Chapter 8

Classification of Abrasion
8.1 The Need for a Classification

Generally successful cbp applications are the result of four interested parties cooperating together in different ways.

Firstly there is the owner. He decides to invest money in paving an area.

Secondly there is the engineer/architect. He turns the owner's idea into a workable plan. It is the responsibility of the engineer to correctly specify the cbp in terms of structural bearing capacity and abrasion resistance if the surface is to remain serviceable and aesthetically pleasing.

Thirdly there is the manufacturer. He obtains the materials, produces the blocks according to the engineer's specifications, and delivers to site.

Fourthly there is the paviour who installs the blocks.

However, in executing his responsibilities the engineer faces a number of problems:

a. There is no recognised means of quantifying or assessing the wear on a paved surface.

b. It follows that there can be no classification defining the limits of wear on sites.

c. Although some limited abrasion testing is done in South Africa (e.g. ASTM C418, SABS 541, C&CI.TM.7.11, MA20SA) no one test is used for cbp in South Africa. Ideally the engineer is looking for an accelerated wear test that will, for example, simulate in five minutes ten years of wear for a given traffic intensity.

d. The abrasion tests that do exist have not been 'calibrated' in terms of wear on site. Without this it is not possible for the owner, engineer or manufacturer to know how the blocks will wear.

This chapter addresses points a. and b. by describing and quantifying wear on in-service blocks. A classification of acceptable limits for various applications is proposed. Chapters 9 through 12 focus on different abrasion tests and therefore attempt to resolve point c. Chapter 14 correlates the wear of the experimental blocks at Westgate with the results of the abrasion tests, thus further addressing point c. Finally the matter of establishing limiting criteria is discussed in chapter 15, thus resolving point d.
8.2 Degrees of Abrasion

In paved areas subjected to a high volume of either pedestrian or vehicular traffic for some years, it is often possible to identify five distinct stages of wear, or degrees of abrasion.

[Instead of ‘degrees of abrasion’, it would be more correct to say ‘degrees of wear’, or still more correct to say ‘degrees of abrasion-wear’, since the term is meant to convey the amount of wear that has taken place from an abrasion process, rather than allude to the severity of the abrasion process. While it is true to say that severe abrasion generally leads to substantial abrasion wear, this is not always the case. For example severe abrasion will not lead to substantial wear in very hard materials, nor if the abrasion attack is of a short duration. Notwithstanding, the term ‘degree of abrasion-wear’ is judged to be too cumbersome, and thus ‘degrees of abrasion’ is used throughout this chapter and in the rest of the manuscript].

This chapter however, does not deal with the blocks installed at Westgate bus terminus, as this is done in chapter 14. Instead it lays the foundation for assessing the Westgate blocks in terms of the five degrees of abrasion.

Four sites where cbp was used and which have a known history in relation to the manufacturer, concrete mixes, duration of wear etc., have been photographed to show the different degrees of abrasion. The four sites represent blocks supplied by three of the major producers in South Africa, which all have SABS approved quality management systems.

A general view of these sites is given in figures 8.1 through 8.4.

The four sites are as follows:

a. a shopping mall in Roodepoort, blocks ex Brickor Precast;
b. vehicular entrance to Brickor Precast's Roodepoort factory, blocks ex Brickor Precast;
c. vehicular entrance to Randparkridge Mall, blocks ex Grinaker Precast;
d. vehicular entrance to Lifestyle garden centre, blocks ex Concor Technicrete.

A comparison of close view photographs of selected blocks from the various sites gives an appreciation of the variation in surface texture that can be expected in blocks made by different manufacturers and subject to different traffic conditions.

Figures 8.6 through 8.49 illustrate photographically, at close range, the five degrees of abrasion as they occur at the four sites. The photographs have been taken at places of varying traffic intensity to illustrate the five degrees of abrasion.

Although so many photographs may appear to be excessive, they are in actual fact just sufficient to give an appreciation of the kind of variation that occurs from one degree of abrasion to the next for different manufacturers (different mix designs, manufacturing machines, curing regimes), different traffic conditions etc. For this reason they have not been relegated to the appendix. The photographs also reveal the variation in surface texture from site to site for blocks with the same degree of abrasion.

