SOME ASPECTS OF CONCRETE BLOCK PAVERS QUALITY

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SUMMARY

Australia is among the countries with high use of Concrete Block Pavers (CBP) per head. This fact could be considered as one of the reasons why a relatively significant amount of research has been conducted here. The main areas of research are the structural behavior of segmental pavements and the mechanical properties of individual paving units. The individual mechanical properties are traditionally compressive strength, abrasion resistance, flexural strength and skid resistance. Considerably less effort (and less conclusive results) could be found in the area of efflorescence problems research despite the fact that the questions of colour stability and uniformity are important issues in Australia due to a relatively high demand for colored concrete products. The resistance to abrasion together with efflorescence (probably two major problem areas for Australian CBP manufactures) are addressed in this paper.

INTRODUCTION

The author of this paper had the opportunity to work over two years as a R&D Engineer for a major Australian CBP manufacturer. Production data collection and analyses during this period enabled him to examine correlations between the various mechanical properties of CBP and come up with some (perhaps useful) conclusions and suggestions related to CBP production quality control (see paper "Quick Quality Control of Concrete Block Pavers in Australia" in these proceedings).However the most challenging areas are those with the least conclusive results so far:

- Resistance of CBP to abrasion forces - decisive factors

- Efflorescence on CBP - factors, reduction of and possible evaluation of potential for efflorescence.

OBJECTIVES

Abrasion Resistance

It is generally accepted that the failure of abrasion resistance is usually caused by a combination of several factors such as:

- inadequate compressive strength (low cement content)
- soft aggregate
- early application of abrasion load
- inadequate curing
- short period of curing .

The last two factors are certainly very important but probably the most neglected. It is believed that the key to abrasion resistance is strength of concrete, but in fact the most important is strength of the top 1-3 mm and not throughout the depth of concrete. It is often a misleading exercise to try to establish the relationship between compressive strength of product and its abrasion resistance without having exact information about the product's curing process. Hence it is sometimes concluded that only a poor correlation exists between CBP strength and abrasion resistance. What is measured in the laboratory is actually the strength of whole unit and not the top-layer-strength. If this top-layer-strength varies greatly among tested pavers due to unequal curing conditions, then there is little chance to establish any reasonable relationship between abrasion resistance and compressive strength of unit.

The hypotheses mentioned above are probably neither new nor surprising to anybody who has some experience and basic knowledge in the area of concrete technology. The objective therefore was not to determine if proper curing improves the abrasion resistance of CBP but to find which type and what length of curing have the most positive effect on this important property.

Problems with Efflorescence

There are many kinds of efflorescence which can develop on CBP. The most common one is so called **Lime Bloom** - particularly noticeable on colored concrete made from Portland cement. $Ca(OH)_2$ is formed during the hydration processes from Portland cement. This $Ca(OH)_2$ can migrate through the product and then on the surface react with CO_2 from the atmosphere to produce a surface deposit of water insoluble Calcium Carbonate ($CaCO_3$). This is the most frequent type of efflorescence.

A lot of factors (usually a combination of them) more or less contribute to the efflorescence development. The main are:

- Low density of concrete
- Rapid drying of the surface
- High alkali cement content
- Poor mix design (grading of the aggregate, plasticisers)
- Open capillary system
- Impurities in aggregate....

Some authors (5) differentiate between primary and secondary efflorescence. Primary is considered to be that efflorescence which occurs during hardening of concrete, and that resulting from weathering of the hardened concrete is called secondary efflorescence.

Primary efflorescence (developed a few hours after the CBP are manufactured) is a very unpleasant matter for manufacturer. Since it is visible on blocks when being sold. The main cause of a producer's concern is usually the deposit of water insoluble calcium carbonate ($CaCO_3$) - the most common form of efflorescence. It is difficult to remove when deposited and is often the source of customer's complaints. The argument that this efflorescence will be eventually washed away by rain within 1 year or so doesn't usually convince the worried customer.

