# DURABILITY OF BLOCK PAVING IN A MARINE ENVIRONMENT

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## ABSTRACT

Concrete paving blocks have been used successfully in South Africa in a marine environment for several decades. More recently, however, it was found that rapid deterioration occurred on new pavers and the blocks became unserviceable within three years. This was a matter of grave concern and there was a need to identify the problem. A research study was conducted and is reported in this paper.

The aim of this paper is:

- To determine the properties of those blocks that deteriorated rapidly in contrast with those that had provided long-term satisfactory service.
- To identify test methods and specifications that will ensure that blocks are durable.

Blocks from various sources that had been placed in different marine environments were tested in the laboratory for water absorption, porosity, steel brush abrasion resistance, durability in sodium chloride and sodium sulphate and for cement content. These test results were compared with reported performance. To evaluate the appropriateness of the laboratory test protocol a further nine panels were constructed with paving blocks from different sources. Anticipated performance was predicted before the test was started, and the performance results after six and twelve months service are compared with the predicted results.

The following main conclusions were found:

The critical parameters to ensure durability were cement content, sodium chloride resistance and low water absorption.

The test protocol was able to correctly predict the performance of the test panels, which shows that the correct parameters have been identified.

Application of the findings from this study should lead to more durable concrete paving block along coastal regions.

## 1. INTRODUCTION

Concrete paving blocks have been used successfully in a marine environment for several decades in many places around the world, including South Africa. Blocks used on a pedestrian walkway along the esplanade in Cape Town had performed magnificently for more than 20 years. Because of settlement of the substrate the blocks were replaced. It was, however, found that rapid deterioration occurred on the new pavers and the blocks became unserviceable within three years. This was a matter of grave concern and there was a need to identify the source of the problem and how to avoid the future occurrence. A research study was conducted and is reported in this paper.

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## 2. REVIEW OF THE LITERATURE

The concrete paving blocks used in South Africa are made in two grades. Class 25 blocks have an average compressive strength of 25 MPa and a minimum individual strength of 20 MPa whereas class 35 blocks have an average compressive strength of 35 MPa and a minimum individual strength of 30 MPa. The concrete mix for paving blocks has a water-cement ratio of less than 0.4 and contains 14% cement. The cement used in the mix complies with the requirements of SABS 471, 626 or 831.

Concrete blocks exposed to aggressive conditions must be durable. The types of the aggressive conditions in marine environments and the protective measures to resist this aggression are discussed next.

### 2.1 Chemical attack

Sulphates in sea water have a similar effect to certain types of soil which contain sulphates, which attack concrete materials. These chemicals destroy the external appearance of the concrete paving blocks. Sulphates also cause a chemical reaction between aggregates and cement or the atmosphere.

To improve the resistance of the paving blocks to sulphate attack, a concrete mix with low water-cement ratio is used. The paving blocks must be fully compacted to reduce permeability. However, this has proven not to be sufficient, and it is becoming common to use sulphate-resisting cement (Dowson 1980). To reduce chemical reaction between the aggregates and cement, the use of deleterious aggregates should be avoided.

### 2.2 Sea water attack

The following two actions occur between blocks and sea water:

- chemical reactions, resulting in softening and disruptive expansion of the blocks.
- crystallization of salts on the block surface.

Chemical reactions cannot cause serious problems, unless they take place within the paving block. To reduce chemical reactions is to produce impermeable concrete blocks (Neville 1973).

Problems with blocks in a marine environment occur where repeated cycles of wetting and drying take place. The water is drawn up through the capillaries in the blocks. As the moisture evaporates and the blocks dry out, the dissolved salts in the form of crystals are left within the joints of concrete blocks as well as in the pores of the blocks. To prevent the capillary flow the blocks should be well compacted and have a low porosity. Furthermore, concrete containing high-alumina cement is recommended, since high-alumina cements have greater resistance to seawater than Portland cement (Dowson 1980).

## 2.3 Abrasion

Abrasion is the wearing-off of the concrete paving block caused by amongst others high water-cement ratio and excess of air-entraining admixture in the concrete mix. The high compressive strength of a concrete paving block indicates high abrasion resistance, but evaluation only on the basis of strength will not identify the thin abrasion susceptible block surface (Dreijer 1980). Available abrasion tests are sandblast tests, rattler-type tests and mechanical tests with wheels or steel balls. However, these tests only allow an evaluation of relative quality without any defined acceptable criteria for wear-off of concrete surfaces (Lane 1978).

# 3. EXPERIMENTAL PROGRAMME

From the literature review, it was concluded that the following tests could give an indication of durability in a marine environment:

- Cement content
- Salt resistance
- Water absorption
- Porosity
- Abrasion resistance

## 3.1 Cement content

The X-Ray Fluorescence Analysis test was used to determine the calcium oxide (CaO) content in the paving blocks, in order to establish the cement content. The material from the block is ground to be finer than 75 microns. This material is fused at 1000 $^{0}$C in a muffle furnace. Major element analysis is carried out on fused beads, following the standard method used in the XRD and XRF laboratory at the University of Pretoria.