Each block has a paper frame of inside dimensions 30 mm x 50 mm, which serves to focus attention on a small area of the surface. An example may be seen in figure 8.6, while the enlarged view of the framed area is given in figure 8.7.

Within this framed area five typical craters on each block were measured with a depth gauge. The respective craters are identified on the photographs with the letters A, E, N, S, or T (e.g. see figure 8.7) and the corresponding depths recorded in the caption below the
photograph. The *crater depth* from 'mean crater depth' (mcd), referred to in the caption, refers to the relative depth between the deepest point of the crater and the highest protruding particle in close proximity to the crater, and the term *mean* implies the average of five measurements. The 'visible wear' and 'mean visible depth' (explained in 8.2.3), are also indicated in the captions, as alternative expressions for each of the five degrees of abrasion.

Figure 8.1 Nine year old blocks in a Roodepoort shopping mall. Traffic is limited to pedestrians. All five degrees of abrasion may be identified on this site.

Figure 8.2 Ten year old blocks at vehicular entrance to brick factory. This area was paved with 'seconds' of doubtful quality, and experiences heavy loads from large articulated vehicles, thus providing a site where all five degrees of abrasion can be seen.
Figure 8.3 Five year old blocks in vehicular entrance to Randridge Mall. Traffic loadings are almost exclusively limited to cars. Signs of advanced abrasion are evident at the corner of the entrance.

Figure 8.4 Three year old blocks in vehicular entrance to Lifestyle garden centre. Considerable abrasion has occurred at the entrance due to the slewing action of cars and heavy vehicles.
8.2.1 Zero Degree Abrasion

In zero degree abrasion virtually no signs of wear are noticeable. There may however be a slight amount of discoloration owing to the presence of dirt, efflorescence, ageing or weathering.

Szadkowski (1987) for example has stated that exposure to the weather changes the colour of normal Portland cement, depending on its composition, in the direction of yellow. He states that it still cannot be said with certainty whether this process is due more to rearrangement of the cement constituents, caused by weathering, or to decomposition of the cement matrix. He continues by saying that this phenomenon has no adverse affect on the cement's mechanical properties, and is only of interest in so far as it affects the colour of concrete. Assuming that the colour of the cement matrix is thus changed, then, of course, the colour will also change if pigment is present. The colour of the concrete will likewise be affected; the concrete will show a yellow cast, which will be more or less conspicuous, depending on its original colour.

However apart from such colouring effects, blocks in this stage of wear are essentially the same in texture as they were when newly manufactured.

These blocks are normally to be found on the verge of paved surfaces close to shop windows, next to the kerb in the case of a road, and generally in places where they are out of the way of traffic.

Although a certain amount of dirt and discoloration are noticeable, their surfaces show no appreciable signs of wear. The binder still covers most of the aggregate particles and hence no appreciable colour shift in the direction of the aggregate has occurred. The texture of the surface is virtually as it was at the time of manufacture, with almost no signs of polishing or abrading.

A method for determining the ‘mean crater depth’, ‘visible wear’ and ‘mean visible depth’ (e.g. see captions in figures 8.6, 8.7) is described in 5.3.2 and 5.3.3. In the case of zero degree abrasion, these terms do not represent actual wear, but are an indication of the initial surface texture of the block.

Zero degree abrasion is shown diagrammatically in figure 8.5 below.
Figures 8.6 through 8.13 are typical examples of zero degree abrasion on the four sites. Most of the aggregate particles are still coated with a thin skin of mortar/cement paste, and this is the most dominant feature of zero degree abrasion.
Figure 8.6  Zero degree abrasion at Roodepoort mall. Paving blocks installed on the inside verge of the mall next to windows and walls show virtually no signs of wear. Visible wear = 4,5 ml, mean visible depth = 0,272 mm (Surface area, excluding bevelled area = 16544 mm $^2$).

