

## **Chapter 5**

### **Site Testing**

## 5.1 Introduction

Determining the relationship between laboratory tests and insitu wear is a crucial aspect of this research. Accordingly, one of the stated objectives (objective 4, chapter 1) of this thesis is to calibrate the three abrasion tests in terms of wear induced by traffic. To this end, blocks from the same mixes as those tested in the laboratory were installed in a heavily trafficked bus lane and pedestrian sidewalk.

By far the most common application of cbp is surfacing sites subject to vehicular and / or pedestrian traffic. For example cbp is used for *vehicular* traffic in sites as diverse as bus depots, shipping yards, residential roads, industrial parks, parking areas in shopping centres, residential driveways etc. It is used in *pedestrian* applications such as municipal sidewalks, shopping malls, parks, etc. It was therefore crucial to find a site where both types of traffic could be tested.

The co-operation of the Johannesburg City Council in making Westgate bus terminus available for this purpose is gratefully acknowledged.

This site proved to be ideal. There is only one access road in and out of the bus terminus, and the pedestrian sidewalk is situated such that commuters are funnelled into a relatively narrow sidewalk, to and from work.

Traffic volumes are considerable. The terminus is situated adjacent to Westgate station, which is itself a terminus for trains arriving from Soweto, the major residential area for people working in downtown Johannesburg. Many commuters get off the train to get on the buses. Others walk on the pedestrian sidewalk leading to the city. The considerable volume of this vehicular and pedestrian traffic is therefore an ideal test for inducing rapid wear in the blocks.

## 5.2 Paving at Westgate

On the 15th and 16th of October 1987 the entrance road and sidewalk were paved at Westgate bus terminus. The foundation layers of the road had been designed/constructed by the City Engineer's Department to withstand numerous busloads on a daily basis.

The paving blocks were placed in the usual way on a 30 mm thick screed of river sand and finally compacted with a plate vibrator. The blocks were installed in a herringbone pattern (see figure 5.1). A fine mortar-sand was used to fill the joints.

In both the sidewalk and road the blocks were laid in 48 consecutive colour-coded strips (see figures 5.2 and 5.3) corresponding to the 48 mixes.

Table 5.1 identifies the various mixes in their respective rows.



**Figure 5.1** Blocks are being installed in a herringbone pattern on a selected 30 mm sand screed in the pedestrian sidewalk



**Figure 5.2** Newly completed sidewalk showing the 48 colour-coded mixes

TABLE 5.1 LAYING PLAN FOR PAVED ROAD AND SIDEWALK AT WESTGATE INSTALLED ON 22nd AND 23rd SEPTEMBER 1987			
STRIP NUMBER	MIX NUMBER	PAINT CODE	PIGMENT CODE
1	1.1	PURPLE DOT	BAYER 110 - 4%
2	2.1		BAYER 960 - 4%
3	3.1		BAYER 318 - 4%
4	4.1		BAYER 610 - 4%
5	5.1		BAYER 160 - 4%
6	6.1		BAYER 663 - 4%
7	7.1		CARBOFIN - 4%
8	8.1		BAYER 960 - 1.5%
9	1.2	GREEN DOT	BAYER 110 - 4%
10	2.2		BAYER 960 - 4%
11	3.2		BAYER 318 - 4%
12	4.2		BAYER 610 - 4%
13	5.2		BAYER 160 - 4%
14	6.2		BAYER 663 - 4%
15	7.2		CARBOFIN - 4%
16	8.2		BAYER 960 - 1.5%
17	1.3	BLUE DOT	BAYER 110 - 4%
18	2.3		BAYER 960 - 4%
19	3.3		BAYER 318 - 4%
20	4.3		BAYER 610 - 4%
21	5.3		BAYER 160 - 4%
22	6.3		BAYER 663 - 4%
23	7.3		CARBOFIN - 4%
24	8.3		BAYER 960 - 1.5%
25	1.4	ORANGE DOT	BAYER 110 - 4%
26	2.4		BAYER 960 - 4%
27	3.4		BAYER 318 - 4%
28	4.4		BAYER 610 - 4%
29	5.4		BAYER 160 - 4%
30	6.4		BAYER 663 - 4%
31	7.4		CARBOFIN - 4%
32	8.4		BAYER 960 - 1.5%
33	1.5	RED DOT	BAYER 110 - 4%
34	2.5		BAYER 960 - 4%
35	3.5		BAYER 318 - 4%
36	4.5		BAYER 610 - 4%
37	5.5		BAYER 160 - 4%
38	6.5		BAYER 663 - 4%
39	7.5		CARBOFIN - 4%
40	8.5		BAYER 960 - 1.5%
41	1.6	YELLOW DOT	BAYER 110 - 4%
42	2.6		BAYER 960 - 4%
43	3.6		BAYER 318 - 4%
44	4.6		BAYER 610 - 4%
45	5.6		BAYER 160 - 4%
46	6.6		BAYER 663 - 4%
47	7.6		CARBOFIN - 4%
48	8.6		BAYER 960 - 1.5%
NOTE:	1.) The various mix designs corresponding to the paint and pigment codes can be seen in Table 3.1		
	2.) The pigmentation percentage refers to the total binder content in each mix		
	3.) Strip number one is on the south end for both the road and sidewalk		