## 3.2 Salt resistance

Specimens (50 mm cubes) cut from paving blocks were subjected to 15 cycles of soaking in 60g per 1000 ml solution of either sodium sulphate or sodium chloride, oven drying and cooling. When particle losses occur, the total mass of the 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 loss of particles of more than 1% as specified by the Australian/New Zealand standard AS/NZS.10: 1997.

## 3.3 Porosity

Porosity is an indication of the interconnected pores present in the paving block. From each block, a specimen is cut into a cylinder of approximately 65 mm diameter and 20 mm thick. The specimens are placed in an oven for four days to dry completely at a temperature of 105 $^{o}$C. After four days the specimens are removed from the oven and placed in a vacuum desiccator, where approximately 87 kPa pressure was maintained over the specimens by means of a vacuum pump. The vacuum is left for about 8 to 12 hours before distilled water can be added in the vacuum desiccator. The vacuum is then maintained for another 6 hours to ensure that air is completely removed from the specimens. The vacuum within the specimens draws the water in the desiccator into the pores. From this the porosity is calculated.

3.4 Water absorption

The absorption of water by immersion of the paving blocks in water is measured as the difference between the mass of a test specimen (100 mm square block and 50 mm thick) after immersion in water for at least 48 hours, and the mass of the same specimen when dry (Rilem test method 1979).

3.5 Abrasion resistance

The wire-brush method measures the average wear to which a standard wire brush, abrades the paving blocks. A drill press was adapted for this test. The sample was abraded with the wire brush at 400 rpm for 4 minutes with a force of 145 N. The average depth of wear was taken over 20 measurement points.

3.6 Samples evaluated

Specimens used in the initial laboratory tests were selected to cover a range in the durability, and consisted of the following blocks:

- 20-year old blocks without a capping layer, which were removed from the marine environment footpath and which had not deteriorated. These blocks are referred to as “old blocks”.
- New blocks which had deteriorated or were still intact (without a capping layer) were removed from the footpath after having been in service for only three years. These blocks are referred to as “new deteriorated blocks” and “new intact blocks”.
- Typical Gauteng blocks with a 10-mm capping layer of a different mix from the rest of the block were also included to determine whether there are major differences between blocks designed for the interior and marine environment. It is known that these blocks manufactured in the interior near Johannesburg do not perform well in a marine environment.

## 4. LABORATORY EVALUATION OF THE BLOCKS THAT HAD BEEN IN SERVICE

A summary of the laboratory test results is presented in Table 1.

Table 1. Summary of the laboratory test results on in-service blocks

| Block | Water absorption (%) | Porosity (%) | Cement content (%) | Abrasion (mm) | | Sodium Chloride solution | Sodium Sulphate solution |
|---|---|---|---|---|---|---|---|
| | | | | Top surface | Bottom surface | Mass loss (%) | Mass loss (%) |
| **Old block** | **3.9** | **12 .6** | **26.7** | **1.51** | **1.72** | **1.6** | **0.4** |
| **New block (deteriorated)** | **5.1** | **17.7** | **10.4** | **1.88** | **1.62** | **16.8** | **10.0** |
| **New block (intact)** | **3.2** | **14.3** | **16.1** | **1.36** | **1.56** | **0.9** | **0.4** |
| **Gauteng block** | **6.8** | **17.8** | **11.6** | **2.57** | **1.98** | **5.0** | **2.4** |

The reasons for the early deterioration of the concrete paving blocks were the following:

- The sodium chloride salt resistance test was more discriminatory than the sodium sulphate test, and correctly identified those blocks that had a durability problem.
- The cement content of the deteriorated blocks was below the guideline limit of 14%.
- The blocks were not well compacted and the mix design was inadequate, because the porosity and water absorption were high on the deteriorated blocks.
- The abrasion test and air voids determination did not provide adequate discrimination for durability.
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Indications are that to ensure good and durable blocks in a marine environment:

- Use at least 14% of cement in the concrete mix.
- Provide good compaction.
- Ensure a dense aggregate grading with low voids.
- Consider using cement extenders to reduce the voids.

The findings from the initial laboratory evaluations were used to predict the potential performance of the test panels that were placed to evaluate the applicability of the findings. This is discussed next.

## 5. PREDICTION OF PERFORMANCE OF NEW PANELS

Nine panels of blocks with different strengths and compositions were constructed in a marine environment where splash and spray occur regularly. The selected area was the same as where the problem that initiated this study occurred. Details of the blocks as well as a summary of the laboratory results are given in Table 2. The untinted blocks had different strengths and aggregate compositions, whereas the charcoal blocks were all from the same batch but used in different parts of the experiment. The cement content results are the average of three tests, and the water absorption and salt resistance is the average of four tests.

