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ASSESSING THE DURABILITY OF MASONRY MORTARS

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ABSTRACT

The durability of a mortar joint in masonry is often determined by its resistance to the physical forces tending to cause degradation, such as abrasion and salt crystallisation just below the surface. Established tests for resistance to freeze-thaw and sulphate-attack have little relevance for assessing this resistance. The paper presents an overview of research to develop a salt-cycling laboratory test and a mechanical field test for assessment of resistance to mortar degradation. The salt-cycling test is based on small mortar tablets and uses weight loss as a means of measuring degradation. The mechanical test is a new approach to mortar testing in-situ, which involves subjecting the joint to a controlled scratching action designed to measure its resistance to physical damage.

Key words: *Masonry mortars, non-destructive testing, durability, hardness, salt-attack, abrasion.*

1. INTRODUCTION

In assessing the service life of masonry structures, one of the most important considerations is the condition and expected lifetime of the mortar joints. This is important for heritage structures and monuments, where the desired life of the structure is likely to be longer than for other buildings, but also for domestic housing, where the lack of control over workmanship can lead to inadequate durability of the joints. If the mortar lifetime is assessed as inadequate, remedies such as re-pointing of the joints, coating of the wall, or demolition and rebuilding are costly and may require specialist skills.

While much work has been done on freeze-thaw and sulphate-attack resistance of mortar joints, little has been done on resistance to mechanical breakdown caused by abrasion, wind and salt crystallisation. Test methods have been prepared for determination of pointing hardness (RILEM, 1997a), mortar strength by pull-out (RILEM, 1997b) and freeze-thaw or salt attack (RILEM, 1996) and while these relate to some extent to the mortar hardness, they do not adequately reflect the surface hardness required in order to resist mechanical abrasive damage. Although the mechanisms of breakdown are well understood, there is no accepted method for assessing resistance and the likely lifetime of the joints in normal service. Some experienced site inspectors have a 'feel' for mortar hardness and might scratch it with a nail to gain a subjective assessment of quality. However, this is no substitute for a properly calibrated and reproducible test method that gives a quantitative measure of performance. Particularly common are cases where the mortar has low cement content and masonry strength is not an important consideration, while other cases involve poor workmanship and aggressive environments. In all of these cases, a method of assessing serviceability of the joints is required.

The desirable criteria for a suitable mechanical test are that it should be simple to apply, it should not require a complex apparatus and it should provide measurements that correlate with the durability performance of the mortar in service. Two types of mechanical test have been tried, namely indentation and scratching or penetration. These were considered to offer the best potential for a practical test method with a relatively simple apparatus. Preliminary work on the development of a mechanical test method has been reported previously (Lawrence & Samarasinghe, 1998) and this paper discusses further development work. In parallel with this work, investigations have been carried out to develop a salt-cycling test suitable for laboratory measurements of resistance to mechanical damage.

2. SALT-CYCLING TEST

Many reported cases of mortar breakdown in Australia are caused by salt attack, by salts either in the ground or carried though the air when the building is located close to the sea. A controlled regime of soaking in salt solution, followed by oven drying was therefore considered to be an ideal candidate for simulating this

breakdown. The intention was not to use a sulphate salt solution that chemically attacks the cement in the mortar, but to use a solution that crystallises at the surface in the drying phase and causes mechanical breakdown as described earlier.

The properties of mortar made in steel moulds are quite different from those of mortar cast between bricks, where the water/cement ratio is reduced substantially by suction. It is therefore imperative that specimens for any investigation of the properties of in-situ mortar should be cast in a realistic way. For this investigation, the mortar was placed as a joint between two clay bricks, using normal bricklaying techniques, with the exception that layers of surgical gauze were placed between each brick and the mortar. This gauze allowed separation of the mortar from the bricks after the desired curing time. The sheet of mortar was then carefully sawn into tablets 55 mm by 35 mm. This procedure is similar in principle to that used for producing test specimens for assessing the durability of mortar to freeze/thaw or sulphate attack (RILEM, 1998).

