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MORTAR DURABILITY – DEVELOPMENT AND STANDARDIZATION OF TEST METHODS

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Abstract

Many factors influence mortar durability, some of which are related to environmental and in-service conditions, which should be designed for, and some of which are related to the properties of the masonry units, the cement mortar and their interactions. Because of the large number of factors influencing durability, it has been difficult in the past to develop test methods. There have therefore been no standard performance criteria for durability of mortar. This paper briefly reviews mechanisms of deterioration of masonry mortars and describes work carried out to develop laboratory and field test methods to assess the service life of masonry mortars subjected to salt crystallisation, abrasion and wind action. The paper describes the adoption of the field test into the current Australian masonry standard and the performance criteria adopted.

Key Words

mortar, durability, tests, standards

1 Introduction

Durability of the mortar joints is essential for the satisfactory performance of a masonry structure throughout its lifetime. Mortar durability is influenced by many factors, some are external factors and are related to service conditions which are outside the designer's control and should be considered in the design. Others are internal factors, including the properties of the masonry units, the mortar constituents, workmanship and interactions between these various elements, which are considered to be within the designer's control in terms of being able to select the most suitable levels for optimum performance.

Because of the large number of factors affecting durability, it has proved difficult in the past to develop a representative test method to predict the performance of masonry against degradation. Reliance has been placed on prescriptive mix compositions and local experience, and there have been no comprehensive studies of the many factors and their interactions.

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In Europe, the United Kingdom and other parts of the northern hemisphere, most attention has been focussed on the effects of chemical attack and freezing and thawing. Several reviews of the range of relevant factors have been made (Bowler 1993, RILEM 2000) but their emphasis has been on chemical attack and freezing and thawing. In Australia and many other areas, degradation is much more likely to occur as a result of the physical effects of salt crystallization, abrasion and wind action and these effects require further investigation.

A review by Page (1993) discussed the various factors and concluded that the existing test methods for durability are not adequate for all causes of degradation. The report recommended development of suitable test methods to accelerate the physical mechanisms causing degradation by salt crystallization and abrasion.

This paper briefly reviews mechanisms of deterioration of masonry mortars and describes work carried out to develop laboratory and field test methods to assess the service life of masonry mortars subjected to salt crystallization, abrasion and wind action. The paper also describes the performance criteria derived for both laboratory and field tests and their advantages and/or limitations. The adoption of the field test into the current Australian masonry standard is also described.

2 Mechanisms of Deterioration

There are a number of mechanisms for the degradation of masonry mortars, which lead to inadequate durability. These have been reviewed by Bowler (1993). The presence of water is said to be the common factor in all the various mechanisms, although physical abrasion from wind-blown sand particles and other causes can also produce significant erosion if the mortar lacks sufficient strength.

Salt attack is usually considered to be more of a physical action than a chemical action. Crystallisation of the salts in the pores of the mortar results in disruption from the pressure exerted by the salt crystals. Under this mechanism, the denser the material, the less is the likely deterioration.

Poor batching practices on site can often result in cement content lower than that specified. The quantity of cement in the mix will directly influence the potential weathering rate of a mortar joint by wind action or abrasion. With the continued development and increasing use of supplementary cementitious materials and chemical admixtures, their effect on the durability of mortars also needs to be investigated.

There are two mechanisms of deterioration most relevant to Australian conditions:

- Wetting and drying – where repeated cycles of wetting and drying produce expansion/contraction cycles at the surface, which combined with wind action, lead to fretting of particles. This mechanism is most damaging when the mortar contains insufficient cement or there is some other problem of workmanship or materials.
- Salt crystallization – where salt-laden water is absorbed into the masonry and, when the water dries out, the formation of salt crystals just below the surface causes spalling of particles. This mechanism will also be quicker in the presence of wind movements, particularly because of the quicker drying action leading to more rapid salt crystallization.

