technical hotline 1300 667 617
ABN 30003873309
**www.thinkbrick.com.au**

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# 1. Introduction

This manual discusses the properties of clay masonry units including strength, durability, size, tolerances and ability to absorb water. The information is presented in terms of the current Australian /New Zealand standard AS/NZS 4455, *Masonry Units, Pavers, Flags and Segmental Retaining Wall Units, Part 1: Masonry Units*[1] and its companion standard, AS/NZS 4456 *Masonry Units, Segmental Pavers and Flags – Methods of Test*[2].

For all states except Western Australia, the CBPI Laboratory, a NATA-accredited facility formerly operated by the Clay Brick and Paver Institute (now Think Brick Australia), is the principal data source. Test information from WA comes from the now defunct Building Development Laboratories Pty Ltd. A small number of results come from other NATA-accredited laboratories.

No information is available for the products of the few Australian clay masonry manufacturers that are not Think Brick Australia members.

Note that the information on the properties of clay masonry units provided in this publication is based on data collected until the mid-1980s. For this reason it should be treated only as an illustration of the variability in the properties of fired clay masonry units according to their method and place of manufacture.

# 2. Standards

## 2.1 General

In construction, there is a hierarchy of minimum requirements for essential properties, designed to ensure that technical requirements do not provide barriers to new materials, techniques and designs. The Building Code of Australia (BCA)[3] provides minimum performance requirements for all structures in Australia.

The Australian Standard AS 3700 *Masonry Structures*[4] provides the basic rules for the design and construction of masonry structures to meet the requirements of the BCA.

All other standards covering the properties of building products such as bricks and blocks are written in such a way as to describe the properties of the materials concerned. They also provide test methods for the determination of those properties and set very low, or no, limits of performance. It is the designer's responsibility to specify the performance level required for the units selected for use in a given project.

The current masonry unit standard, AS/NZS 4455 Part 1, covers all masonry units (fired clay, concrete, calcium silicate, autoclaved aerated concrete and dimension stone). It does not cover unfired earth units.

In accordance with the general intent of AS 3700 there are no specific performance requirements apart from some basic product requirements such as strength, dimensional deviations and integrity. If verification of the nominated values is required, it refers to AS/NZS 4456 which describes the test methods for the determination of 17 different properties of masonry units and segmental pavers, as well as sampling procedures and the assessment of the mean and standard deviation of test results. Not all the tests described in this standard are required to be specified. AS 3700 sets out the tests and properties required in each case.

## 2.2 Defining a masonry unit

Section 1.4 of AS/NZS 4455 Part 1 provides definitions for the terms used, along with illustrations of configurations and terms applied to masonry units in the standard.

Whereas earlier standards defined bricks in terms of their shape and maximum volume, no such definition exists in AS/NZS 4455.

Section 1.4.12 of the standard provides the following definitions:

a) Solid unit – Unit that may contain recesses not greater than 10 percent of gross volume and intended to be laid with full bed joints.

b) Cored unit – Unit with cores, intended to be laid with its cores vertical and with full bed joints.

c) Hollow unit – Unit with cores, intended to be laid with its cores vertical and with face-shell-bedded joints.

d) Horizontally-cored unit – Unit with cores, intended to be laid with its cores horizontal and with full bed joints.

e) Special purpose unit – Unit intended for a special purpose that does not fall within the definitions of items a) to d) above.

Note that according to section 6.5.2 of AS 3700, dealing with the fire resistance period for insulation, the material thickness of a cored unit with 30 percent or less perforations is accepted as identical to a solid unit.

## 2.3 Quality

Standards do not refer to, or provide guidance on, the classification of bricks according to appearance. However in the trade when it comes to ordering, it is still common to describe bricks as first, second, or common quality.

The general principle regarding quality is that the standard specifies only the essential properties that should be common to all bricks, and more stringent requirements that might need to be complied with – higher strength, higher precision, particular colours and textures – would best be specified by the prospective purchaser as the need arises.

A manufacturer's display panels are useful guides to the expected quality and appearance of a specific product.

AS/NZS 4455 Part 1 Appendix D, *Purchasing Guidelines* provides guidelines for a purchasing agreement for masonry units.

## 2.4 Demonstrating compliance

AS/NZS 4455 Part 1 Appendix A, *Demonstration of Compliance for Strength* provides acceptable methods for demonstrating compliance with the strength requirements of this standard.

If compliance of a single lot is to be demonstrated with a specified characteristic value, then the mean value of the test results has to be equal to or greater than the specified characteristic value, plus 1.2 times the unbiased standard deviation.

The value of the standard deviation may be based on existing data (if more than 30 specimens), or can be taken as 0.15 times the mean.

For demonstrating compliance for lots taken during continuous manufacture, the mean of the sample must not fall below a control level, which is set as greater than the following:

Specified characteristic value $+ 1.65s - \frac{2s}{\sqrt{n}}$

where n is the number of specimens in each sample and s is the unbiased standard deviation.

AS/NZS 4455 Part 1 Appendix B, *Means for Demonstrating Compliance with this Standard* provides guidance on other compliance systems including:

- Statistical sampling
- Product certification
- Supplier's quality management system
- Other means proposed by the manufacturer or supplier and acceptable to the customer.

The physical properties listed in AS/NZS 4455 Part 1 Appendix E, *Testing for Additional Properties* are not requirements of the standard. However some may be specified at the discretion of the purchaser. Properties listed in this appendix have to be determined according to the test methods in AS/NZS 4456.

## 2.5 Test sample

Obviously it is impractical to test every unit. Therefore a sample taken from a consignment is assumed to be representative of the rest of the units in that consignment or lot. Whether it is so will depend upon the person doing the sampling. That person must not allow any bias in the way the sample is selected.

AS/NZS 4456.1 *Sampling for Test*[5] sets out appropriate sampling techniques. Table 1 of that standard provides information regarding the numbers of units needed for the individual tests.

This document also provides guidance on the use of units for more than one test, and other reporting and administrative requirements.