Initial trials were carried out with a range of mortars and three types of solution – plain water, sodium chloride (3% and 5% solutions) and simulated seawater. Weighing of the specimens at intervals after a number of soaking/drying cycles was used to monitor breakdown. Initially, the specimens increased in weight because of progressive hydration of the cement. After a certain number of cycles, the weight began to decrease because of the shedding of particles dislodged by salt crystallisation below the surface. It is important in using this procedure to ensure that the specimen is completely dry before weighing so that residual moisture is not considered as part of the specimen weight.

The temperature of the salt solutions was controlled and the solution was replaced every ten cycles to maintain the desired concentration. Two mortar tablets were tested for each combination and these two results were averaged. Trial tests were carried out on 1:3 lime mortar and on cement mortars using both Portland and blended cements with composition ranging from 1:50 (cement:sand by volume) to 1:5.

During the initial trials it also became apparent that oven-drying the specimens (even at 60° Celsius) might accelerate hydration with some binders. The sequence of soaking and drying was therefore adjusted so that drying in air (with fan assistance) was used as much as possible. Weighing was performed after every five cycles and a longer period (over the weekend) was allowed before weighing to ensure that the specimen was completely dry.

As expected, cycles of soaking in plain water followed by drying did not produce signs of degradation within about 50 cycles. Solutions of 3% and 5% sodium chloride produced results of different magnitudes, but not otherwise significantly different. The artificial seawater was less aggressive in its action than the 5% sodium chloride solution and is more difficult to produce in the laboratory. Because the aim was to produce an accelerated method of test, 5% sodium chloride was chosen after the initial trials as the preferred salt solution for this test procedure.

Figure 1. Typical Weight Curves for Portland Cement Mortars in 5% NaCl.