Figure 8.7  Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: $A = 0.5$ mm, $E = 0.5$ mm, $N = 0.6$ mm, $S = 0.6$ mm, $T = 0.4$ mm: Mean crater depth = 0.52 mm. These craters are a measure of the initial surface texture, and not the result of abrasion. Although some of the aggregate particles are exposed, the majority are coated with a thin layer of binder paste.
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Figure 8.8 Zero degree abrasion at factory entrance. Blocks installed at a remote perimeter of the paved area show negligible signs of wear. Visible wear = 6.0 ml, mean visible depth = 0.385 mm (Surface area, excluding bevelled area = 15600 mm$^2$).

Figure 8.9 Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 0.7 mm, E = 0.4 mm, N = 0.6 mm, S = 0.7 mm, T = 0.7 mm: Mean crater depth = 0.62 mm. The primary characteristic of zero degree abrasion is that the majority of the aggregate particles are still coated with a thin skin of binder paste.
Figure 8.10 Zero degree abrasion at Randridge Mall. Paving blocks installed near the kerbs show virtually no signs of wear. Visible wear = 3.8 ml, mean visible depth = 0.193 mm. (Surface area, excluding bevelled area = 19712 mm²)

Figure 8.11 Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 0.0 mm, E = 0.1 mm, N = 0.0 mm, S = 0.3 mm, T = 0.0 mm: Mean crater depth = 0.08 mm. This block is a very good example of zero degree abrasion. The binder paste still covers the majority of aggregate particles. Some of the craters measured refused the depth gauge, which has a diameter of 1.5 mm, and does not therefore enter small crevices and holes.
Figure 8.12 Zero degree abrasion at Lifestyle garden centre. Blocks installed at a remote area of the car park have minimal wear. Visible wear = 6.0 ml, mean visible depth = 0.403 mm. (Surface area, excluding bevelled area = 14900 mm²).

Figure 8.13 Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 0.7 mm, E = 0.5 mm, N = 0.8 mm, S = 0.6 mm, T = 0.6 mm: Mean crater depth = 0.64 mm. This photograph is not an ideal example of zero degree abrasion, and is closer to first-degree. In many places the binder paste covering the surface aggregate particles is gone.
8.2.2 First-degree Abrasion

During the process of manufacturing paving blocks the mechanical vibration assists in causing the binder to cover the individual aggregate particles and bind them together. At this time the shoes of the press are in contact with the upper surface of the block and a skin of binder develops on this interface as well. In most cases the aggregate particles at the surface of the block are also coated with this thin layer of binder. The net effect after demoulding is that the block has a uniform colour on the surface created by the binder paste, which remains in place after the concrete has set. It is the removal of this thin skin of paste by traffic that constitutes first-degree abrasion, illustrated below.

![Figure 8.14 Section illustrating first-degree abrasion](image)

The thickness of this paste may vary depending on such factors as the water content, binder content, duration of vibration, shape, texture and grading of aggregate etc., but a minimum covering of 0.1 mm to 0.5 mm over the topmost aggregate particles is usual. This surface paste may be weakened by the extra water that is drawn to the surface as a slight degree of floating and trowelling occurs during vibration. The writer has discovered that by vigorously rubbing with a wet rag the surface of pavers of even well cured pavers, this thin skin can be removed, leaving the top face of the surface aggregate exposed. It appears that this thin layer of binder does not develop a strong bond to the top face of the surface aggregate, which further supports the view of a low b/w ratio. Inadequate curing will exacerbate this.

Nevertheless in view of the minimal thickness of this layer, the surface of the block still retains a smooth appearance after its removal.
Thus it can be stated that the degree of wear is minimal, and the main consequence is that a slight colour shift becomes visible due to the influence of the intrinsic colour of the aggregate. According to Szadkowski (1987) the eye perceives both the colour of the newly exposed aggregate and that of the binder matrix. This effect is more pronounced in coloured blocks, especially where the pigmentation is in striking contrast to the colour of the aggregate.

Generally first-degree abrasion occurs in lightly trafficked blocks.