# 3. Essential physical properties

## 3.1 General

Section 2.1 of AS/NZS 4455 Part 1 requires masonry unit suppliers to make available the work size, including the face shell width for hollow units, the characteristic unconfined compressive strength for all units, and to declare the salt attack resistance grade.

## 3.2 Dimensions and tolerances

### 3.2.1 General

Depending on their deviation from the declared work size and the method by which compliance to a specification is determined, masonry units are divided into five categories: DW0, DW1, DW2, DW3 and DW4, where DW stands for dimensional deviations for walling units. The relevant tolerances for each of these categories are listed in Table 2.1 of AS/NZS 4455 Part 1 (see Table 1).

Note that on those rare occasions when pavers are sold as masonry units, the tolerances for the different categories listed in Table 1 apply.

**Table 1.** Dimensional deviations of masonry units

| Category | Work size dimensions, mm | | |
|---|---|---|---|
| | Under 150mm (for example, width & height) | 150 - 250mm (for example, length) | Over 250mm (for example, length of blocks) |
| DW0 | No requirement | | |
| DW1* | ±50 | ±90 | ±100 |
| DW2* | ±40 | ±60 | ±70 |
| DW3 | By agreement between supplier and purchaser | | |
| DW4** | Standard deviation of not more than 2 mm and the difference between the mean and the work size of not more than 3 mm. | | |

* As determined by the cumulative method over 20 units (Method A of AS/NZS 4456.3)
** As determined from the individual dimensions of 20 units (Method B of AS/NZS 4456.3)

### 3.2.2 Selection of test method

AS/NZS 4456.3 *Determining Dimensions*[6] provides two methods for measuring the dimensions of masonry units. The manufacturer can nominate the method appropriate to their manufacturing process and quality assurance program.

### 3.2.3 Determining dimensions

**By cumulative measurement**

Generally, the cumulative measurement method described in Method A of AS/NZS 4456.3 is the most appropriate for fired clay masonry. It is easy to apply, requiring the measurement of the overall length, width and height of 20 units placed side by side in a straight line (see Figure 1).

While the units are lined up for height determination, a quick appraisal may be made of their general appearance, particularly colour, texture and size variation.

**By individual measurements**

This method is rarely used for fired clay masonry, and then only by prior arrangement between the supplier and the customer. It involves the measurement of the length, width and height of each of 20 units.

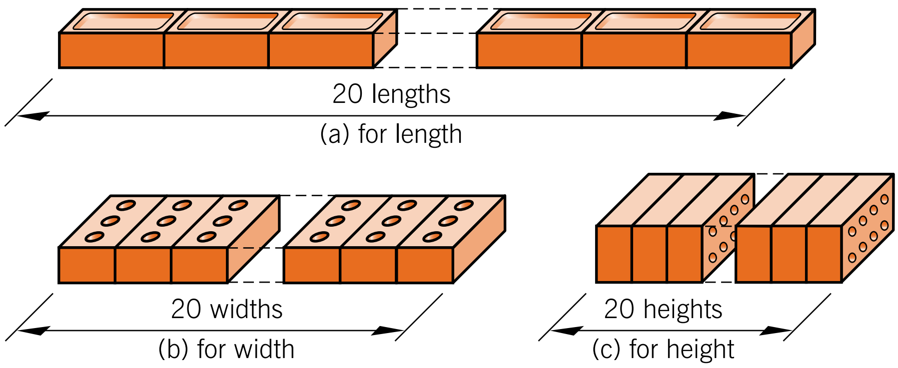



**Figure 1.** Measuring cumulative dimensions

### 3.2.4 Compliance

All masonry units are expected to comply with the requirements of category DW1 unless by prior agreement to the contrary. No tolerances apply (category DW0) where the intended surface character of the overall unit is irregular or rough, for example, tumbled bricks.

Where it is intended that only a face or faces of the unit are irregular – textured or rock face bricks for example – the length and height of such units have to comply with category DW1. In this circumstance there are no width tolerance requirements other than that the average width on any plane parallel to the bed has to be at least 90 percent of the declared work size.

Supply of units to closer tolerances such as in category DW2, DW3 and DW4 must be negotiated with the supplier. Some types of units may not be available to those tolerances.

Compliance with Category DW4 is determined by measuring the individual dimensions corresponding to each of the three principal work sizes as described by Method B in AS/NZS 4456.3.

### 3.2.5 Consistency between deliveries

For units in dimensional categories DW1 and DW2, the overall dimensions of 20 units taken from separate deliveries of units of the one type and the subject of a single order must not differ by more than 40 mm.

## 3.3 Characteristic unconfined compressive strength

### 3.3.1 General

In line with requirements set out in AS 3700, the masonry unit standard AS/NZS 4455 Part 1 requires that "the suppliers of masonry units shall make available the .... characteristic unconfined compressive strength ($f'_{uc}$)."

The use of a characteristic strength is to minimize the risk of units being weaker than the nominated strength. The use of an unconfined strength provides a more reasonable assessment of their bearing capacity when built in a wall.

### 3.3.2 Characteristic strength

This test measures the strength of clay masonry units only, not that of the masonry assembly. Even so, problems can arise in understanding the meaning or reliability of results obtained from a small sample of units.

As stated before, it is impractical to test every unit in a consignment, therefore the strength of the lot or consignment must be assessed from the strength of a sample. The number of specimens tested in a sample is very small in relation to the large number of units that the sample represents.

It is reasonable to expect that the test results could be different if another sample were taken from the same production run. To overcome this problem, characteristic strength values derived from accumulated test results are often specified.

For these reasons, the standard is based on the 95 percent characteristic value at a 75 percent confidence level. This means that there is a 75 percent certainty that the strength of 95 percent of the units in the lot is higher than the characteristic strength determined from testing the sample.

Although AS/NZS 4455 Part 1 does not require the calculation of a characteristic strength, it provides means for demonstrating compliance with a specified characteristic value.