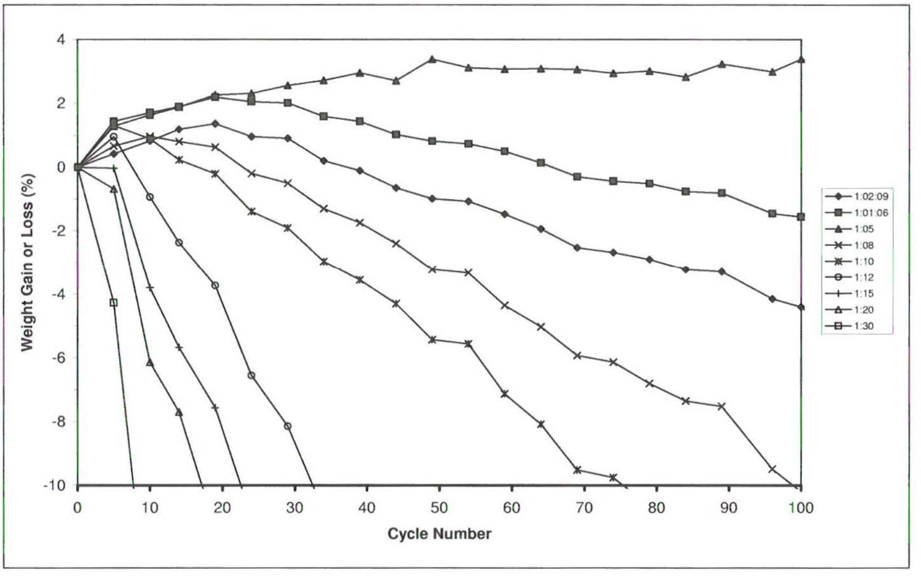
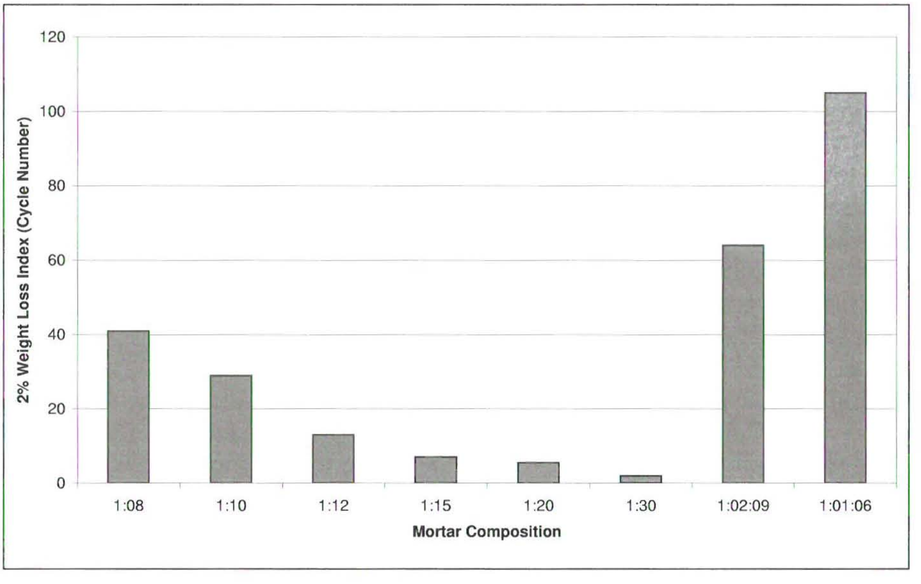
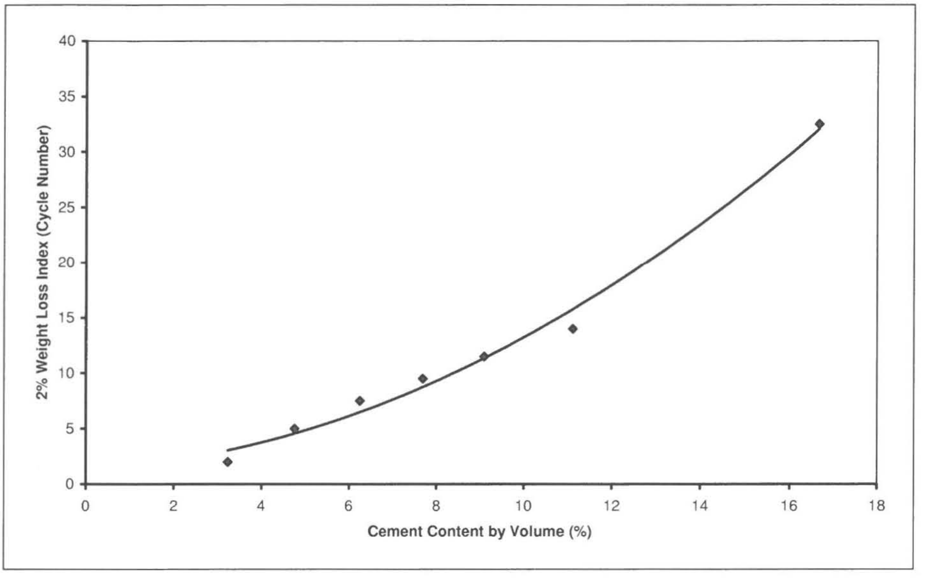


Figure 2. Typical 2% Weight Loss Index for Portland Cement Mortars in 5% NaCl.



A typical set of weight curves for various mixes made with Portland cement is shown in Figure 1. The percentage weight gain or loss is plotted against the number of soaking/drying cycles, up to 100 cycles. These results are from the 7th series of tests and used 5% sodium chloride solution. Mortar compositions are given as cement:lime:sand (by volume). For the higher cement content mortars the weight gain by cement hydration is marked and the onset of deterioration is delayed. On

Figure 3. Relationship Between 2% Weight Loss Index and Cement Content.



the other hand, the weaker cement mortars begin to deteriorate rapidly and fall below their starting weight almost immediately after commencement of cycling.

An index of performance was required for comparison with the scratch test and to form the basis of an acceptability criterion. The cycle number at which deterioration started (defined as being when the weight first started to reduce) and the cycle number at which the tablet weight returned to its starting value were both considered as candidates. However, it was found that the most repeatable results were obtained by taking the cycle number at which the weight fell to 2% below the original tablet weight. Typical values for this index of performance (from the 7^{th} test series) are shown in Figure 2 for Portland cement mortars subjected to soaking and drying cycles in 5% sodium chloride solution. The increase in resistance as the cement content increases and the higher resistance of the common composition mortars is evident.