It is most important to recognize that with these two mechanisms, and particularly with the second, there is no chemical reaction involved between the absorbed salts and the mortar constituents. The cause of degradation is purely the physical forces arising from the expansion caused by formation of the salt crystals. This crystallization takes place where the salt solution is saturated, at the point where evaporation of the moisture occurs, and because this is just below the mortar surface the effect is a destructive spalling of the surface layers.

3 Factors affecting mortar durability

The factors affecting mortar durability can be divided into two groups – external or environmental conditions and internal factors. These are outlined below, within the context of Australian conditions, that is, excluding freezing and thawing and chemical salt attack.

3.1 External factors

The external factors arise from the environment and constitute the factors that a designer should consider and design for. They include the following:

- Exposure to air-borne salts
- Repeated wetting and drying
- Physical abrasion
- Wind effects such as abrasion from wind-blown particles and rapid drying from air movement
- Carbonation (which can have a positive effect)

3.2 Internal factors

Internal factors derive from the material properties and workmanship and are fixed once the masonry has been constructed. They include the following:

- Properties of the masonry units
- Cement type and the presence of lime
- Sand grading and clay content
- Presence of admixtures and entrained air
- Mortar mix composition (relative proportions of ingredients)
- Joint tooling, including compaction, raking and 'striking off'
- General quality of workmanship
- The curing regime, if any, during the critical hydration period of the cement

These various factors, both external and internal, will obviously interact with each other in complex ways. For most of these factors, the effects have not yet been quantified, primarily because of the lack of a suitable test procedure. The main purpose of this paper is to describe the development of field and laboratory test methods that can provide a means of investigating the various factors and their interactions.

4 Development of durability tests

There is a wide range of variables that must be considered in developing a representative durability test and the type and nature of the test will depend upon its intended use. If it is to compare the performances of various cement, sand or additive types, the test does not necessarily need to reproduce the site conditions. Developing a test method and relating its results to field performance is a large task. It would require long term monitoring of the durability performance of masonry panels located in severe exposure conditions in parallel with laboratory experiments. Another alternative is to attempt to create in the laboratory an environment and test specimens which represent as closely as possible site conditions. An accelerated test would then be able to give a reasonably quick indication of the long term performance. But more importantly, what is required is a simple apparatus which can assess the durability performance of in-situ masonry.

In the absence of suitable field and laboratory tests to examine resistance to the physical deterioration mechanisms relevant in Australia, new methods of test have been proposed for use in the field (Lawrence and Samarasinghe 1998) and in the laboratory (Samarasinghe and Lawrence 2000). The development of these tests is outlined here, along with work showing the correlation between their respective measures of durability.

4.1 Laboratory test

Many investigators have studied the durability of structures, mostly in relation to the performance of concrete rather than masonry. Tests usually consist of some form of soaking in an aggressive medium and monitoring of the progressive deterioration of the specimen. The laboratory test described here follows this approach, and is modelled on an existing test for durability assessment of hardened mortar under freezing and thawing conditions (RILEM 1998) with some modifications. A controlled regime comprising cycles of soaking in 5% sodium chloride solution, followed by drying, is used. The mortar tablets are prepared from mortar joints cast between bricks, using surgical gauze as a bond-breaker (Figure 1).

At the age of seven days the mortar slabs are detached from the bricks and sawn into tablets measuring 55 mm by 35 mm. These tablets are then air dried for 24 hours, followed by oven drying at 105±5°C for two hours. They are then brushed lightly and individually weighed in preparation for testing.

Figure 1 Using gauze as a bond breaker to cast mortar tablets

A wide range of methods has been suggested by various investigators to assess the degree of deterioration of specimens subjected to accelerated weathering. The most commonly used techniques are physical appearance, change in volume (or dimensions), change in weight and reduction in strength. In masonry joints, most of the durability problems occur at the surface, and therefore strength measurements would not reflect the level of degradation. Hence, percentage change in weight of the specimens was adopted as the indicator of degradation.