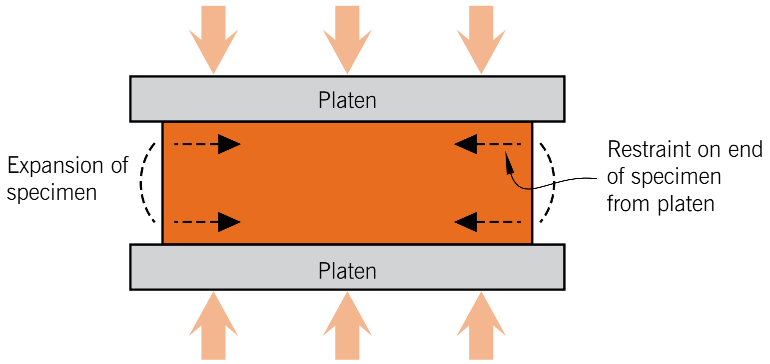
### 3.3.3 Confined vs unconfined – what's the difference?

When a uniaxial compressive load is applied to a clay masonry unit, the specimen is shortened along the axis of the load, and broadened in all directions at right angles to the load. Put simply, the unit is squashed. This broadening sets up tensile forces in the unit that may lead to its failure.

At the upper and lower surfaces of the unit, the tendency to spread is restrained by the testing machine platens (see Figure 2). The friction between the platens of the testing machine and the bearing surfaces of the test specimen causes greater restraint in shorter specimens than in tall ones, thus preventing the specimen from spreading side-ways. More force is required to cause such specimens to fail.

Therefore, the apparent compressive strength resulting from such a test on a masonry unit is critically dependent on the ratio of the height of the specimen to the smaller cross-sectional dimension. This is called the aspect ratio. As this ratio decreases, the observed strength of the specimen increases because of the confining effects of the testing machine platens.

**Figure 2.** Mechanism of platen restraint




The result of this test without compensating for the effect of the platen restraint gives the confined compressive strength, commonly known as the compressive strength of the material.

The simplest way to compare the compressive strength of units with different aspect ratios is to convert the results of the standard test to an equivalent 'unconfined compressive strength' value, in which the effects of platen restraint have been eliminated. This factor is called the aspect ratio factor ($K_a$) (see Table 2). As a guide, for traditional size bricks, the value for the *characteristic unconfined compressive strength* is approximately 60 percent of the *characteristic* (confined) *compressive strength*.

### 3.3.4 Test method

The method for determining the unconfined compressive strength (C) of masonry units is given in AS/NZS 4456.4 *Determining Compressive Strength of Masonry Units*[7].

The units are tested 'as received' instead of being saturated with water before testing as was done in the past. The bearing area and the aspect ratio are calculated from the declared work size rather than from measurements of the individual units.

The test involves placing a unit between two sheets of plywood in a compression testing machine and subjecting it to increasing load until failure. From the maximum load, the unconfined compressive strength is calculated using the following equation:

$$C = K_a \, 1000 \, P/A$$

where C = unconfined compressive strength in megapascals

$K_a$ = aspect ratio factor derived from Table 1 of the standard

P = total load at which the specimen fails, in kilonewtons

A = area, in square millimetres, calculated as follows:
For whole masonry units of a specified work size, the area is calculated from the work size. When this is not known, the mean dimensions of three units are used. When only part of the unit is tested, the work width multiplied by the cut length is used.

This correction factor ($K_a$) as set out in Table 2 (from data prepared by Page[8]) is used to compensate for the confining effects of the platen during testing.

**Table 2.** Aspect ratio factor ($K_a$)

| Height-to-thickness ratio | 0 | 0.4 | 1.0 | 5.0 or more |
|---|---|---|---|---|
| Aspect ratio factor ($K_a$) | 0 | 0.50 | 0.70 | 1.00 |

*Notes:*

1. *The thickness used for evaluating the height-to-thickness ratio is:*
   I. *For solid or cored masonry units – the work size width of the unit or the minimum width of a portion of the unit tested; or*
   II. *For hollow masonry units – the work size of the face shell.*
2. *The height used for evaluating the height-to-thickness ratio is the work size height.*
3. *Linear interpolation is permitted.*

### 3.3.5 Requirements

As part of the integrity requirement in AS/NZS 4455 Part 1, solid or vertically cored masonry units are expected to achieve at least 3 MPa characteristic unconfined compressive strength, while the requirement for horizontally cored units is 2.5 MPa.

As discussed previously (Section 2.4), the method for demonstrating compliance with strength is given in Appendix A of AS/NZS 4455 Part 1.

### 3.3.6 Applying compressive strength results

Under compressive loads masonry walls develop tension cracks as do individual units in a compression machine. Although it is the tensile strength of the unit that controls the strength of the wall, there is no standard method for measuring this.

Therefore AS 3700 bases the compressive strength of masonry assemblies on the characteristic unconfined compressive strength of masonry units and the mortar type used for the construction. These relationships were derived by fitting to test results and are illustrated for clay masonry units in Table 3.

Table 4 sets out typical compressive strengths (unconfined) for Australian fired clay masonry, based on accumulated test results.

**Table 3.** Characteristic compressive strength of masonry ($f'_{mb}$)

| Type of masonry unit | Bedding type | Mortar class | Characteristic unconfined compressive strength ($f'_{uc}$) MPa | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 5 | 10 | 15 | 20 | 25 | 30 | 40 | ≥50 |
| Clay | Full | M2 (e.g. C1:L2:S9) | 2.5 | 3.5 | 4.3 | 4.9 | 5.5 | 6.0 | 7.0 | 7.8 |
| Clay | Full | M3 (e.g. C1:L1:S6) | 3.1 | 4.4 | 5.4 | 6.3 | 7.0 | 7.7 | 8.8 | 9.9 |
| Clay | Full | M4 (e.g. C1:L½:S4½) | 4.5 | 6.3 | 7.7 | 8.9 | 10.0 | 10.9 | 12.7 | 14.1 |
| Clay | Face shell | M3 (e.g. C1:L1:S6) | 3.6 | 5.1 | 6.2 | 7.2 | 8.0 | 8.8 | 10.1 | 11.3 |