A plot of the weight loss index against cement content is shown in Figure 3 for a slag-blend cement. The second-order polynomial regression line is also shown. Clearly, there is a strong relationship between the index and the cement content. Similar results were obtained for other cement types and for various sands used in mortar.

3. INDENTATION TRIALS

Indentation is often used as a means of assessing surface hardness of materials and it was therefore considered as a candidate for mortar testing. The indenta-

tion trials were carried out using an Instron testing machine with a penetration probe fitted to the moving head. The hemispherical end of the probe is approximately 6-mm diameter. A force of 250 N was applied and indentations were measured with a depth micrometer accurate to 0.025 mm. The testing machine was used for this feasibility study with the intention that, if the trials were successful, a simpler apparatus could be developed to operate as a field test on the same principle.

Three series of trials were carried out using various mortars. The trials showed that the coefficient of variation of the depth of penetration is high and that applying a force higher than 250 N to cause a deeper penetration is not practicable. The depth of penetration measured for very weak mortars is not high enough to distinguish between good and bad mortars.

It was clear from the trials that the indentation probe has a strong effect of consolidating the mortar directly under the probe, resulting in an ever-increasing force required to cause further penetration. This behaviour leads to a reduced ability to discriminate between soft and hard mortars and is not an accurate representation of the physical degradation mechanisms that the test is intended to model. It was therefore concluded that the indentation test is not worth pursuing as a candidate for a suitable mechanical test.

4. SCRATCH TEST

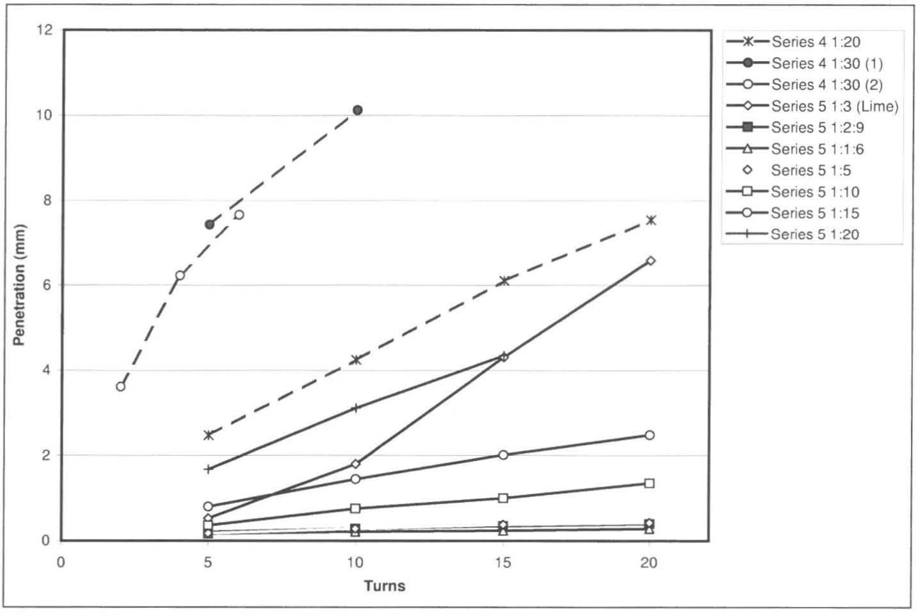
In the absence of a known precedent for this type of test, a prototype apparatus for a scratch test was designed and built for the trials. The principle involved is that a fixed force is applied through a spring to a probe with an abrasive end. The probe is turned through a fixed number of turns and the indentation into the mortar surface is measured with a depth micrometer. 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.

Three trial series were conducted as follows:

- Series 1 – Brick couplet laid in 1:3 (lime:sand) mortar, tested at 7 days.
- Series 2 – Brick couplet laid in 1:14 (cement:sand) mortar with air-entraining agent (AEA), tested at 10 days.
- Series 3 – Brick couplets laid in 6 different mortars, tested at 7 days.

Measurements were taken at a number of points on each of the long sides of the mortar joint in each couplet. After taking a datum reading with the micrometer, measurements were taken after 5, 10, 15, and 20 turns of the scratch device.