The mortar tablets are subjected to five cycles of soaking and drying as follows:

- Immersed in 5% NaCl solution at a controlled temperature of 23±2°C for 8 hours.
- Removed from solution, taking care not to dislodge mortar particles by handling, and dried under a fan in laboratory air (23±2°C) for at least 15 hours.

After five cycles of soaking and drying, the tablets are dried and weighed as follows:

- Dried under a fan in laboratory air (23±2°C) for at least 48 hours, followed by oven drying at 105±5°C for two hours.
- Individually weighed and the weight recorded against the total number of soaking/drying cycles undergone by the specimen to that time.

Any specimen for which the weight loss exceeds 2% of the original weight is then removed from further soaking/drying cycles. Other specimens are returned to the soaking solution for a further five cycles. After ten cycles of soaking the NaCl solution

is discarded and replaced with fresh solution. The salt-cycling durability index is calculated as the number of cycles required to produce 2% weight loss.
Figure 2 shows a typical set of results for the weight change in specimens subjected to cycles of soaking in sodium chloride solution followed by drying. It can be seen from the figure that the weight of a given specimen increases during the early cycles and this is attributed to the take-up of water through cement hydration.

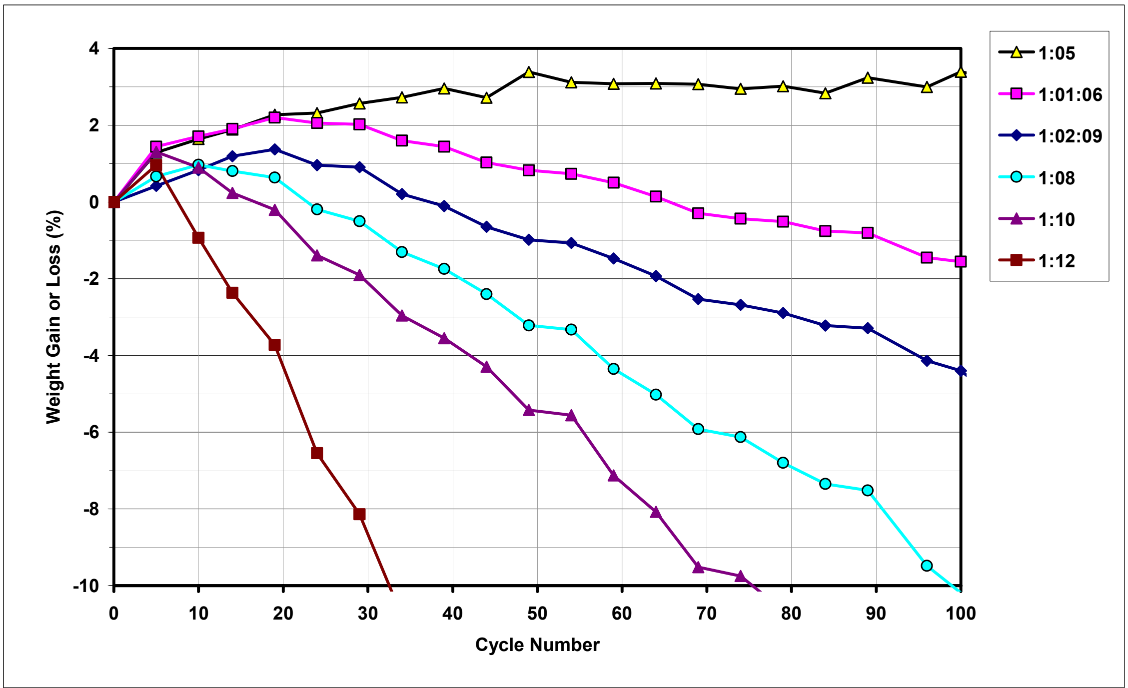

Figure 2 Typical weight-loss curves for Portland cement mortars in 5% NaCl solution