**Table 4.** Typical compressive strengths (unconfined) for Australian fired clay masonry

| Place & method of manufacture | No of sets tested | Characteristic unconfined compressive strength ($f'_{uc}$) (MPa) | Range (MPa) |
|---|---|---|---|
| **New South Wales** | | | |
| extruded | 131 | 25 | 12–48 |
| pressed | 41 | 16 | 9–34 |
| **Queensland** | | | |
| extruded | 45 | 16 | 9–23 |
| pressed | 22 | 13 | 6–23 |
| **South Australia** | | | |
| extruded | 53 | 28 | 13–46 |
| pressed | 5 | 19 | 14–24 |
| **Tasmania** | | | |
| extruded | 35 | 23 | 8–48 |
| **Victoria** | | | |
| extruded | 98 | 34 | 10–59 |
| pressed | 58 | 26 | 14–41 |
| **Western Australia** | | | |
| extruded | 30 | 18 | 11–33 |

*Note: This data was collated from testing conducted by the former CBPI Laboratory until the mid-1980s. The figures in the table are for general information only and cannot be used for specific applications.*

## 3.4 Resistance to salt attack

### 3.4.1 Standards

Resistance to salt attack is required by Table 5.1 of AS 3700. Salt attack resistance grades for masonry units are defined in AS/NZS 4455 Part 1. The test method is set out in AS/NZS 4456.10 *Determining Resistance to Salt Attack*[9].

### 3.4.2 What is durability?

Put simply, the term durability refers to the resistance of a clay masonry unit to attack by soluble salts. It is vital that the ability of units to resist salt attack matches or exceeds the severity of the exposure to salt attack. If not the result may be extensive damage to the units.

The durability of clay masonry units varies. The most important factors are the severity of the environmental conditions the units are exposed to (that is, moisture and the availability of soluble salts), and the amount of glass formed in the masonry unit body during firing. However the durability of a particular type of masonry unit will not vary much from one production run to another if the raw materials and manufacturing conditions are consistent.

Although there is a place in construction for every masonry unit, not every unit is suitable for every requirement. Each type of unit will fall into one of the durability classes defined in Table 5.

**Table 5.** Salt attack resistance grade of masonry units

| Grade | Requirement/description |
|---|---|
| Exposure | (a) Supplier's experience, according to which it is possible to demonstrate that the product has a history of surviving in saline environments.<br>(b) Less than 0.4 g mass loss in 40 cycles in AS/NZS 4456.10 Method B, for materials other than sandstone or porous limestone. |
| General Purpose | (a) Supplier's experience according to which it is possible to demonstrate that the product has a history of surviving under non-saline environmental conditions similar to those existing at the site considered.<br>(b) Less than 0.4 g mass loss in 15 cycles in AS/NZS 4456.10 Method B, for materials other than sandstone or porous limestone. |
| Protected | Units not complying with the requirements for general purpose or exposure grades.<br>As a general rule, units in this category could be expected to suffer substantial and early failure when tested in accordance with AS/NZS 4456.10. |

The test given in AS/NZS 4456.10 may be carried out either with sodium chloride (representing seawater) or sodium sulphate (representing salty ground water). It must be noted that satisfactory performance of a sample in sodium sulphate solution usually guarantees a satisfactory performance in a 14 percent solution of sodium chloride solution, whereas satisfactory performance in sodium chloride *does not* guarantee satisfactory performance in sodium sulphate.

This method of test was developed by the former CBPI Laboratory to assess the likely performance of new products. Extensive trials by this laboratory and brick industry laboratories showed that the current method will deliver reproducible results if it is carried out at the right temperature by experienced testing personnel using the correct equipment. The test correlates with field performance in saline environments.

It is important to understand that this test does not determine the durability of masonry to all circumstances. It only assesses the unit's resistance to the action of salt attack under artificial conditions. For example it cannot be used to determine the frost resistance of a clay masonry unit (see Section 4.2).

### 3.4.3 The test method

**General**

There are two test methods listed in AS/NZS 4456.10. Method A applies to stone and Method B (set out below) applies to materials other than stone.

**Method**

Specimens cut from masonry are subjected to cycles of soaking in a salt solution kept between 16 to 22° C, followed by oven drying and cooling. When particle losses occur, the total mass of particles lost from each specimen is determined by weighing.

A sample is considered to be salt attack resistant when no test specimen has a total mass particle loss of more than 0.4 grams.

When resistance of a sample against the action of sodium chloride is to be determined, the sodium sulphate solution used in the test method may be substituted with a 14 percent solution of sodium chloride.

**Figures 3 & 4.** Salt attack

*Salt attack may cause a weak mortar to crumble or a non-durable masonry unit to spall, as these extreme examples show.*

**The mechanism of salt attack on porous materials**

Although this manual is concerned only with clay masonry units, the problem of salt attack also occurs in other porous building materials such as concrete and some natural stones. These will fail in service if the wrong product is used or if the conditions are too severe.

However it should be remembered that not all salts cause damage, even to products liable to attack. In practice, salt attack is usually caused by sodium sulphate or sodium chloride.

The way in which soluble salts attack porous materials is simple. The salt concentration in the solution gradually increases as the material dries. Crystallisation begins when the volume of water remaining cannot dissolve all the salts present.

Considerable pressure is applied to the walls of the pore during crystallisation. When this occurs near the surface of the material, the pressure applied on the pore walls may exceed the tensile strength of the material and fretting will take place.