**Figure 5.3** (a) The completed road of 100 mm thick paving blocks. Both buses entering and leaving the terminus travel over the blocks.



**Figure 5.3** (b) The 48 colour coded mixes can be seen.

## 5.3 Estimation of Wear

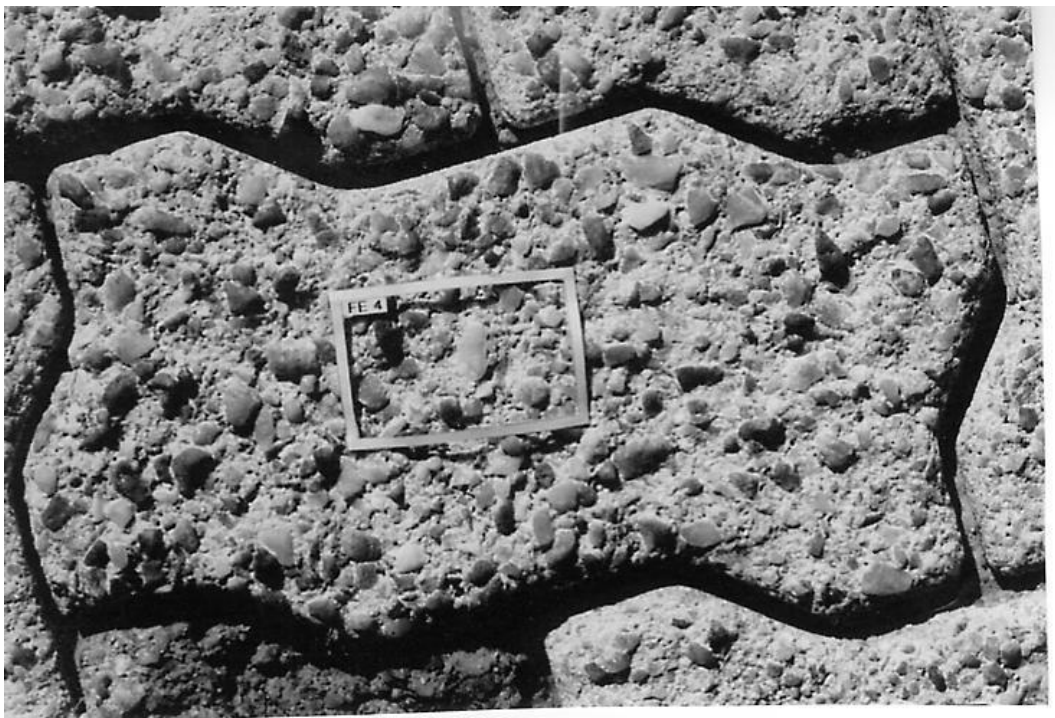
Four methods for determining the abrasion-wear were used in this investigation:

- a. Visual interpretation - photographs
- b. Depth gauge measurements
- c. Syringe method - abrasion expressed in terms of volume
- d. Determination of mass loss

These are described in some detail below.