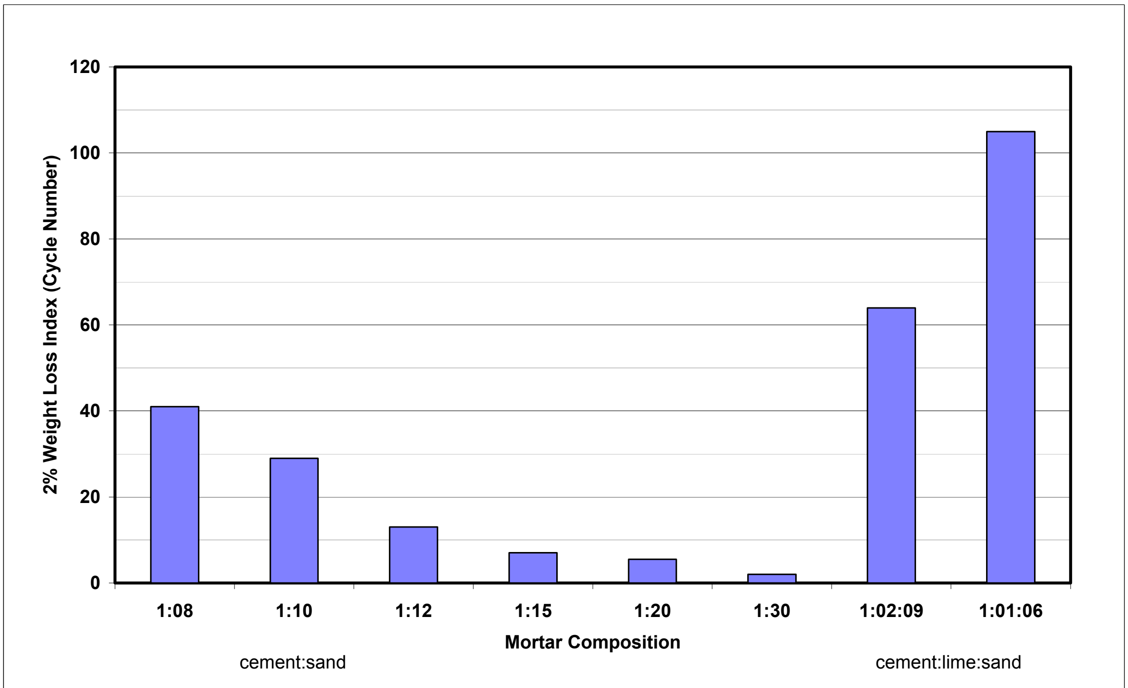

Figure 3 Typical 2% weight-loss index for Portland cement mortars

A range of trials has shown that the salt-cycling test is capable of identifying the effect of different parameters such as cement content, cement type, sand type and brick type. The two-percent weight loss index for a range of mortars with various Portland cement contents is shown in Figure 3. Clearly the test index reflects the cement content in the mortar, which is one of the primary factors affecting durability.

4.2 Field test

The apparatus for a scratch test is based on the principle of a fixed force applied through a spring to a probe with an abrasive end. The probe is turned through a fixed number of turns and the indentation into the mortar surface is measured. It is possible to vary the severity of the test by changing the form of the probe, the spring force and/or changing the number of turns used to make a measurement. The apparatus is shown in use in Figure 4.

Figure 4 Mortar scratch test in progress

The probe has a diameter of 6 mm, with a flat end having a cruciform cross-section. The total range of movement into the mortar joint is 10 mm. The spring stiffness is 0.78 N/mm and the initial force when the probe contacts the mortar surface is 15.6 N.

A typical set of test results for the scratch test is shown in Figure 5.

After a range of trials varying the number of turns and the parameter used as an index of performance, the penetration for the first five turns (in mm) was chosen as the appropriate index for this test. It is called the scratch index for the mortar joint. The procedure for carrying out the test is to give an initial two turns of the probe, to settle it on the surface, followed by five turns to measure the indentation.