# 4. Other properties

## 4.1 Lateral modulus of rupture

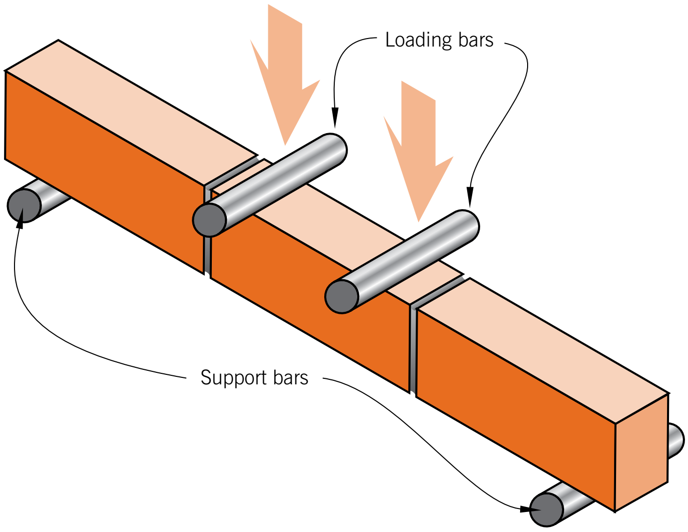
Lateral modulus of rupture measures the extreme fibre tensile stress at the face of a masonry unit in bending. It is used to determine the horizontal bending capacity of masonry assemblies.

A test method is given in AS/NZS 4456.15 *Determining Lateral Modulus of Rupture*[10]. The test method set out in AS/NZS 4456.5 *Determining the Breaking Load of Segmental Pavers and Flags*[11] can also be used for calculating a modulus of rupture of the units. However owing to the nature of the test, the results derived from it are different from those obtained by the AS/NZS 4456.15 test.

It is believed that the results from the lateral modulus of rupture test are appropriate to describe the flexural tensile properties of the units in a wall and for that reason AS 3700 refers to this property when designing for earthquake and lateral loads.

In the absence of test data AS 3700 allows the use of a value of $f'_{ut}$ up to 0.8 MPa.

**Figure 5.** Four-point loading test for lateral modulus of rupture




## 4.2 Resistance to freezing and thawing

Owing to the difficulties experienced in relating the results of tests to the actual performance of fired clay units in a freeze/thaw situation, the current standard does not specify or recommend the use of any of the number of test methods available for the determination of this property. It suggests that the manufacturer's recommendation or local experience should guide the user.

A survey of the performance of fired clay bricks in the Australian Alps was carried out by the Brick Development Research Institute, (now Think Brick Australia) in 1980. The results showed that when properly fired bricks were protected from becoming saturated by water in the structure, no damage due to freeze/thaw occurred after several years. For more information on frost resistance refer to Research Paper 6[12].

**Figure 6.** An example of brick delamination due to the effect of freezing and thawing in an Australian alpine area.

## 4.3 Dimensional changes

### 4.3.1 Thermal expansion

The thermal expansion of clay masonry units varies slightly depending upon their colour and the method of manufacture, but the value is unlikely to be greater than 0.008 mm/m/°C.

### 4.3.2 Short-term wetting and drying change

All clay masonry expands on wetting and shrinks on drying, but the changes do not need consideration in practical brickwork.

### 4.3.3 Long-term permanent change (moisture expansion)

**General**

All fired-clay products, not just masonry, are subject to reactions that cause them to expand. The amount of long-term permanent change in unit dimensions (better known as brick growth) depends upon the material from which the units are made and how well that material was fired. The reactions begin when masonry units cool in the kiln, they are not significantly hastened by wetting and, for practical purposes, are irreversible.

Prior to the development of an accelerated test, expansion potential was determined from the measurement of the natural growth of clay masonry units. The coefficient of expansion ($e_m$) is the term given to the amount of growth expected to take place in fifteen years. (Formerly it was referred to as the '*e*' value, representing five years of expansion.)

This property is determined using an accelerated test developed by the Brick Development Research Institute, (now Think Brick Australia), first published in 1970.

This has been modified to accommodate situations when kiln-fresh units are not available for testing and is included in the current standard AS/NZS 4456.11 *Determining Coefficients of Expansion*[13]. Provision is also included for the estimation of past expansion and of residual expansion to 15 years for units of any age.

**Principle and procedures**

A sample of five units is used to represent the range of firing treatments of the product.

Reference points are established in the ends of the units and the distances between the points are measured between 24 and 34 hours after the units are drawn from the kiln. The units are then exposed to saturated steam at 100° C for four hours, after which they are cooled and re-measured. The difference in length multiplied by an appropriate factor gives the coefficient of expansion – the '$e_m$' value.

The same procedure is used for non-kiln fresh units, except that the units are first re-fired at 915° C, and cooled to room temperature for 24 hours before steaming.

**Interpreting and applying the results**

Characteristic expansions can be classified as:

- Low – up to 0.8 mm/m
- Medium – greater than 0.8 and up to 1.6 mm/m
- High – exceeding 1.6 mm/m.

However it must be remembered that:

- There is no pattern in characteristic expansions based on clay masonry unit colour or manufacturing methods.
- Due to variations in the manufacturing process, the characteristic expansion can vary considerably between batches, even within a single masonry type.

For these reasons designers should obtain current expansion data from the manufacturer for the specific unit they propose to use. A summary of the most recent general data (collected until the mid 1980s and believed to be still relevant today) is given in Table 6. As this table shows, only a small proportion of clay masonry can be expected to have growth characteristics higher than the top end of the mid 65 percent range.

Moisture expansion must be considered when designing and constructing a clay masonry structure. Design and construction details are described in Manual 9, *Detailing of Clay Masonry*[14] and Manual 10, *Construction Guidelines for Clay Masonry*[15].

Experience shows that if expansion gaps are provided at intervals calculated using the characteristic expansion of the unit used in the structure, stresses due to the restraint of further growth are unlikely to cause problems during the practical life of the building.