### 5.3.1 Visual interpretation - photographs

The larger aggregate particles of pavers that have been trafficked for some time will stand out relative to the mortar constituent. The degree to which the aggregate particle is prominent is related to the *degree of wear* in the block, a concept developed more fully in chapter 8. This makes an overall visual assessment of wear a simple matter for an experienced assessor. For example, figure 5.4 shows a block where a significant number of the coarse (and fine) aggregate particles have been plucked out, a characteristic of fourth degree abrasion (see chapter 8).



**Figure 5.4** Example a of block visually assessed to have fourth degree abrasion.

From figure 5.4 it may be seen that a photograph is an excellent means of illustrating wear.

'Before wear' and 'after wear' photographs of a typical block (for each mix design), make it possible to assess the deterioration in surface appearance after almost six years of heavy traffic. Photographic comparisons of this nature make it possible to select a mix design for a project with a demonstrable long-term appearance.

### 5.3.1.1 Experimental Procedure

(a) **'Before wear' photographs.** In October 1987, photographs were taken of a typical block for each of the 48 mixes in both the road and the sidewalk. These photographs were taken directly after the installation of the blocks, and thus represent the 'before wear' appearance. Figure 5.5 is an example of a 'before wear' block.



**Figure 5.5** 'Before wear' photograph of a newly installed block at Westgate. The photograph illustrates the 'before wear' surface texture, which is relatively rough in this instance, owing to this mix being purposely made with too much water. A rough / rippled surface texture is characteristic of blocks from a very wet mix.

The complete record of the 'before wear' blocks for all the 48 mixes associated with the sidewalk may be seen in appendices Y.1 through Y.48. It is not necessary to also include the 'before wear' photographs of the Westgate *road* since they are very similar in appearance to the corresponding sidewalk photographs; the corresponding pavers were made from the same mix.

Figure 5.6 shows a professional photographer photographing the sidewalk. He can be seen to be marking the exact position of the tripod. A hole was drilled into the pavers and an aluminium pin inserted to identify the exact position of each tripod leg at each siting. This would make it possible to photograph the identical block at a later date. The height above ground level was 1020 mm, being the height measured from the back of the camera. A 100 mm macro lens and a topman tripod was used. A flash held at approximately 75 degrees to the horizontal was used.

The photographs were taken along the centre line of the assumed wheel path in the case of the road. In the case of the sidewalk, the central zone was photographed.



**Figure 5.6** A professional photographer photographing the sidewalk at Westgate. Notice him marking the legs of the tripod stand, so that holes could be drilled and pins inserted for repeat photographs at a later date.

**(b) 'After wear' photographs.** In May 1993, photographs of the Westgate road and sidewalk were again taken to determine the visual deterioration after nearly six years of traffic. (Once again one representative block of each mix in the road and sidewalk was photographed). An example of this deterioration may be seen by contrasting the block of figure 5.7 against figure 5.5, (both from the same mix). A complete record of all the 'after wear' photographs for both the road and sidewalk may be seen in appendices Z.1 through Z.196.