Figure 6 shows the relationship between the scratch index and cement content for a range of Portland cement mortars. The test results clearly relate to the cement content and can therefore be expected to be a good indicator of durability. It can be noted from Figure 6 that a small change in cement content below, say, 8% can cause a large change in the penetration rate. As the aim is to identify poor mortar durability resulting from low cement content, this is considered a positive feature of the test.

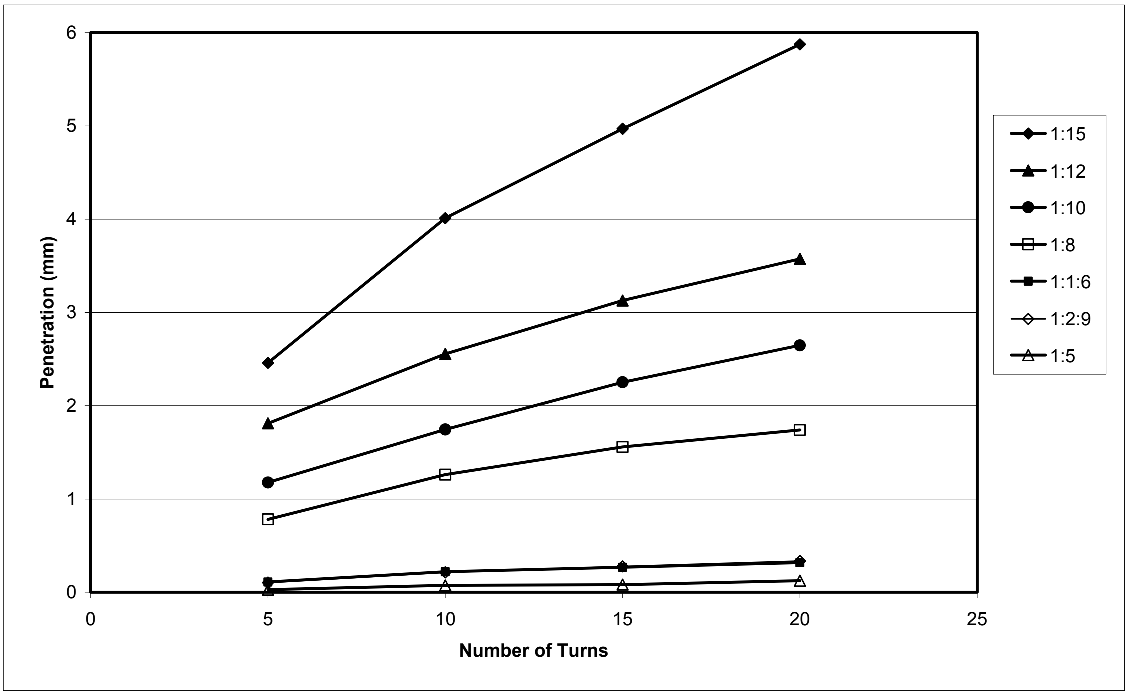

Figure 5 Typical relationships between penetration depth and number of turns for the scratch test on mortars of various proportions