In the case of **secondary efflorescence** the main causation factors are compaction, hardening, storage and weather conditions. Secondary efflorescence is usually unavoidable and generally develops on those pavers where the primary one has not occurred yet. Generally speaking the only difference between primary and secondary efflorescence is time of occurrence and the fact that calcium hydroxide (which is necessary for this type of efflorescence) is the result of different hydration processes.

It is not the purpose of this paper to analyze all possible factors leading to formation of or prevention of primary or secondary efflorescence. So far there is not any method, admixture or additive which would reliably prevent the development of "lime bloom". The intention is rather to share experience in the battle against this so far incurable "cosmetic disease" of concrete.

TESTING PROGRAM

The testing program was devised to achieve the following tasks:

1. **Examine the effect of the length of curing period on abrasion resistance test results**

2. **To identify what effect the curing environment has on abrasion resistance test results.**

3. **Investigate possibilities of suppressing primary and secondary efflorescence on CBP**

4. **Examine current Australian standard test for potential to efflorescence development and compare the results to an alternative test.**

EXPERIMENTAL WORK

Abrasion Resistance

The Length of Curing Period

It is assumed that the length of curing period should affect the hardness of the top layer of the paver's surface which greatly affects its resistance to abrasion forces. The compressive strength of concrete develops as the hydration processes proceed. At the beginning it is controlled by the hydration of cement mineral alit (C_3S) and in later stages by belit (C_2S). These processes control "macro" abrasion resistance of thick sections but do not entirely apply for paving units. The pavers' abrasion resistance is largely a function of the upper surface layer of cement and aggregate. The decisive factors will be cement content, stage of hydration (which is affected by curing regime and time), type of curing and degree of carbonation. It is still not clear how the abrasion resistance of concrete pavers develops with curing time.

The objective was to determine the development of concrete paver abrasion resistance within the time using different types and lengths of curing. This would establish the pattern of abrasion resistance growth and determine what would be an ideal form and length of curing. Also the "mature" age of the paving unit from an abrasion resistance point of view might be established. Three curing regimes were set up:

- **Group 1:** Air curing was adopted to model the typical, uncontrolled conditions which occur under real production situations - typical air conditioned laboratory environment (20°C +/- 2°C)
- **Group 2:** Twenty four hours of mist-curing in curing chambers (cycle - mist 3 minutes on, 57 min. off)
- **Group 3:** Seven days of mist-curing in curing chambers (cycle - mist 3 minutes on, 57 min. off)

Pavers used for this test were rectangular pavers with a thickness of 50 mm, produced by a major Queensland block supplier. Two hundred pavers were randomly sampled over one shift as they were dispatched from the curing chambers such that the "lot" represented a full shift's production.

The mix design:

Cement (GP).....340 kg	Pit Sand.....650 kg
Medium Sand.....1080 kg	4mm aggregate.....940 kg
Clay Dust.....60 kg	Admixture (Lubricrete)...100 ml

Units were then stored in three different environments as stated above. Their weight, height, volume, density and abrasion resistance were determined at the age of 28, 60 and 120 days. Abrasion index was tested by Ball Race Test and calculated using equation 1 and results summarized in Figure 1 and Table 1 suggest that there is an increase in abrasion index with paver age no matter what type or length of curing period was used.

$$I_a = \frac{\sqrt{R}}{P} \quad \text{.....(1)}$$

where I_a = abrasion index
R = ball-race revolutions in thousands
P = penetration in millimeters

Table 1 Effect of type and length of curing on abrasion resistance (Ball race test)

GROUP	CURING	28 day Ia (avg of 30 pavers)	60 day Ia (avg of 30 pavers)	120 day Ia (avg of 30 pavers)
Group 1	**Air cured**	0.49	0.89	1.52
Group 2	**1 day mist**	1.46	2.72	3.54
Group 3	**7 day mist**	2.17	2.75	3.53