It should however not be confused with what might be termed ‘first degree weathering’, which looks similar to first-degree abrasion, in that it also is characterized by the loss of a thin surface layer. The weathering generally occurs from the effects of rainwater, and may be seen in areas where no or very little traffic passes. Rainwater may be quite acidic, especially in industrial areas. pHs of 5.7 have been recorded in the Johannesburg area. On the other hand it may at times be very pure. In either of these states, it will attack the surface of concrete. The various forms and mechanisms of weathering are discussed in greater detail in section 2.2.2 of volume 2. It follows that surfaces that are exposed to both the effects of weathering and abrasion, will wear at a greater rate. Nevertheless for pavers that are well compacted and have adequate binder content, the combined effects of mild traffic and weathering are likely to remain within the limits of first-degree abrasion (see table 8.3).

The removal of the thin skin of binder paste, which constitutes first-degree abrasion, is illustrated photographically in figure 8.15 through 8.22 hereafter.
Figure 8.15 First-degree abrasion at Roodepoort mall. The thin layer of mortar / binder paste has been removed from the upper face of the aggregate particles. Visible wear = 5.25 ml, mean visible depth = 0.317 mm. (Surface area, excluding bevelled area = 16544 mm²).

Figure 8.16 Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 0.7 mm, E = 0.5 mm, N = 0.8 mm, S = 0.6 mm, T = 0.8 mm: Mean crater depth = 0.68 mm. Even the small aggregate particles are visible, following the removal of the thin covering of binder paste.
Figure 8.17 First-degree abrasion at factory entrance. The actual loss of surface material is negligible. The aesthetics of the block is affected to a small degree, but no appreciable increase in wear occurs. Visible wear = 5.0 ml, mean visible depth = 0.321 mm. (Surface, excluding bevelled area = 15600mm²).

Figure 8.18 Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 0.7 mm, E = 0.9 mm, N = 0.7 mm, S = 0.7 mm, T = 0.7 mm: Mean crater depth = 0.72 mm. This block is in an advanced state of first-degree abrasion. Some of the aggregate particles are already prominent and somewhat rounded, as in second-degree abrasion.
Figure 8.19  First-degree abrasion at Randridge Mall, at a relatively early stage. Not all the aggregate particles have been exposed. Visible wear = 5.0 ml, mean visible depth = 0.254 mm. (Surface area, excluding bevelled area = 19712mm²).

Figure 8.20  Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 0.4 mm, E = 0.3 mm, N = 0.4 mm, S = 0.6 mm, T = 0.6 mm: Mean crater depth = 0.44 mm. The thin skin of binder paste has been abraded off the upper surface of the larger aggregate particles.
Figure 8.21  First-degree abrasion (in an advanced stage) at Lifestyle garden centre. Even the smaller aggregate particles are noticeably exposed. Visible wear = 4.0 ml, mean visible depth = 0.268 mm. (Surface area, excluding bevelled area = 14900 mm²).

Figure 8.22  Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 0.6 mm, E = 0.5 mm, N = 0.8 mm, S = 0.7 mm, T = 0.8 mm: Mean crater depth = 0.68 mm. This is an advanced stage of first degree abrasion since nearly all the paste has been removed from the upper face of the surface aggregate.
8.2.3 Second-degree Abrasion

In second-degree abrasion the mortar, as the softer component, is abraded away faster than the aggregate. (The term mortar refers here to the binder paste and very fine aggregate particles). This results in the aggregate particles protruding slightly above the mortar component. The dominant characteristic of second-degree abrasion is that the aggregate particles do not protrude far above the mortar component. Therefore all the coarse aggregate particles, and the majority of the finer particles remain bonded in the matrix.

At this stage it will be useful to introduce some terms for defining abrasion wear.

Invisible, Visible and Absolute Wear

**Invisible wear:** The material lost between the pre-wear face (original surface) of the block and an imaginary plane connecting the peaks of the now protruding aggregate particles is defined here as the ‘invisible wear’. It is an invisible quantity in the sense that this material is gone and lost, and cannot easily be quantified. In bevelled blocks it is sometimes possible to have some idea of the invisible wear, providing the original depth of the bevel is known. Generally this can be determined by contrasting worn blocks in trafficked areas with unworn blocks laid in remote areas on the same site.