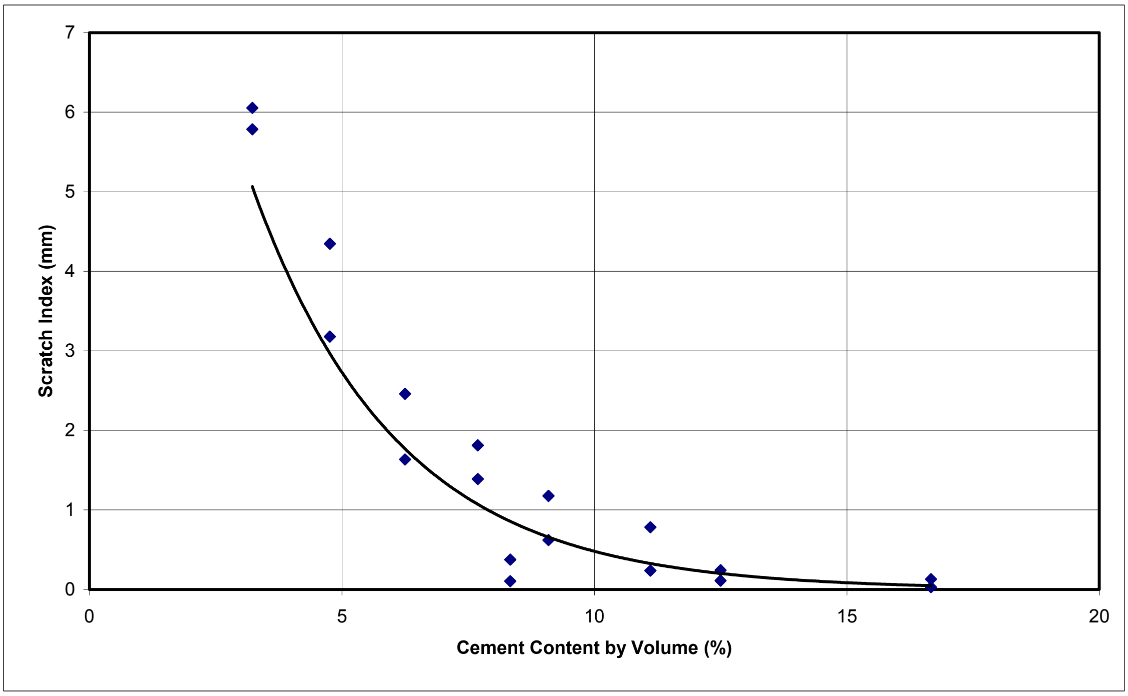

Figure 6. Relationship between scratch index and cement content

4.3 Correlation between laboratory and field tests

In comparing the two test approaches, it is not possible to carry out both tests on the same specimen. A series of tests was therefore performed using specimens made at the same time from the same materials, with pairs of specimens tested by the two methods. These tests showed that the laboratory and field test methods are closely correlated, as shown in Figure 7, where the two test indices are plotted on logarithmic

scales. This close correlation gives further confidence that the two tests, although using different mechanisms to cause degradation in the mortar, are nevertheless measuring a property related to durability.
The relationship between the two measures of durability is as follows:

$$N = 16.3 D^{-0.62} \qquad (1)$$

N is the cycle number at which 2% weight loss occurs
D is the scratch tool penetration after 5 turns (mm)