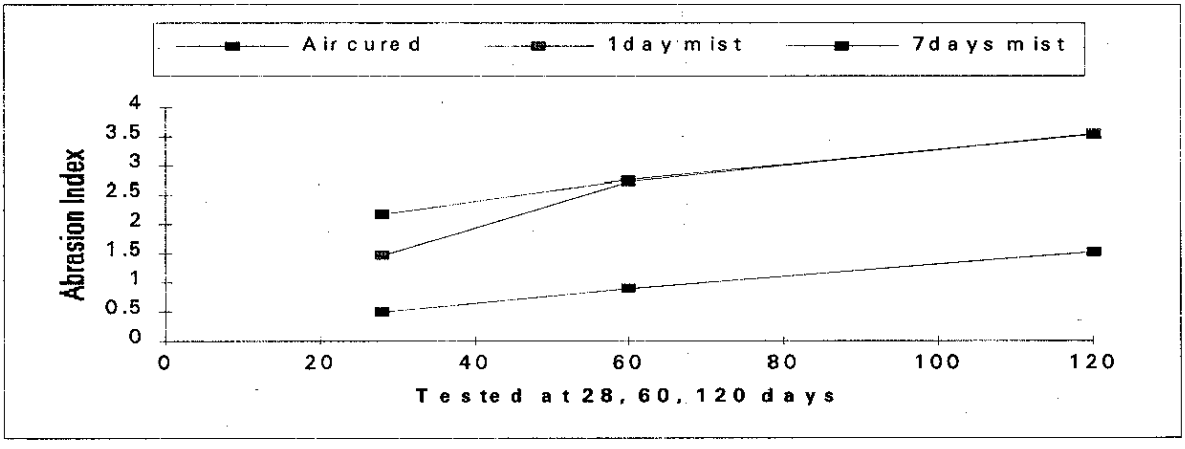


Figure 1 Abrasion resistance development with different initial curing (Ball race test)

The average I_a of particular groups corresponded to quality and length of curing. While the air cured products showed relatively poor 28 day I_a, the average I_a of mist cured products were correlated to the duration of curing. The span of abrasion resistance values between air and mist cured products remained relatively constant within a 4 month period as well as did the growth. Average I_a of 1 day mist cured units reached the same value of those mist cured for 7 days after 60 days and then the patterns of both groups were almost identical.

The new Australian specification for CBP MA34 document includes an abrasion resistance guideline based on so called Tumbler test. The test involves tumbling steel balls against the pavers' surface. Resistance to abrasion is then correlated to loss of volume of tested unit.

It was considered appropriate to do similar testing using this new method. Pavers of the same shape and mix design were tested. This time only two groups of units were tested:

- **Group 1:** Air curing was adopted to model the typical, uncontrolled conditions which occur under real production situations - typical air conditioned laboratory environment (20°C +/- 2°C)

- **Group 2:** Twenty four hours of mist-curing in curing chambers (cycle - mist 3 minutes on, 57 min. off)

Results are in Table 2 and Figure 2. They show a similar pattern as discussed in the case of Ball Race test.

Table 2 Effect of type and length of curing on abrasion resistance (Tumbler test)

GROUP	CURING	3day vol.loss (avg of 32 pavers)	28 day vol.loss (avg of 32 pavers)	120 day vol.loss (avg of 32 pavers)
Group 1	**Air cured**	0.49 cm^3	0.89 cm^3	1.52 cm^3
Group 2	**1 day mist**	1.46 cm^3	2.72 cm^3	3.54 cm^3