The only way to accurately quantify invisible wear is to weigh blocks before installation, then uplift and re-weigh the blocks after a certain time has lapsed. Careful attention to identifying the blocks, and drying to constant mass is necessary. This was in fact done with two sets of five blocks for each of the 48 mixes tested in this investigation; one set was installed in the pedestrian sidewalk and the other in the access road at Westgate. However owing to time and financial constraints these blocks have not been uplifted.

**Visible wear:** By way of contrast, visible wear is defined as the material lost below an imaginary plane connecting the peaks of the coarse aggregate particles. This plane is referred to as the ‘upper abraded surface’ in figure 8.23. Visible wear is easily measured, and a suitable method is given in 5.3.3.

Visible wear is significantly slowed down by the presence of the relatively hard coarse aggregate particles.

On most sites, visible wear accounts for the bulk of the wear, and invisible wear is only likely to be significant where:

a. heavy traffic volumes exist (either pedestrian or vehicular)

b. soft aggregates were used in the blocks, such as decomposed granite or sandstone aggregates

c. inferior strength pastes were used in the blocks; made from mixes that were too dry or with inadequate binder content. Not only does the inferior paste abrade rapidly, but it also bonds weakly to the coarse aggregate, resulting in the aggregate being dislodged instead of resisting the brunt of the abrasive attack.

**Absolute wear** is defined here as the sum of the visible and invisible wear.

As explained previously the mean crater depth (mcd) is the average depth of five craters. The depth of a crater may now be understood as the distance between the trough of a crater and the upper abraded surface. The depth gauge however, has a diameter of 1.5 mm, and thus narrow crevices and craters will not be registered in this test.
The **mean visible depth (mvd)** may now be understood as the average depth of abraded material below the ‘upper abraded surface’. It is calculated by dividing the ‘visible wear’ by the area that the clay is applied to (see 5.3.3). These terms are described further in 8.4.1 and 8.4.2, and illustrated in figure 8.23.

**Figure 8.23** Section through a block, illustrating second-degree abrasion

The distinctive feature of second-degree abrasion is that the **craters are relatively shallow** and only **minor loss of aggregate** is noticeable. Most of the smaller aggregate particles are still well bedded in the matrix.

**Interpretation of second-degree abrasion**

Wear limited to second-degree abrasion in cbp subjected to heavy traffic is an endorsement of good quality. The paste is sufficiently strong to anchor the hard aggregate particles, which take the brunt of the attack.

In second-degree abrasion where heavy traffic exists, the larger aggregate particles:

a. begin to show signs of surface polishing (smooth upper face)
b. have slightly rounded edges
c. protrude only slightly out of the matrix.

Wear limited to second-degree abrasion where the aggregate particles retain their initial surface texture (e.g. sharp edges, uneven surfaces), is an indication of a surface that has not been heavily trafficked, and in this case second-degree abrasion does not endorse the quality of the blocks.

Second-degree abrasion is illustrated in figures 8.24 through 8.31.
Figure 8.24 Second-degree abrasion at Roodepoort mall. The aggregate component is distinctly visible, slightly prominent, but well anchored. Visible wear = 8.5 ml, mean visible depth = 0.514 mm. (Surface area, excluding bevelled area = $16544\text{mm}^2$).

Figure 8.25 Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: $A = 0.9$ mm, $E = 0.7$ mm, $N = 0.5$ mm, $S = 0.7$ mm, $T = 0.6$ mm. Mean crater depth = 0.68 mm. Even the fine aggregate particles are still well anchored. Only the finest of the fine aggregate particles have been abraded.
Figure 8.26 Second-degree abrasion at factory entrance. Some of the finer aggregate particles have been dislodged, indicating an advanced stage of second-degree abrasion. Visible wear = 9.0 ml, mean visible depth = 0.577 mm. (Surface area, excluding bevelled area = 15600 mm²).