**Table 6.** Moisture expansion of Australian clay masonry units – $e_m$ values

| Place & method of manufacture | No. of sets tested | Average (mm/m) | Range (mm/m) | Mid 65 % (mm/m) |
|---|---|---|---|---|
| **New South Wales** | | | | |
| extruded | 93 | 1.5 | 0.3 – 3.7 | 0.7 – 2.2 |
| pressed | 55 | 0.8 | 0.1 – 2.6 | 0.4 –1.1 |
| **Queensland** | | | | |
| extruded | 36 | 0.8 | 0.1 – 2.1 | 0.4 – 1.0 |
| pressed | 25 | 1.0 | 0.3 – 2.5 | 0.6 – 1.4 |
| **South Australia** | | | | |
| extruded | 10 | 1.0 | 0.7 – 1.6 | 0.8 – 1.0 |
| pressed | 3 | 1.0 | 0.8 – 1.2 | – |
| **Tasmania** | | | | |
| extruded | 16 | 1.5 | 0.3 – 3.3 | 0.7 – 2.3 |
| **Victoria** | | | | |
| extruded | 88 | 1.0 | 0.3 – 2.6 | 0.6 – 1.2 |
| pressed | 65 | 0.8 | 0.1 – 3.0 | 0.4 – 1.0 |
| **Western Australia** | | | | |
| extruded | 30 | 0.6 | 0.1 – 1.3 | 0.3 – 0.8 |

*Note: This data was collated from testing conducted by the former CBPI Laboratory. The figures in the table are for general information only and cannot be used for specific applications.*

**How long does brick growth last?**

Studies by Zsembery and others[16] have shown differences in the growth rates between low and high-growth clay masonry units. However Cole[17] showed that, for practical purposes, there is a reasonably linear relationship between expansion and the logarithm of time. Put simply this means the rate of growth will slow gradually.

This can now be predicted accurately for up to fifteen years. However, there is evidence that it continues even after this time. The relationship means that about one third of the fifteen-year growth occurs in the first twelve months. Table 7 indicates the rate of growth versus time.

**Table 7.** Percentage of coefficient expansion ($e_m$) of fired clay products, versus time

| | Age of product | Moisture expansion (% of $e_m$) |
|---|---|---|
| Months | 1 | 13 |
| | 3 | 19 |
| | 6 | 26 |
| | 9 | 32 |
| Years | 1 | 36 |
| | 2 | 52 |
| | 3 | 61 |
| | 4 | 68 |
| | 5 | 73 |
| | 6 | 77 |
| | 8 | 84 |
| | 10 | 90 |
| | 12 | 94 |
| | 15 | 100 |

## 4.4 Lime pitting

If the clay used for brickmaking contains particles of limestone, these may be changed to quicklime when the units are fired. If the units are later exposed to moisture, either as vapour or water, the quicklime will slake causing it to expand. If the lime particles are large, this expansion can cause flakes or chips to be forced off the surfaces of a unit. Figure 7 shows an example.

In Australia this flaw is uncommon and is becoming even less so. Finer grinding and harder firing result in smaller particles of lime and stronger masonry units and therefore a reduced chance of spalling. A test method is set out in AS/NZS 4456.13 *Determining Pitting Due to Lime Particles*[18].

## 4.5 Absorption properties

### 4.5.1 Initial rate of absorption

The initial rate of absorption (IRA) is defined as the amount of water absorbed in one minute through the bed face of the unit. It is a measure of the 'suction' of the unit and in experienced hands is an important factor in the design of mortars that will bond strongly with units. This property is determined by the test method described in AS/NZS 4456.17:1997 *Determining Initial Rate of Absorption (Suction)*[19].

The bond between the masonry unit and mortar is largely influenced by the tug-of-war between the capacity of the unit to absorb water and the ability of the mortar to retain the water that is needed for the proper hydration of cement.

If the unit wins this tug-of-war (and sucks the water too quickly from the mortar), the mortar strung out for the bed joint stiffens so rapidly that the units in the next course cannot be properly bedded. If the mortar retains too much water the units tend to float on the mortar bed, making it difficult to lay plumb walls at a reasonable rate. In either case there will be poor bond.

The power of a clay masonry unit to absorb water is measured by the initial rate of absorption (IRA) test. It is usually considered that optimum values are between 0.5 and 1.5 $kg/m^2/min$.

**Figure 7.** Example of lime pitting

It would be convenient if all clay masonry had an ideal IRA value. However this is not possible and IRA values are used to ensure reasonable compatibility between the units chosen and the mortar in which they are laid:

- **Low suction clay masonry** needs a leaner mortar to give good bond. Usually increasing the proportion of washed sand in the mix does this.
- **High suction clay masonry** requires a mortar with very high water retention, shortening of the length of the bed joint and (rarely) wetting of the units to reduce their suction. Higher water retention can usually be achieved by adding lime to the mortar mix.

Traditionally, gross values have been used to measure the initial rate of absorption for solid and cored units. The current standard provides for the calculation of both $IRA_{gross}$, which is based on the gross bedding area, and is a measure of the suction rate of the unit, and $IRA_{net}$ which accounts for the area of cores on the bedding face and is a measure of the suction rate of the material from which the unit was made. $IRA_{net}$ is used for hollow units and $IRA_{gross}$ is used for solid and cored units.

Table 8 gives information about the gross IRA properties of Australian clay masonry units. It shows that only a very small proportion of Australian clay masonry has suction rates that are likely to cause problems due to excessive drying out of the mortar. It is clear that those building specifications requiring all units to be wetted before laying are long overdue for revision.