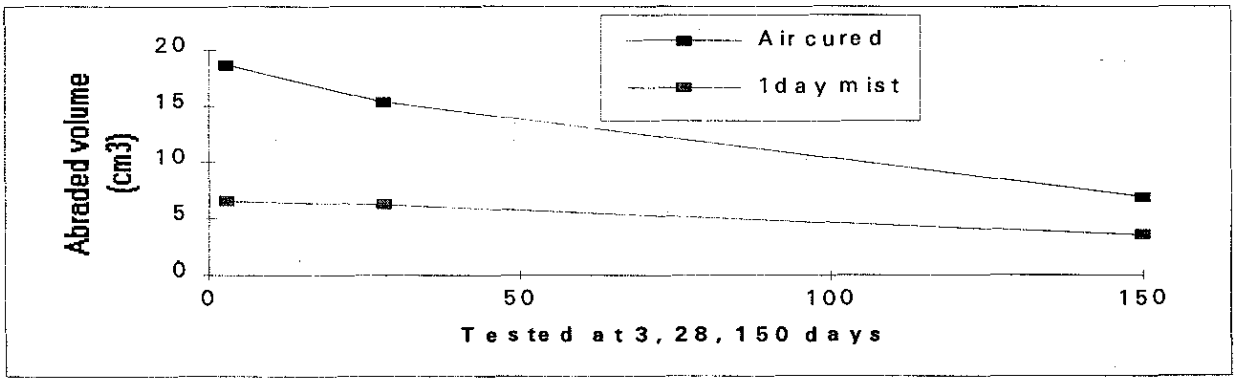


Figure 2 Abrasion resistance development with different initial curing (Tumbler test)

Type of Curing

Having established basic patterns of abrasion resistance development, the effect of four curing regimes were investigated:

- **Group 1:** Air curing - typical air conditioned laboratory environment (20°C +/- 2°C)
- **Group 2:** Fifteen hours of mist-curing in curing chambers (cycle - mist 3 minutes on, 57 min. off)
- **Group 3:** 5 days air curing. Then after 5 days pavers were immersed into the water for 24 hours.
- **Group 4:** Fifteen hours of steam curing at production plant's curing chambers (see figure 3_a for curing regime).

Pavers from the same lot as for previous tests were used. The Tumbler test (loss of volume) was applied for determination of 28 day abrasion resistance. Results are summarized in Table 3 and Figures 3_b and 3_c.

Results emphasize again the importance of the curing environment. Air and steam cured pavers performed significantly worse compare to those which underwent mist curing. The performance

of blocks from group 4 - "re-cured" ones, was very interesting Compressive strength results followed similar patterns according to expectations.

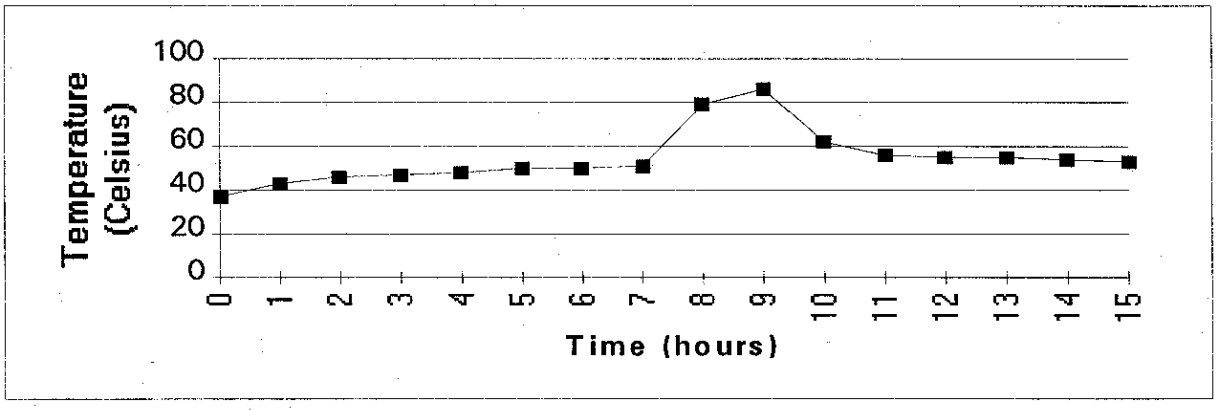


Figure 3a Curing regime of steam cured pavers (group 4)

Table 3 Effect of type of curing on abrasion resistance (Tumbler test) and compressive strength

GROUP	CURING	28 day loss cm^3 (avg of 32 pavers)	Related to mist curing (%)	28day Comp.str. MPa (avg of 32 pavers)	Related to mist curing (%)
Group 1	Air cured	5.7 cm^3	126 %	64.2 MPa	85 %
Group 2	15 hours mist	4.5 cm^3	100 %	75.4 MPa	100 %
Group 3	5 days air, then immersed in water	4.1 cm^3	92 %	70.3 MPa	93 %
Group 4	15 hours steam	5.7 cm^3	126 %	66.7 MPa	89 %