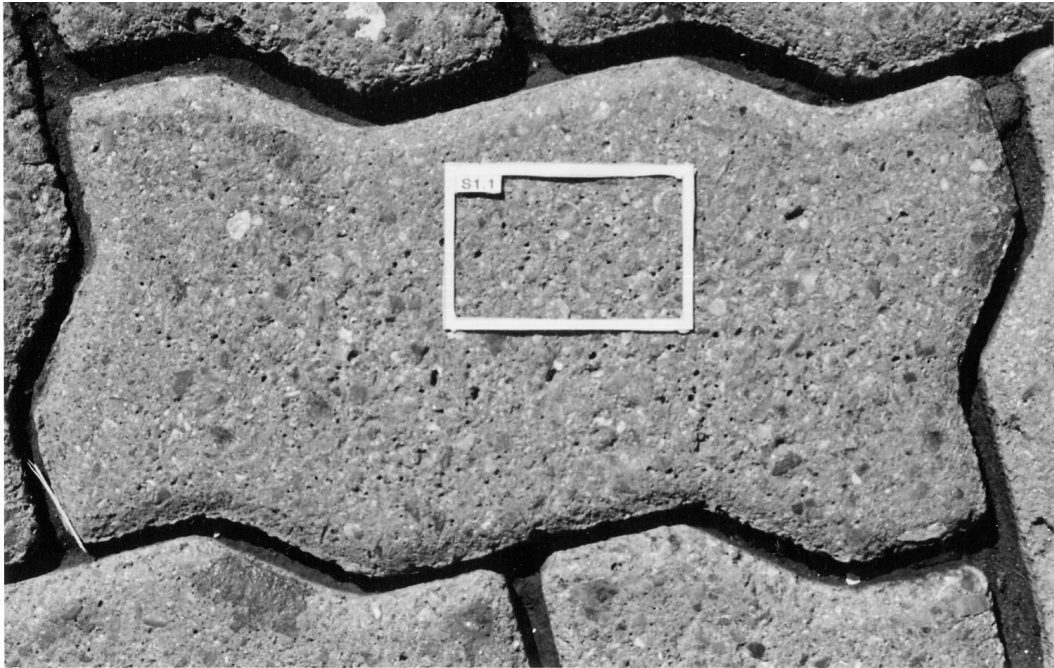
Two photographs of each block were taken to illustrate the 'after wear' appearance. The first photograph shows the full surface of a paver, and in this respect is similar to the 'before wear' photography. The second photograph shows an enlarged view of a relatively small portion of that surface. It was taken 70 mm from the surface with a special lens. An area of 50 mm x 30 mm was thus magnified to the standard jumbo photographic size of 128 mm x 77 mm. In order to identify the exact location of the enlarged area relative to the 'full surface' photograph, a paper frame of internal dimensions 50 mm x 30 mm was fastened to the block with prestik as may be seen in figure 5.8 and 5.7.

In spite of the care taken to mark the position of the tripod legs in the Sept 87 photographs, it proved difficult to locate these blocks in May 1993. Thus the May 93 photographs are of the same mix but do not necessarily represent the same blocks photographed in 1987.

**(c) Other sites.** Further photographs were also taken at four sites other than Westgate, to illustrate the five 'degrees of abrasion'. Once again two photographs were taken of each block to illustrate the appearance of the whole upper-face of the block, and a magnified view of a portion of the block. The location of these sites and the work done there is fully discussed in chapter 8.

**(d) Photographic equipment:** Figure 5.9 shows a view of the camera and tripod used to take the full block 'after wear' photographs. The back of the camera was situated approximately 400 mm above the surface.