Figure 8.27 Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 0.7 mm, E = 1.1 mm, N = 0.9 mm, S = 0.9 mm, T = 0.7 mm: Mean crater depth = 0.86 mm.
Second-degree abrasion at Randridge Mall. The aggregate component is distinctly visible, slightly prominent, but well anchored. Visible wear = 8.2 ml, mean visible depth = 0.416 mm. (Surface area, excluding bevelled area = 19712 mm$^2$).

Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 0.8 mm, E = 1.0 mm, N = 0.9 mm, S = 1.0 mm, T = 1.0 mm: Mean crater depth = 0.94 mm. There is some degree of third-degree abrasion, since a few of the finer aggregate particles have been dislodged.
Figure 8.30  Second-degree abrasion at Lifestyle garden centre. This is a good example of second-degree abrasion in good quality cbp. The coarse aggregate is being polished away, as it takes the brunt of the attack. The aggregate is only slightly prominent. The fine aggregate is nearly all present. Visible wear = 5.0 ml, mean visible depth = 0.336 mm. (Surface area, excluding bevelled area = 14900 mm²).

Figure 8.31  Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 0.9 mm, E = 0.8 mm, N = 0.8 mm, S = 0.8 mm, T = 0.8 mm: Mean crater depth = 0.82 mm.
8.2.4 Third-degree Abrasion

In third-degree abrasion the coarse aggregate component is sufficiently proud of the mortar component to provide a significant level of protection and so slow down the abrasion of the mortar component. By the same token, the prominence of the coarse aggregate implies that the finer aggregate and paste have been scratched out.

Therefore the most distinctive feature of 3rd degree abrasion is that a significant number of the smaller aggregate particles are dislodged, while the larger particles remain firmly anchored. The peaks of the larger particles make contact with the 'upper abraded surface', which is still a flat plane. The coarse aggregate is now generally well proud of the mortar component. The polishing and rounding of the coarse aggregate indicates that it is taking the brunt of the traffic.

The structural aspect of the block is unimpaired.

The aesthetics of the block is significantly altered, with a rough surface texture in evidence and a marked shift in colour towards the direction of the aggregate colour. Visible wear will generally still be more pronounced than invisible wear.

Third-degree abrasion can be the result of extreme service conditions, but where it occurs on a relatively large scale, it is more likely to be the result of inadequate binder strength.

Third-degree abrasion is illustrated diagrammatically and photographically in figures 8.32 through 8.40.

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**Figure 8.32** Section through a block illustrating third-degree abrasion
Figure 8.33  Third-degree abrasion at Roodepoort mall. The coarse aggregate component is very visible, but still anchored in the matrix. Some loss of fine aggregate is evident. Visible wear = 17,5 ml, mean visible depth = 1,06 mm. (Surface area, excluding bevelled area = 16544 mm²).

Figure 8.34  Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 2,2 mm, E = 1,7 mm, N = 1,7 mm, S = 1,3 mm, T = 2,2 mm: Mean crater depth = 1,82 mm.
Figure 8.35 Third-degree abrasion at factory entrance. Coarse aggregate particles can be seen proud of the mortar component. Their rounded shape shows that they are taking the brunt of the abrasive forces. Significant loss of fine aggregate is evident. Visible wear = 18,0 ml, mean visible depth = 1,15 mm. (Surface area, excluding bevelled area = 15600 mm²).

Figure 8.36 Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 1,8 mm, E = 2,5 mm, N = 2,7 mm, S = 1,7 mm, T = 1,7 mm: Mean crater depth = 2,08 mm.
Figure 8.37 Third-degree abrasion at Randridge Mall. The coarse aggregate component is very visible, but still anchored in the matrix. A significant loss of fine aggregate is evident. Visible wear = 17.5 ml, mean visible depth = 0.888 mm. (Surface area, excluding bevelled area = 19712 mm²).