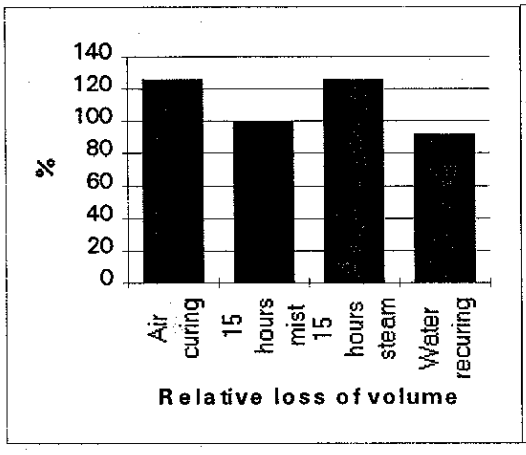


Figure 3b Effect of type of curing on abrasion resistance

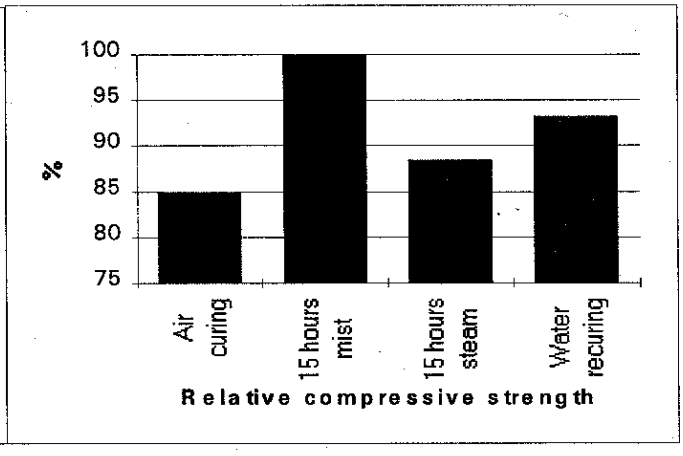


Figure 3c Effect of type of curing on compressive strength

Efflorescence

Fighting Primary Efflorescence

As already mentioned that there is an endless number of factors which contribute to the formation of primary efflorescence. The author was lucky enough to have time and opportunity to try "almost everything" in battle against primary efflorescence in production. This included a combination of changing mix designs, types of cement, adding fly-ash, silica fumes, blast furnace slag, trying numerous types of sands and aggregate and changing curing regimes. Some of these attempts appeared to be more or less successful but none solved the problem entirely. It should be kept in mind that talking about efflorescence means mainly calcium carbonate deposits since the others are not so common and are usually easily removable.

The solution was surprisingly simple and appeared to be reliable. The fact that stearate based admixtures suppress efflorescence is nothing new. They belong among the so called water repellents. Stearates ($C_{17}H_{35}COO$) are salts of fatty acids. They react with cement hydrates, especially with calcium which is present in the form of calcium hydroxide. So $(C_{17}H_{35}COO)_2$ - calcium stearate is created. Calcium stearate coats the surface of pores in concrete and the end result is that the hydrophobic coating causes a reversed angle of contact. Now the surface tension pushes the water out of the pores instead of into the pores. As the water is the best transport medium for elements causing efflorescence(in our case Ca cations), these elements have now less chance to migrate onto the surface of the paver.

There is however one strong argument against use of stearates. It is based on the fact that water repelling admixtures have a generally negative effect on concrete strength performance. Therefor it is necessary to keep the content of admixture as low as possible.

Sixteen trial mixes were run straight in the production plant. It was decided not to make trial mixes in the laboratory since it was difficult to simulate conditions in curing chambers were recurrence of primary efflorescence used to be surprisingly regular.