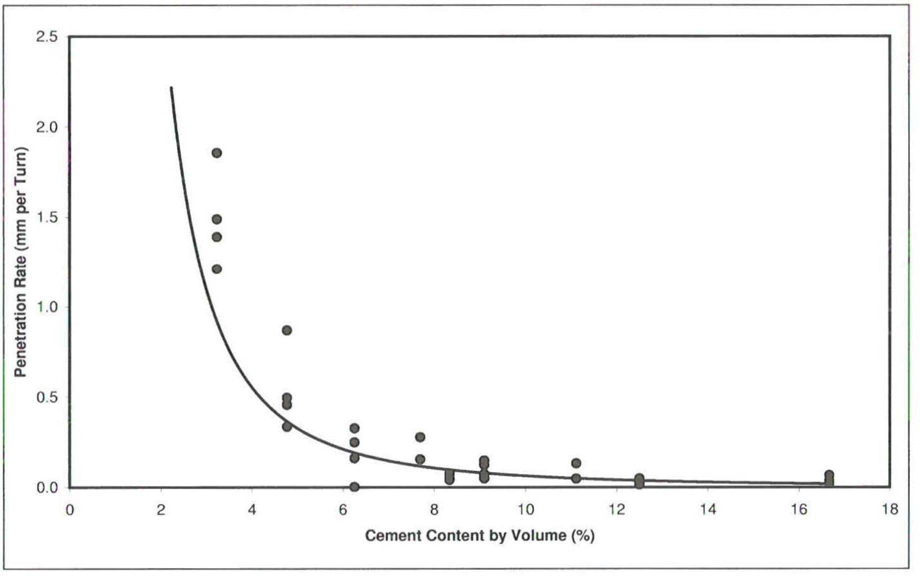
Figure 4. Typical Relationships Between Penetration Depth and Number of Turns for the Scratch Test.



These trials showed that the apparatus produces measurable indentations, which appear to correlate with the cement content of the mortar and could be expected to be indicative of durability performance. While there is variation from point to point on a specimen, this would be expected with a variable material such as mortar. When this variability is averaged out, the resulting patterns of penetration depth with number of turns are clear and repeatable. There is a large spread between the results for the soft 1:3 lime mortar and those for the composition mortars (1:2:9 and 1:1:6) and the cement mortars (1:5, 1:10 and 1:15).

The conclusion from these trials is that the test method is a viable way of determining relative hardness of the mortar surface, which is expected to be a reliable indicator of durability in service. Further tests were then planned with a range of mortars, including compositions as weak as 1:20 and 1:30, to explore the range between the 1:3 lime mortar and the cement mortars tested in Series 3. Figure 4 shows the results for the Series 4 and Series 5 tests. The range of mixes tested shows a good spread of results with measurable indentations up to the limit of the device (approximately 10 mm). For all mixes except the 1:3 lime mortar there is a steady increase of indentation with increasing number of turns. For the lime mortar, the rate of penetration increased after the first ten turns and this trend of increasing rate of penetration is tentatively attributed to a 'skin' effect at the surface of the joint, which, once penetrated, allows the probe to dig into the joint more quickly. The formation of this harder skin could be caused by reaction with carbon dioxide in the atmosphere.

Figure 5. Relationship Between Penetration Index and Cement Content.



For comparing these results with others and exploring correlation with salt-cycling tests it is necessary to reduce the results to an index of performance. Two possibilities are the initial slope of the curves (indentation for the first five turns of the scratch device) and the average slope after the first five turns. Examination of these indices shows that, while there is variation in the results, both appear useful to represent the indentation results and they both appear to correlate with the cement content in the mix. From these trials the index of average penetration for the first five turns (mm per turn) was chosen as the representative index for this test.

The correlation with cement content was explored by plotting the penetration indices against cement proportion by volume, as shown in Figure 5. The regression line is also shown and indicates a strong correlation. Since there is a general expectation that durability performance is closely correlated with cement content and this penetration index correlates strongly with cement content, it is likely that this index is a useful measure of durability performance. This is especially true considering that this index is measuring a surface hardness property and the resistance of mortar joints to mechanical degradation is likely to be strongly influenced by the surface properties.