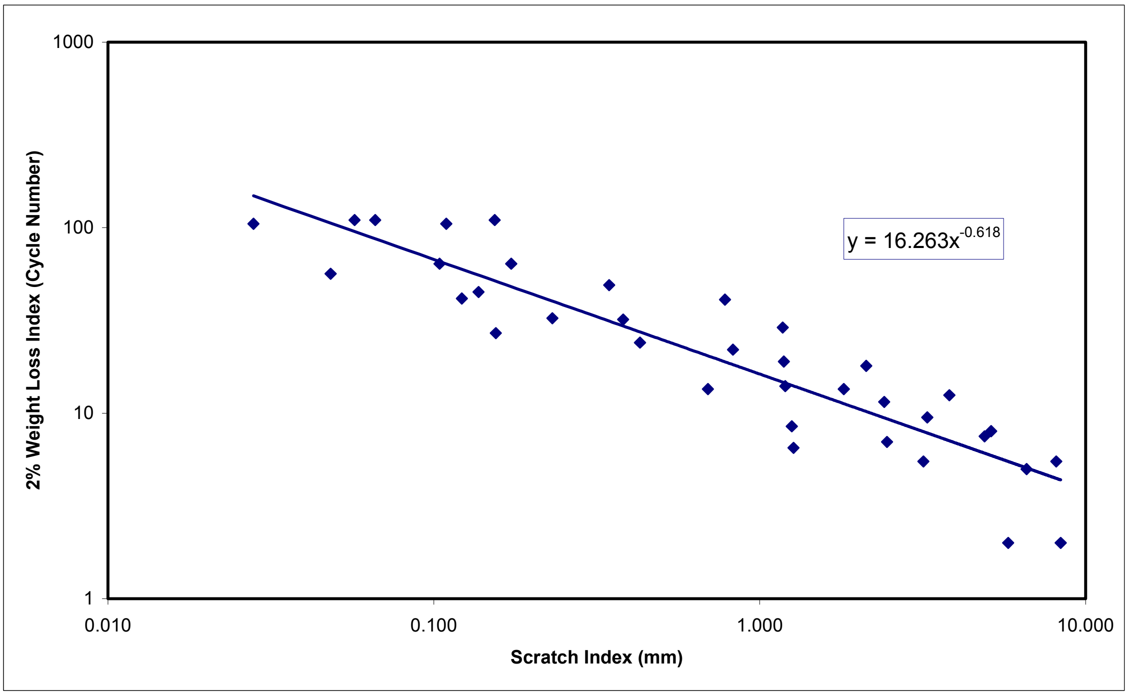

Figure 7 Correlation of weight-loss index with scratch index

5 Standardization

Because of its speed, ease of use and relative simplicity, the scratch test is an excellent candidate for a field test providing the basis of an acceptance test in a national building code. To facilitate acceptance of the test, it was necessary to correlate the results with field performance and develop suitable acceptance criteria. Assessing wall performance in the field without a test is subjective, and some calibration tests were therefore necessary for the purpose of setting criteria.
Calibration of the scratch index was conducted using exposure tests on specimens prepared under laboratory conditions. Four-course prisms were prepared with 1:5, 1:8, 1:12 and 1:15 mortar mixes and placed on exposure racks after 14 days curing time. Three cement types (Portland, blended with slag and blended with fly ash) and two types of sand (washed and ‘fatty’ sand with moderate clay content) were used with each of the mixes selected. One prism was built for each combination of materials. The prisms were orientated in the North-South direction with greatest sunlight exposure on the northern face and the greatest wind and rain attack on the southern face.
Scratch tests were carried out on the weather-exposed mortar joints after 22 months. Observations were also made of the appearance of the joints after the weather exposure, and they were gently rubbed with a finger along the joint to make a qualitative assessment of the abrasion resistance. It is expected that durable mortar should not have any loss of surface particles under a gentle abrasive force.
The abrasive resistance of the joints was categorised into four levels:

A. No dislodging of mortar particles.
B. Slight dislodging of particles, but stopping after 2-3 rubs.
C. Moderate dislodging of particles, with some loosened at every rub.
D. Severe dislodging of particles with large quantities loosened at every rub.

Moderate and severe dislodging of mortar particles is not acceptable, and the building owner will be unhappy with such masonry.

All the scratch test data were considered together, irrespective of the mortar mix, and investigated for correlation between the scratch index and the rubbing grade. The average scratch index corresponding to each rubbing grade is plotted in Figure 8.