Standard mix **S** design (1 batch):
Portland cement.....300 kg
Medium sand.....1000 kg
Pit sand..... .....200 kg
4 mm aggregate.....500 kg
Plasticiser.....0.1 l

Trial mixes **A, B** and **C**, were identical except of additions of a stearate based admixture AL1606 - see Table 4. All units (interlocking pavers 60 mm thick) were mist cured overnight. One batch represented over 400 units. The result was very encouraging: while there were heavy white deposits of calcium carbonate on all pavers from group **S**, units from groups **A, B** and even **C** (with only 0.5 l of stearate/100kg cement) were efflorescence free. Fifty pavers from each group were randomly sampled and tested for 28 day abrasion resistance and compressive strength (Table 4). None of a 4 tested groups showed any significant difference in strength or resistance to abrasion.

Table 4 Test of stearate based admixture as primary efflorescence inhibitor

Mix	Mix design	Primary efflorescence	28 day abr.res. (tumbler test) (avg of 50 pavers)	28 day comp.strength (avg of 50 pavers)
S	S	**Heavy**	**3.0 cm^3**	**75.4 MPa**
A	S+0.5 l All606 per 100kg cem.	**Not present**	**3.2 cm^3**	**76.7 MPa**
B	S+1.0 l All606 per 100kg cem.	**Not present**	**2.9 cm^3**	**77.1 MPa**
C	S+1.5 l All606 per 100kg cem.	**Not present**	**3.5 cm^3**	**69.4 MPa**

The occurrence of primary efflorescence was practically non existent in this production plant since usage of the admixture was introduced on a regular bases.

Secondary Efflorescence

While the primary efflorescence was successfully suppressed as described above, no cure was found for the secondary type. Only spraying of the paver's surface immediately after production appeared to enhance color of product and eliminate both primary and secondary efflorescence. The mechanism is obvious. Pores are sealed in the "fresh" stage and calcium hydroxide or other efflorescence susceptible elements can't migrate onto the surface of the product. Plastic emulsions for this purpose are supplied by Bayer, BASF and other companies.

How to Test for Efflorescence Potential

There are various tests for efflorescence potential. Ideally the test should be simple and reliable. Unfortunately none satisfies the second requirement. Generally there are two basic types of these tests. The first is based on immersing specimens into water and measuring the quantity of deposited salts on the paver's surface (used in Australia). The other one involves soaking the units in distilled water and measuring the conductivity of the resulting salt solutions. Another test (used for secondary efflorescence) is based on spraying the product with distilled water in certain intervals and thus simulating rain.

The author tried all these methods but none of them seemed to be correlated to real life. Very often pavers which showed very little efflorescence potential in laboratory developed severe efflorescence in the field.

The test developed by the author showed high correlation to reality - pavers which failed in this test were usually most likely to develop efflorescence in some stage of their life. The testing equipment is simple (fig. 4). The base is a metal plate with a heating element. Temperature of distilled water in a glass tray is maintained at 70°C. A set of three pavers is placed on the plate and steam from water below has constant access to the pavers' surface and speeds up efflorescence development which would otherwise take a long time. Specimens from different sources must be placed on different trays to avoid mutual contamination.

Illustrated at fig.5,a) are three different specimens tested according to Australian standard. They seem to have the same efflorescence potential according to this test. The same pavers showed in part b) were tested using the above described method. The result of both tests varied significantly.

CONCLUSIONS

The Length of Curing Period

Duration of mist curing affects 28day abrasion resistance of pavers. However the duration of mist curing does not make any difference when the paver's age is 60 days or more. Longer curing probably initially speeds up the hydration processes in the top layer of the paver. This explains the differences between 28day values of abrasion resistance. Air cured pavers don't "catch" mist cured ones even after 120 days. Development of abrasion resistance had an increasing trend, no matter what curing was applied. Results were similar for both types of test currently used in Australia. This shows the importance of proper curing which plays a substantial role in achieving desirable abrasion resistance. Adequate curing may save tons of cement which is often used in excessive amounts to improve hardness of pavers.

The Type of Curing

Mist curing contributes significantly to higher abrasion resistance and compressive strength compared to steam or air curing (almost 30% better resistance). The poor result of abrasion resistance of steam cured pavers is probably due to the rapid drying out of the top surface layer during the drying cycle. The drying cycle of steam curing is detrimental to abrasion and compression strength. If the good results of water re cured units are proved as general rule it might be used as a "repair method" for pavers with poor initial abrasion resistance values.