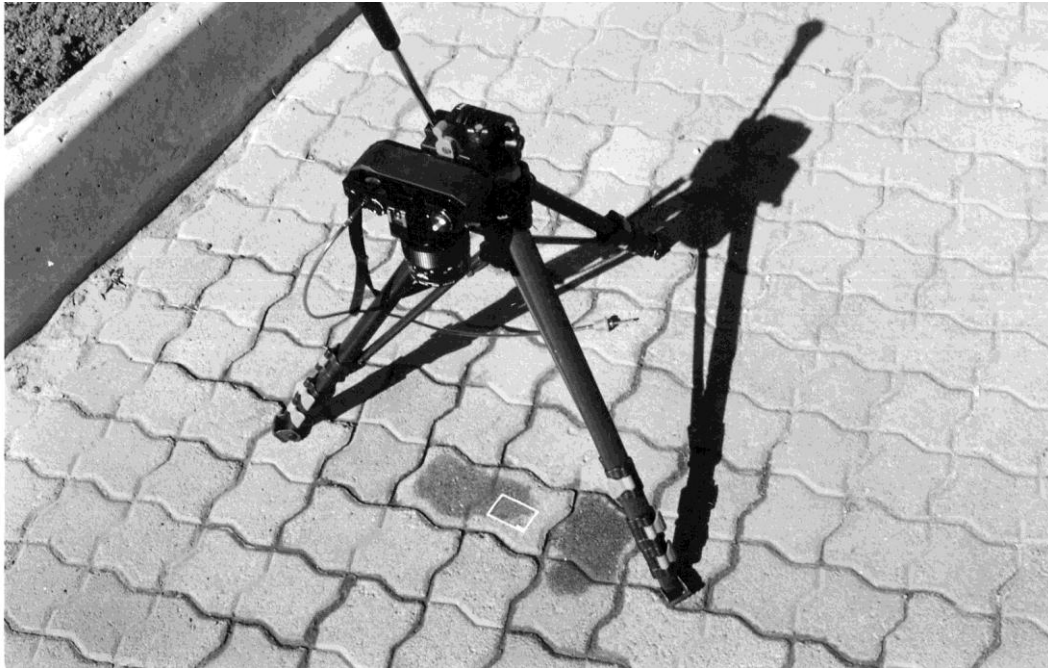




**Figure 5.7** 'After wear' photograph of full block, after five and a half years of pedestrian traffic.



**Figure 5.8** Magnified view of 50 mm x 30 mm frame facilitates a critical analysis of the surface texture.



**Figure 5.9** Camera used to take full block 'after wear' photographs

Figure 5.10 shows a view of the camera (XE-5 Minolta, 50 mm 1:1,7 lens) used to take the close up pictures. A 58 mm ZIVNON cl-up +10 lens, was attached to the front of the camera's lens. This made it possible to photograph from a range of approximately 70 mm. A special home-made tripod was used to hold the camera steady.



**Figure 5.10** Camera used to take close view 'after wear' photos



**Figure 5.11** View of sidewalk blocks at Westgate, which have been cleaned and prepared for 'after wear' photography.

In conclusion, the 'before wear' and 'after wear' photographs of a typical block for each mix design makes it possible to assess what a heavily trafficked block will look like after some years. Thus it is possible to select a mix design on the basis of the visual surface deterioration shown by a photograph. (See chapter 15 for further discussion).

### 5.3.2 Depth Gauge Measurements

The relative depth between the crest of the protruding aggregate particles and the adjacent mortar component troughs is another way of expressing wear. (See chapter 8 for further discussion).

This method uses a depth gauge with a vernier scale to determine the depth of five typical craters relative to the 'upper abraded surface' of the block. (The '*upper abraded surface*' is an imaginary plane connecting the topmost crests of the protruding aggregate particles, see chapter 8 for more detail). The '*mean crater depth*' (**mcd**) is the average depth of the five craters relative to the upper abraded surface. Care must however be exercised not to measure any untypical craters. These may have been present at the time of manufacture (especially for very wet blocks), or be the result of a very unusual impact load. Such craters are normally easily recognisable.

In this investigation the five measurements were all taken within the confines of a 50 mm x 30 mm frame placed on a representative area of the block (see figure 5.13). Taking five measurements in such a confined area reduces the risk of measuring untypical craters. It also makes it possible to identify the position of the craters on the magnified framed area as in appendices Z.2 through Z.196.

In good quality blocks it may only be possible to establish one or two wear craters of any significance, and the remaining measurements will be very small. The mcd will therefore be low, indicating good quality.