Field tests to examine the usefulness of the scratch test as a predictor of durability performance are being carried out. These investigations will then permit the establishment of acceptance criteria, allowing the method to be considered for inclusion in building codes. Investigations of other aspects, such as the effect of various types of joint finishing (tooling, recessing and so on) and the effect of sand properties are also being considered.

5. CORRELATION BETWEEN SALT-CYCLING AND SCRATCH TESTS

Both of the test methods give good resolution across a wide range of mortar compositions and both indices correlate well with the cement content of the mortar. Correlation between the two test indices has been examined and is shown in Figure 6. Correlation is good, indicating that the scratch test used in the field is likely to measure the same property as the cycling test used in the laboratory.

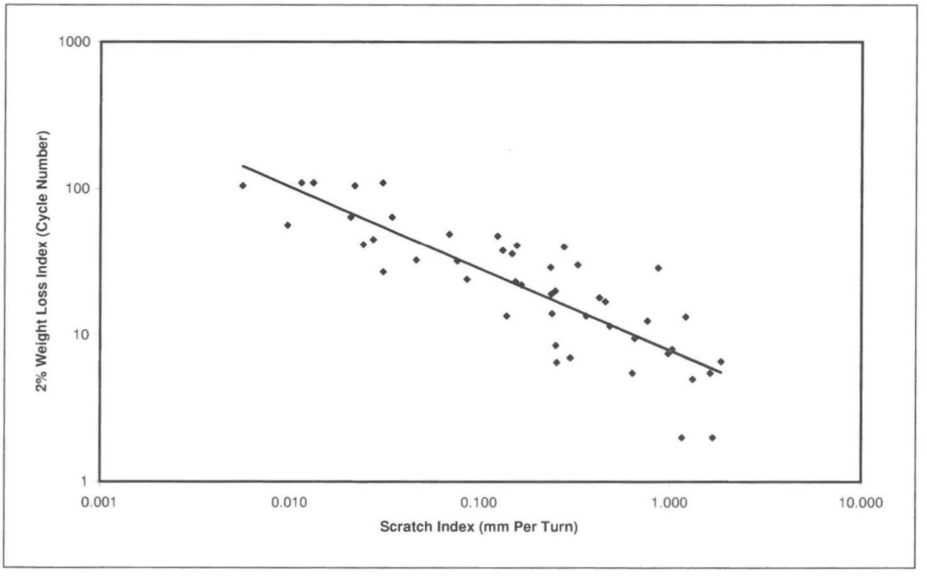
The outcome of these trials is therefore a pair of test methods. The first (the salt-cycling test) is useful for laboratory evaluation of the potential durability of various mortar mixes, and the second (the scratch test) is useful for field evaluation of mortars in-situ.

6. CONCLUSIONS

A salt-cycling test has been developed, using mortar tablets cast between bricks. Trials have shown that 5% sodium chloride solution gives repeatable results that correlate strongly with cement content. The cycle number for 2% weight loss has been chosen as the most useful index of performance for this test.

Trials of an indentation test on mortar joints have shown that the test is not promising as a measure of surface hardness, due to the compaction occurring under indentation pressure, the high variability of results and the lack of ability to distinguish between good and bad mortars.

Figure 6. Correlation of Scratch Index With Weight Loss Index.



A controlled scratch test has been shown to be superior to the indentation test for assessing the surface hardness of mortar joints, and provides a useful measure of the durability resistance of the mortar. The average penetration per turn for the first 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 gives results that correlate very well with the cement content of the mortar. Further investigations of the effect of joint tooling are required.

Results of the scratch test for 1:3 lime mortars show a different behaviour to that observed for cement and composition mortars, namely an increasing rate of penetration with the number of turns of the scratch device. This behaviour is tentatively attributed to a harder skin formed on the joint by reaction with the atmosphere.

The salt-cycling test and the scratch test give measures that correlate well with each other and are therefore probably measuring the same property. Further field testing is required to establish acceptance criteria for both test methods.

7. ACKNOWLEDGEMENT

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