Efflorescence

Primary efflorescence can be reliably controlled by very low dosage of stearate based admixtures (0.5 l / 100 kg cement). The only reliable safeguard against secondary efflorescence appears to be spraying of plastic emulsions on the product's surface a few minutes after production. Water steam inducing of efflorescence might be a reliable test for efflorescence potential.

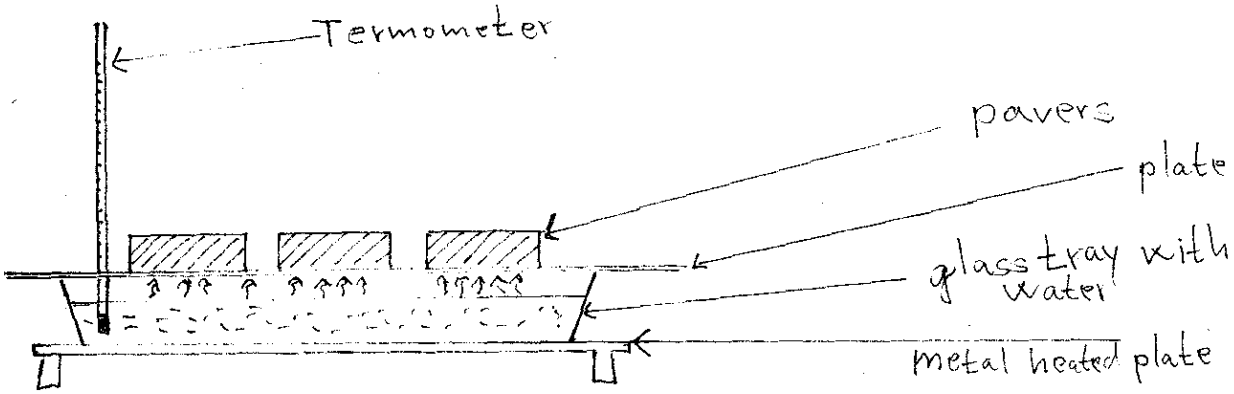
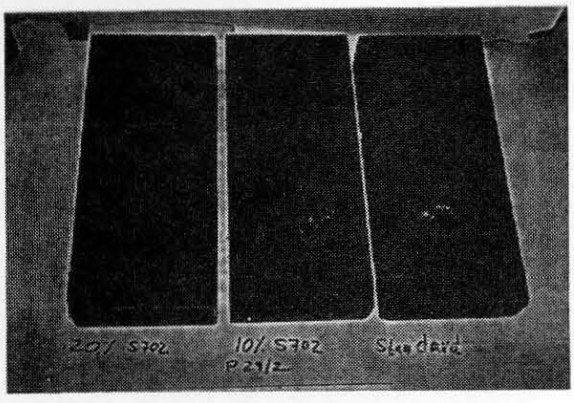


Figure 4 Alternative test for efflorescence potential



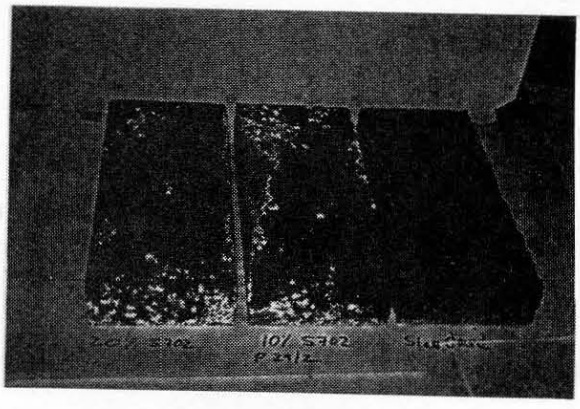


Figure 5 **a)** Pavers tested for efflorescence potential according to Australia standard

b) Same pavers tested as seen on fig. 4

9. REFERENCES

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