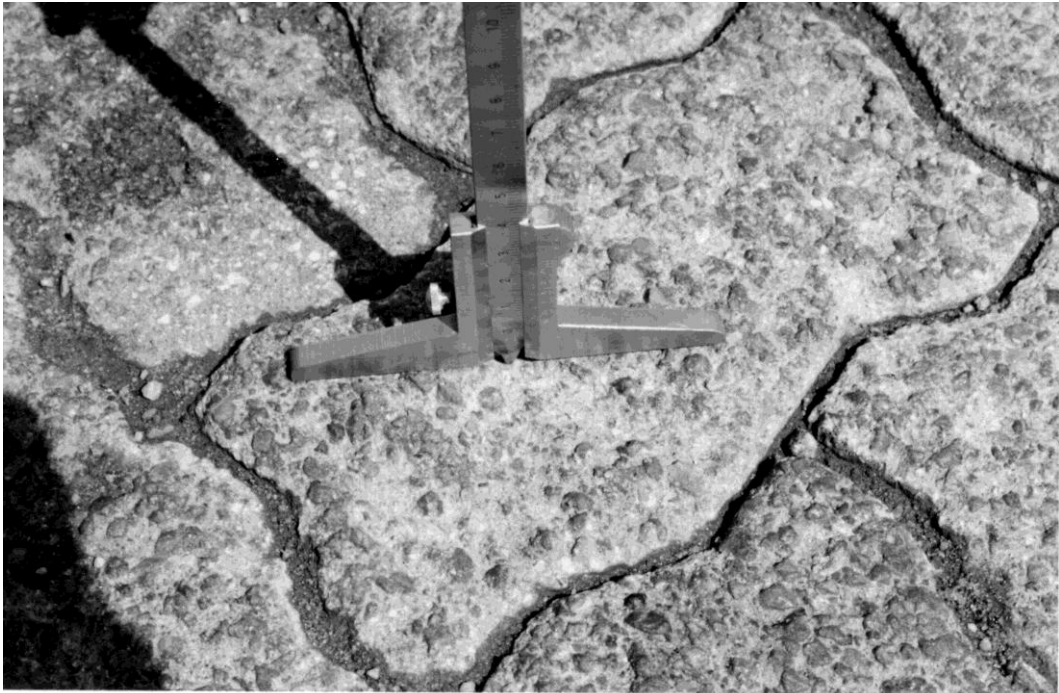
### 5.3.2.1 Experimental Procedure

In May 1993, depths of wear measurements were taken on site to obtain an indication of wear. These measurements were taken on pavers representative of the average wear for each of the 48 mixes in both the sidewalk and road. In each case care was taken to select only blocks lying in the path of maximum traffic i.e. the centre of the wheel path and central regions of sidewalk. Blocks considered non-representative were not measured. The results of these measurements and corresponding discussion are given in Chapter 14.

**(a) Apparatus.** Figure 5.12 and 5.13 show two possible types of depth gauge. The first type is shown in figure 5.12, and it has a relatively long horizontal 'beam', which is generally preferable, since it is capable of spanning most of the way across the face of the block and establishing the difference between the highest protruding aggregate particle and the trough being measured for depth. This type of gauge is particularly useful in measuring fourth degree abrasion (see chapter 8), where the uppermost surface is often wavelike, or where the protruding aggregate particles may be spaced far apart. The long reach of the 'beam' is capable of spanning the distance between a certain trough and a relatively distant protruding aggregate particle. A disadvantage is that it is awkward to use near the edge of the block, particularly where an adjacent block is at a higher level. Here the smaller depth gauge (see figure 5.13) may be more practical. The lighter and smaller vernier may be used wherever the distance between a trough and an adjacent protruding aggregate particle is small.

**(b) Method.** The ends of the depth gauge shafts had been machined to a diameter of approximately 1,5 mm. This end was inserted into a typical surface trough. Next the horizontal 'beam' attachment came to rest on the crest of a nearby protruding aggregate particle. The reading was taken and the results were recorded to one decimal place, in appendices Z.1 through Z.196. It is appreciated that these measurements do not indicate the 'invisible wear' (see chapter 8).