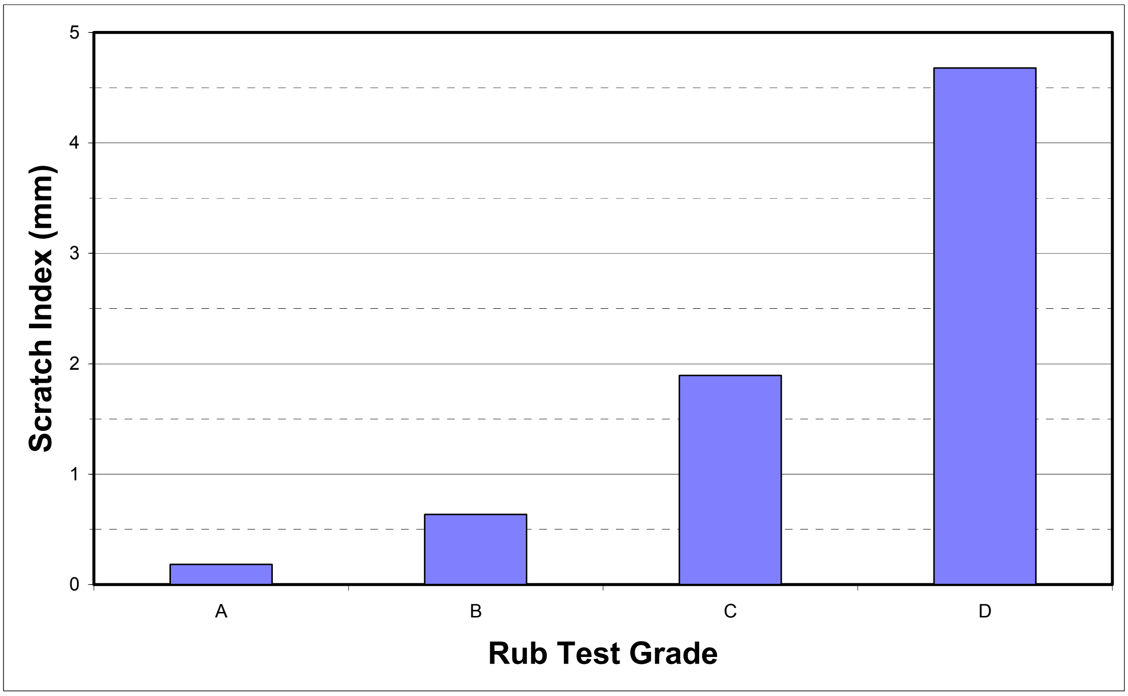

Figure 8 Correlation between the rubbing grade and the scratch index

Comparing the results of the rubbing abrasion test and the scratch tool penetration, the chosen criterion was that any mortar with a scratch index greater than 0.5 mm is not acceptable and is likely to be damaged under a mechanical abrasive force. This criterion was later verified with additional field trials.

Following the establishment of acceptance criteria, the scratch test method has been accepted into the Australian Masonry Structures Code AS 3700 (Standards Australia 2001) through an amendment published in May 2002. This permits further experience to be gained in its use in the field, which might lead to refinement of the acceptance criteria in the future. For grades of mortar M2, M3 and M4, scratch test acceptance criteria of 0.5 mm, 0.3 mm and 0.1 mm respectively have been adopted.

6 Conclusion

A salt-cycling test has been developed, based on mortar tablets cast between bricks. Results have shown that soaking in 5% sodium chloride solution causes breakdown of the specimens within a reasonable number of cycles, making the test method suitable for laboratory assessment. The method is repeatable and is capable of distinguishing between the resistances to degradation of mortars with various compositions. The cycle number for 2% weight loss has been adopted as the most appropriate index of performance for this test.

A controlled scratch provides a useful measure of the durability resistance of the mortar and a test apparatus based on this principle has been developed. The penetration

distance for five turns of the scratch device has been selected as the index of performance for this test. Tests on a wide range of mortars have shown that the test is repeatable and is capable of distinguishing between the resistances to degradation of mortars with various mix proportions.

The salt-cycling test and the scratch test give measures that correlate well with each other and are therefore taken as measuring the same property, namely the hardness of the mortar. Exposure tests and subjective field assessments have been used to establish suitable criteria for the performance assessment of various grades of mortar. As a result, the scratch test has been accepted into the Australian Masonry Structures Code for field assessment of durability.

With the availability of these test methods, it will now be possible to quantify the effects of the various factors influencing mortar durability and establish the relative significance of each.

7 Further work

Following development of the test methods, further research work is being carried out at The University of Newcastle, with funding provided by the Cement & Concrete Association of Australia (Testone et al 2004). This work is using the scratch test method to investigate the principal factors affecting durability. The factors being investigated are sand grading, cement type, mortar composition, brick suction, joint finish and exposure environment. While the range of each variable is necessarily limited, it is hoped that the results of the work will provide a greatly enhanced understanding of the relative magnitude of these factors and allow improved industry guidelines in the future for control of the durability of masonry mortars.

8 Acknowledgement

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