**Table 8.** Initial rate of absorption ($IRA_{gross}$)

| Place & method of manufacture | No of sets tested | Average (kg/m²/min) | Range (kg/m²/min) | Mid 65 % (kg/m²/min) |
|---|---|---|---|---|
| **New South Wales** | | | | |
| extruded | 58 | 1.0 | 0.1 – 2.0 | 1.0 – 1.2 |
| pressed | 29 | 4.6 | 1.9 – 6.4 | 3.8 – 5.7 |
| **Queensland** | | | | |
| extruded | 26 | 1.3 | 0.1 – 2.7 | 0.8 – 2.0 |
| pressed | 18 | 2.9 | 0.9 – 4.7 | 2.3 – 3.7 |
| **South Australia** | | | | |
| extruded | 47 | 1.0 | 0.1 – 2.1 | 0.6 – 1.6 |
| pressed | 5 | 2.0 | 1.4 – 2.5 | 1.9 – 2.3 |
| **Tasmania** | | | | |
| extruded | 35 | 1.7 | 0.3 – 6.6 | 0.7 – 2.6 |
| **Victoria** | | | | |
| extruded | 96 | 0.7 | 0.1 – 3.4 | 0.2 – 1.0 |
| pressed | 53 | 1.6 | 0.7 – 5.1 | 1.0 – 1.9 |
| **Western Australia** | | | | |
| extruded | 30 | 1.5 | 0.5 – 3.3 | 1.0 – 2.0 |

*Note: This data was collated from testing conducted by the former CBPI Laboratory. The figures in the table are for general information only and cannot be used for specific applications.*

### 4.5.2 Total water absorption

The ability of clay masonry to absorb water is one of its most useful properties. Water may enter a masonry assembly from many sources – in fresh mortar or plaster, during construction, from rainfall, rising ground water, condensation or leaky plumbing. The porous nature of clay masonry makes a major contribution to the water-tightness of a wall. The blotting paper action of clay masonry considerably reduces the load on flashings and other waterproofing elements.

The amount of water that a clay masonry unit can absorb is measured by the water absorption test in AS/NZS 4456.14 *Determining Water Absorption Properties*[20]. The significance of the test result is frequently misunderstood or overestimated. There is no proven relationship between water absorption and the water-tightness of walls, or the durability of units themselves.

However there are few, if any, instances where clay masonry units having less that six per cent cold water absorption failed because of soluble salt attack. But there are many units resistant to salt attack that have much higher cold water absorption. The results of water absorption tests are of possible use to the clay masonry manufacturer for quality assurance, but are rarely of practical value to the masonry user.

## 4.6 Thermal properties

Although not referred to in AS/NZS 4455 Part 1, thermal properties are increasingly important for compliance with the BCA energy efficiency performance requirements. The properties of importance are thermal capacitance (thermal mass), thermal resistance (R value) and solar absorptance. Good thermal design takes all these properties into consideration; poor thermal design usually focuses on only one property such as R value.

Thermal capacitance increases with the mass of the masonry unit. Put simply, the more mass in the building, the more stable the temperature will be. The masonry units slowly absorb and release heat preventing the air inside the building heating or cooling as quickly or as much as the outside air.

Thermal resistance is a measure of how well a material or construction prevents heat passing through it.

The R value of the constructed wall is important in design and the R value of the masonry units is only one component of that. The R value varies considerably with the weight of an individual unit as shown in Table 9 for standard 230x110x76 mm bricks (from data prepared by McNeilly[21]).

The R value for any construction depends on the thermal resistance (R) of each layer, including any air space or cavity, and the inner and outer surfaces. For design purposes, an R value of 0.18 $m^2$ K/W has been proposed for Australian bricks.

Solar absorptance is a measure of how well a material absorbs heat from the sun. Solar absorptance is reported as a number from 1 to 100 but, because the effect of absorptance by walls is not large, it is usually shown as 'light', 'medium' or 'dark'. Unlike many other materials, clay masonry units absorb and release heat almost equally well. 'Light' bricks and 'dark' bricks do exist, but most bricks are classed as 'medium'.

**Table 9.** Brick mass and R values

| **Brick mass (kg)** | 2.5 | 2.75 | 3.0 | 3.25 | 3.5 | 3.75 | 4.0 | 4.25 |
|---|---|---|---|---|---|---|---|---|
| **R value $m^2$ K/W** | 0.22 | 0.20 | 0.18 | 0.17 | 0.16 | 0.14 | 0.13 | 0.12 |

# 5. Soluble salts in clay masonry

## 5.1 Introduction

Soluble salts are those that dissolve in water. Although all clay masonry contains some soluble salts, these are usually not evident and there is no cause for concern. However soluble salts do sometimes appear on the surface of masonry units and mortar. This is called efflorescence.

The aim of this section is to describe the likely sources of these soluble salts and some of the problems that persistent efflorescence may cause.

## 5.2 Sources of soluble salts

Nearly all the salts that cause efflorescence come from sources outside the clay masonry unit such as ground water, sea spray, acidic atmospheric gases, mortar ingredients and other materials in contact with the units. For example, salts used to purify swimming pools can be absorbed by surrounding materials, particularly paving.

It is nearly always wrong to assume that the soluble salts occurring naturally within masonry units cause efflorescence. Most uncontaminated Australian clay masonry units show no efflorescence when tested by the methods set out in the standard.

Although some clay masonry units made from shales associated with coal seams may show moderate efflorescence under this test, these units are not in themselves the cause of damage from salt attack. However when staining occurs, the masonry unit is usually the source of the staining salt.

## 5.3 Salts causing kiln scum

Any soluble salts of calcium, magnesium, aluminium or titanium occurring in the clay used in manufacture may be deposited on the unit surface during the drying process that precedes firing.

During firing these deposits will usually be turned into kiln scum, an insoluble surface residue on the finished unit. It varies in colour and, being insoluble, is almost impossible to remove except by abrasion. Depending on fashion and personal taste a particular kiln scum may impart an attractive appearance.

**Figure 8.** Kiln scum

## 5.4 Salts causing stains

### 5.4.1 Iron

Iron oxide or rust stains are relatively rare and, when derived from the masonry unit itself, are found mostly on light-coloured clay masonry units or those with a black core containing iron and possibly iron sulphide. On darker bricks iron stains are less visible but may show up on mortar, especially the lighter colours. When acidic water seeps into the core, the iron rusts and a red-brown deposit forms on the unit surface. The correct use of cleaning acids will reduce the risk of such staining. This is described in Manual 10, *Construction Guidelines for Clay Masonry*.