The surfaces of the blocks were thoroughly cleaned prior to taking these measurements. This was easy to do with a standard scrubbing brush with nylon bristles.



**Figure 5.12** Depth gauge suitable for measuring severe abrasion.



**Figure 5.13** Depth gauge suitable for measuring normal abrasion.

### 5.3.3 Syringe method - abrasion expressed in terms of volume

A full specification of the syringe method is given in appendix A.7. A brief summary is given below.

#### 5.3.3.1 Description of test

In this method of measuring wear, the volume of the material that has been abraded below the peaks of the protruding aggregate particles is measured. Modelling clay of a suitable consistency is used to fill up all the craters.

Initially the clay is sucked up into a 60 ml plastic syringe. (The front end must be filed away so that the mouth of the syringe is completely open). If the consistency of the clay is correct, no air bubbles will enter the tube during this process. Next the clay is evenly applied to the surface (see figure 5.14) using small circular movements of the hand, whilst applying even downward pressure on the plunger with the thumb. If correctly done, only minimal finishing with a standard paint scraper or trowel is required.

The *mean visible depth (mvd)* can now be obtained by dividing the volume of applied clay (= 'visible wear') by the surface area covered with the clay. (It is better to express wear in terms of an equivalent depth rather than volume, since meaningful comparisons can then be made with wear in blocks which may have different surface areas).

Compared to the depth gauge method, the syringe method gives a better indication of the true wear in the block, since it accounts for each and every crater and every uneven spot. Blocks that have significant non-wear related defects should ideally not be measured. As in 5.3.2 it is important to thoroughly clean the surface of the blocks prior to filling.

Essentially the mvd is a measure of the roughness of the block, not to be confused with total or absolute wear, which is described in 5.3.4.

Chapter 8 has a classification of various degrees of abrasion in terms of the mvd. The author is of the opinion that such a classification could prove to be a very useful tool for designers and specifiers of cbp surfaces.

#### 5.3.3.2 Apparatus

The apparatus consists of modelling clay, a scraper for applying the clay, and a 60 ml syringe.

#### 5.3.3.3 Site measurements

**May 1993:** Measurements of the abraded volume were taken at both the bus lane and the pedestrian sidewalk. A typical block, representative of the average wear for each of the 48 mixes was measured. [Prior to applying the modelling clay each of the selected blocks were photographed (see 5.3.1) and measured with a vernier (see 5.3.2)]. The results are recorded in columns C and E of table 14.1.

**October 1993:** The May 93 results had a few anomalies. In order to obtain more meaningful results the two sites at Westgate were remeasured. However this time eight blocks were measured for each mix, and the average mvd recorded in columns F and H of table 14.1. Figure 5.15 shows the sidewalk at the end of this exercise.

Prior to the application of the clay the blocks were visually assessed for wear in terms of degrees of abrasion. This is recorded in columns G and I of table 14.1.





**Figure 5.14** Application of clay to paving blocks using the syringe method



**Figure 5.15** Application of clay to eight paving blocks in each of the 48 mix designs (October 1993)

### 5.3.4 Determination of Mass Loss

The former sections have expressed wear in terms of a visual assessment of the degree of abrasion, supported by a comprehensive photographic presentation. Wear was also expressed quantitatively in terms of mcd and mvd. All of these methods express the 'visible wear'. Where abrasion is relatively mild, the mvd is a fair reflection of the '*absolute wear*'. (i.e. 'visible wear' + 'invisible wear', see chapter 8). However where severe abrasion occurs and all vestiges of the original surface may be gone, then the mvd is essentially reduced to a measure of the roughness of the blocks.

The only way to accurately determine the absolute wear is to weigh the blocks before and after traffic.

Consequently pre-weighed blocks were installed in both the road and the sidewalk, prior to trafficking.