Table 2. Laboratory results of the validation study

| Block | Design Strength MPa | Water absorption (%) | Cement content (%) | Sodium Chloride solution | |
|---|---|---|---|---|---|
| | | | | Mass loss First 15 cycles (%) | Mass loss Further 15 cycles (%) |
| **Charcoal (pink)** | **45** | **6.1** | **11.2** | **0.9** | **1.1** |
| **Untinted (pink)** | **35** | **6.9** | **18.7?** | **1.3** | **3.0** |
| **Charcoal (rust)** | **45** | **4.7** | **12.2** | **1.3** | **1.5** |
| **Untinted (rust)** | **45** | **4.0** | **15.3** | **1.3** | **0.6** |
| **Charcoal (white)** | **45** | **4.2** | **11.4** | **1.2** | **1.2** |
| **Untinted (white)** | **35** | **4.0** | **12.3** | **1.0** | **0.6** |
| **Charcoal (yellow)** | **45** | **4.3** | **16.7** | **1.4** | **1.7** |
| **Untinted (yellow)** | **45** | **3.3** | **15.4** | **1.2** | **0.3** |
| **Untinted** | **35** | **5.3** | **18.3** | **1.2** | **0.3** |

The untinted (pink) block visually did not appear to be the same as the others as during cutting it felt soft. The untinted (rust) blocks were made of the same mix as the charcoal blocks.

An intriguing aspect of the test results is that the salt resistance is almost the same for all the blocks, even after subjecting them to a further 15 cycles in sodium chloride, and water absorption was relatively low. As would be expected, the cement content is related to compressive strength – the design cement content was 13% for the 35 MPa blocks (except for the unmarked type), and 16% for the 45 MPa blocks. The laboratory study corroborated the design cement contents, but in some instances the actual values were lower than the design value. In fact, the large variability (11.2% to 16.2% vs design value of 16%) of the charcoal blocks is of concern, and suggests poor quality control. From the previous study it would be expected that the blocks with the higher cement contents would perform better than the 35 MPa strength blocks, although the salt resistance tests did not show a difference. Previous observations of the performance of blocks had indicated that blocks that had an added pigment performed better that untinted blocks. It is hypothesized that the pigment acts in a similar manner as fly ash, which has proven beneficial effects on the durability of concrete in a marine environment. The fine material reduces pore sizes and their interconnectivity. The actual performance of these blocks will be discussed in the next section.

## 6. FIELD PERFORMANCE OF BLOCKS USED IN THE VALIDATION STUDY

The experimental panels were inspected after six months and again after 12 months exposure to the marine environment. The observations are given in Table 3. The trend noticeable after six months remained the same after 12 months. The hypothesized beneficial influence of the pigment is validated by the field performance. Although the general performance was good, variability in the performance was evident, which substantiates the cement content determinations. It was also noticeable that Panel No. 5, although made to be a 35 MPa block, but with the high cement content of 18.3% was providing the best performance. This corroborates general practice that a high cement content is required in a marine environment.

Table 3. Performance results after six months

| Block | Panel No | Design Strength MPa | Observations on performance |
|---|---|---|---|
| **Charcoal (pink)** | **4** | **45** | **Good** |
| **Untinted (pink)** | **4** | **35** | **Some degradation visible** |
| **Charcoal (rust)** | **2** | **45** | **Good** |
| **Untinted (rust)** | **2** | **45** | **Some degradation visible** |
| **Charcoal (white)** | **1** | **45** | **Good** |
| **Untinted (white)** | **1** | **35** | **Good** |
| **Charcoal (yellow)** | **3** | **45** | **Some degradation visible** |
| **Untinted (yellow)** | **3** | **45** | **Some degradation visible** |
| **Untinted** | **5** | **35** | **Very good, no degradation visible** |

The location of the block in the production mould, and the ability of the production equipment to fill each mould cavity with the same amount of material, could influence absorption and ultimately durability. This could explain the variable performance, even of adjacent blocks, but was not controlled in the experiment.

## 7. CONCLUSIONS AND RECOMMENDATIONS

The primary requirement for resistance to degradation in a marine environment is a cement content greater than 14%, and preferably greater than 18%. Laboratory tests that provide an indication of potential durability are the cement content test and 15 cycles of soaking, in a sodium chloride solution, and drying. In the validation study it was found that variability in the materials used in the manufacture of the blocks played a major role. This was noticed in the cement content determination, and also in the field where some blocks were found to degrade while others in the immediate vicinity remained in good condition. Location of the block in the production process could play an important role, and should be controlled in future experiments.

It was observed that pigmented blocks had a better performance than untinted blocks made with the same mix to the same strength. It is well-known that fly ash improves the durability of concrete in a marine environment. It is hypothesized that the pigment functions in the same manner as fly ash and that the resultant pores are smaller in size, and probably not interconnected, leading to improved durability. It is recommended that fly ash be used as a cement extender to improve durability, particularly for untinted blocks.

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