**Figures 9 & 10.** Iron stains

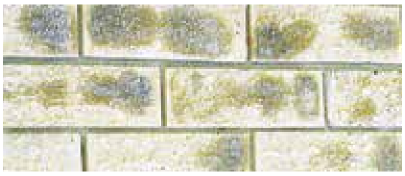
#### 5.4.2 Manganese

Brown manganese stains can occur on the clay masonry unit surface or on mortar joints when manganese oxides have been used to colour the unit. Staining may occur when all the manganese has not fused or reacted with the clay during firing.

When acidic water seeps through such clay masonry (or when acids are improperly applied during cleaning) some of the manganese oxides are converted to sulphates or chlorides. On drying, they are deposited on the unit or mortar joint surface. Here they change back into brown coloured oxides because of the alkalis from the cement in the mortar.

Manganese stains are harmless and will usually weather away.

**Figures 11, 12 & 13.** Manganese stains



*Manganese stains may vary from a purple sheen (top) to a brown stain (centre). Both examples are extreme. Sometimes the manganese reacts with the mortar giving a 'picture-frame effect' (bottom).*

#### 5.4.3 Vanadium

Green, yellow, brown or blue vanadium stains occur on light-coloured clay masonry units. Their most likely cause is the clay, as vanadium is often present in those clays that burn to a light colour.

The vanadium is released during firing and may be extracted by water and deposited on the unit surface. In a chemically neutral or slightly alkaline environment, vanadium salts are white and are therefore inconspicuous or invisible. In an acid environment, they are coloured.

It is difficult to prevent vanadium stains on porous clay masonry units if their raw materials contained large amounts of vanadium. They will form acids when they are in contact with water and do not need other acids to produce vanadium salts. Acid solutions in contact with such units (for example, acid cleaning agents) could produce comparatively dark stains.

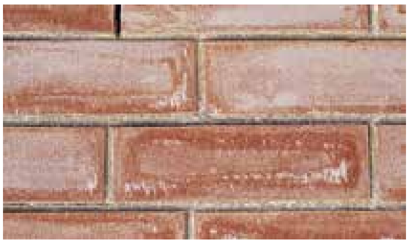
**Figures 14 & 15.** Vanadium stains

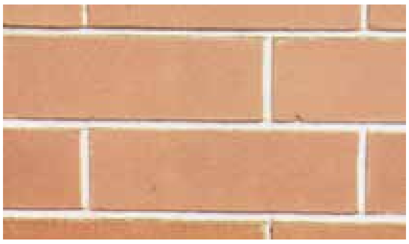
### 5.5 Salts causing efflorescence

The small amounts of soluble salts found in some fired clay masonry units of Australian origin result from chemical changes during manufacture. These salts are sulphates of calcium, magnesium, aluminium, sodium, and potassium. Chlorides are almost never found, but in some instances carbonates of calcium, sodium and potassium may appear.

Efflorescence is easily removed, but it is essential that correct cleaning practices be followed (see Manual 10, *Construction Guidelines for Cleaning Clay Masonry*.

**Figures 16 & 17.** Efflorescence before and after cleaning





# 6. References


1. AS/NZS 4455 Part 1:2003 *Masonry Units, Pavers, Flags and Segmental Retaining Wall Units, Part 1: Masonry Units*, Standards Australia, Sydney

2. AS/NZS 4456:2003 *Masonry Units, Segmental Pavers and Flags - Methods of Test*, Standards Australia, Sydney

3. Building Code of Australia, Australian Building Codes Board, Canberra, 2009 (Volumes 1 and 2).

4. AS 3700:2001 *Masonry Structures*, Standards Australia, Sydney

5. AS/NZS 4456.1:2003 *Sampling for Test*, Standards Australia, Sydney

6. AS/NZS 4456.3:2003 *Determining Dimensions*, Standards Australia, Sydney

7. AS/NZS 4456.4:2003 *Determining Compressive Strength of Masonry Units*, Standards Australia, Sydney

8. Page, AW *Design of Masonry for Compression and/or Shear*, Unified Masonry Code Seminar Standards Australia, Sydney, 1989

9. AS/NZS 4456.10:2003, *Determining Resistance to Salt Attack*, Standards Australia, Sydney

10. AS/NZS 4456.15:2003 *Determining Lateral Modulus of Rupture*, Standards Australia, Sydney

11. AS/NZS 4456.5:2003 *Determining the Breaking Load of Segmental Pavers and Flags*, Standards Australia, Sydney

12. Research Paper 6, S Zsembery and J Macintosh, *A Survey of Frost Resistance in the Australian Alps*, Clay Brick and Paver Institute, Sydney, 1980

13. AS/NZS 4456.11:2003 *Determining Coefficients of Expansion*, Standards Australia, Sydney

14. Manual 9 *Detailing of Clay Masonry*, Think Brick Australia, Sydney, 2008

15. Manual 10 *Construction Guidelines for Clay Masonry*, Think Brick Australia, Sydney, 2008

16. Zsembery, S Sharpe, K & McDowall, IC *Review of the experimental data on prediction of long-term natural expansion of clay bricks*, Proceedings of 12th Australian Ceramics Conference (AUSTCERAM 86), Australian Ceramics Society, Melbourne, 1986.

17. Cole, WF *Possible significance of linear plots of moisture expansion against log of time function*, Nature 196,431-443 (3 Nov 1962)

18. AS/NZS 4456.13:2003 *Determining Pitting Due to Lime Particles*, Standards Australia, Sydney

19. AS/NZS 4456.17:2003 *Determining Initial Rate of Absorption (Suction)*, Standards Australia, Sydney

20. AS/NZS 4456.14:2003, *Determining Water Absorption Properties*, Standards Australia, Sydney

21. McNeilly, T R *Values for Australian Clay Building Bricks*, AIRAH Journal, Australian Institute of Refrigeration, Air-conditioning and Heating, Melbourne, May 1998.

PO Box 275, St Leonards NSW 1590 Australia
Suite 7.01, Level 7, 154 Pacific Highway, St Leonards NSW 2065 Australia
Telephone +61 2 8448 5500
**Technical hotline** 1300 667 617
ABN 30003873309

**www.thinkbrick.com.au**

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