Furthermore, in order to compensate for minor mass increase in these blocks due to ongoing hydration and carbonation effects, other pre-weighed blocks from the same mixes were also installed in the side of the road where there is virtually no traffic. The blocks were thus subjected to the same climatic conditions, but not to traffic. These blocks may actually increase in mass due to the hydration and carbonation effects, and this change in mass can be used as a correction factor for the blocks subject to traffic, thus enabling the true wear to be determined.

Still other pre-weighed blocks were placed in a chamber with a relative humidity of 60% at constant temperature 23° C, while others were submerged in water, at the laboratories of the Department of Civil Engineering, University of the Witwatersrand. It was hoped in this way to determine the maximum possible increase in mass due to carbonation in the case of the 60% humidity blocks, and similarly the maximum possible mass increase owing to ongoing hydration of the submerged blocks. It was hoped that this would give an indication of the extent of carbonation and hydration that actually occurred on site.

However, owing to time and financial constraints, this aspect of the programme was never completed. Furthermore, regrettably, the blocks that were in the 60% RH chamber, and those in the curing chamber, were inadvertently disposed of. This means that while the mass correction for carbonation and hydration are still possible, by comparing the masses of the trafficked and untrafficked blocks with their respective pre-traffic values, it is no longer possible to establish the degree of carbonation and hydration.

#### 5.3.4.1 Experimental Procedure

The decision to measure abrasion in terms of actual mass loss was taken subsequent to the commissioning of the terminus. In November 1988 blocks from the side of the road which had experienced minimal wear were uplifted, scrubbed clean, dried at 60 degrees centigrade to constant mass and weighed. These measurements are recorded in appendices M.1 through M.8.

For each of the 48 mix designs five groups of six blocks were uplifted. They were treated as follows:

- a. 6 x 48 blocks were cleaned, dried, marked, weighed. In January 1989 they were reinstalled in the centre of what was becoming a clearly defined *wheel path*.
- b. 6 x 48 blocks were similarly cleaned, dried, marked, weighed and reinstalled in the *centre of the pedestrian sidewalk*.
- c. 6 x 48 blocks were cleaned, dried, marked, weighed and reinstalled adjacent to the



*kerbstone of the road*, where they are subject to almost no traffic.

- d. 6 x 48 blocks were cleaned, dried, marked, weighed and placed inside a chamber at the university which is kept at a constant temperature of 23 C and a relative *humidity of 60 %*. Unfortunately, as explained, these blocks are gone.
- e. 6 x 48 blocks were cleaned, dried, marked, weighed and submerged in water tanks, also at the university. After approximately five years these blocks were moved to a *100% humidity* chamber. These blocks are also gone.

Thus a total of 1440 blocks were weighed. They were identified with a number (see appendices M.1 through M.8), painted on one of their vertical faces. It remains for the three sets of blocks on site to be uplifted from the road and sidewalk (funds permitting). Once again they should be cleaned, dried to constant mass at 60 degrees centigrade and weighed.

These readings can then be compared to the values in appendices M.1 through M.8. From this it should be possible to calculate the loss in mass due to abrasion, after a correction for site hydration and carbonation has been made.

The total wear thus calculated is referred to as the 'absolute' wear (see chapter 8).

## 5.4 Summary

Blocks from the same mixes as those tested in the laboratory (see chapter 4) were installed in the access road to a busy bus terminus, and a busy pedestrian sidewalk.

After approximately six years, the actual wear on these blocks was measured in four ways:

- a. visually (photographs, degrees of abrasion)
- b. depth gauge measurements (mcd)
- c. syringe method (mvd)
- d. in terms of mass loss (still to be completed).

Finally it may be said that this chapter summarises the construction of the cbp road and sidewalk at Westgate, and the subsequent methods of measuring the wear after six years. The measured wear as determined by these methods forms the basis for calibrating the abrasion tests (see chapter 14, 15).