Figure 8.38 Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 1.3 mm, E = 2.2 mm, N = 1.6 mm, S = 2.2 mm, T = 2.0 mm: Mean crater depth = 1.86 mm.
Figure 8.39 Third-degree abrasion at Lifestyle garden centre. The coarse aggregate is not yet very prominent, indicating an early stage of third-degree abrasion. Significant loss of fine aggregate is nevertheless evident. Visible wear = 10.5 ml, mean visible depth = 0.707 mm. (Surface area, excluding bevelled area = 14900 mm²).

Figure 8.40 Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 2.0 mm, E = 1.8 mm, N = 1.8 mm, S = 1.8 mm, T = 1.3 mm: Mean crater depth = 1.74 mm.
**8.2.5 Fourth-degree Abrasion**

Here the mortar component is abraded away to the degree where the coarse aggregate particles are no longer sufficiently anchored in mortar and consequently break out under the action of the applied abrasive forces. Relatively large coarse aggregate particles (e.g. 13 mm) that are anchored deeply, will delay the onset of fourth-degree abrasion. Conversely, sand mixes of maximum particle size 5 mm or less, will arrive at fourth-degree abrasion sooner.

This process can go on until a depth of 20 mm or more has been abraded, or until the structural integrity of the blocks are compromised and / or serviceability limits have been exceeded.

The aesthetics is seriously impaired and the blocks have a very rough surface.

Invisible wear may be very pronounced in fourth-degree abrasion, even more so than visible wear.

The upper abraded surface is generally no longer a flat plane.

Fourth-degree abrasion is nearly always a sure sign of poor quality. Commonly this occurs as a result of too little water to adequately lubricate the mix, too little binder in the mix, wrong machine settings resulting in inadequate vibration, and little or no curing. Correctly proportioned blocks made in a controlled process should never reach this stage of wear, unless very extreme service conditions exist.

The distinctive characteristic of fourth-degree abrasion is the loss of the coarse aggregate particles.

The mechanism of wear associated with fourth-degree abrasion is stable (though not desirable) in that it represents a continuing process of loss of coarse aggregate (and other constituents) until such a substantial amount of invisible wear has occurred that the blocks are too thin to disperse the applied loads and consequently crack, leading to the eventual complete disintegration of the blocks. This might be termed 5th degree abrasion, but it is rarely seen in practice as a surface in an advanced state of fourth-degree abrasion is very rough and uneven and is usually replaced before any '5th degree' stage is reached.

The process leading to fourth degree abrasion has been alluded to by Fwa (1990): 'Field observation indicated that the distress originated from deterioration of surface cement mortar. Once initiated, disintegration of the mortar would continue, under the action of weathering and repeated [bus] traffic loadings, up to a depth of as much as 12mm. Loss of coarse aggregates did not occur until an advanced stage, when they were almost fully exposed'.

Fourth-degree abrasion is illustrated diagrammatically and photographically in figures 8.41 through 8.49.
Figure 8.41 Section through a block illustrating fourth-degree abrasion
Figure 8.42 Fourth-degree abrasion at Roodepoort mall. Small craters are seen where coarse aggregate particles have been plucked out, indicating a significant loss of material. The blocks have a very rough appearance. Visible wear = 32.5 ml, mean visible depth = 1.96 mm. (Surface area, excluding bevelled area = 16544 mm²).

Figure 8.43 Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 1.9 mm, E = 2.1 mm, N = 1.8 mm, S = 1.9 mm, T = 2.7 mm: Mean crater depth = 2.08 mm.
Figure 8.44  Fourth-degree abrasion at factory entrance. Coarse aggregate particles are very prominent, and are easily dislodged. Visible wear = 46.0 ml, mean visible depth = 2.95 mm. (Surface area, excluding bevelled area = 15600 mm²).

Figure 8.45  Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 3.9 mm, E = 3.5 mm, N = 2.9 mm, S = 3.6 mm, T = 2.7 mm: Mean crater depth = 3.32 mm.
Figure 8.46  Fourth-degree abrasion at Randridge Mall. Some large craters indicate the loss coarse aggregate. Visible wear = 30.0 ml, mean visible depth = 1.52 mm. (Surface area, excluding bevelled area = 19712 mm²).  

Figure 8.47  Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 2.0 mm, E = 2.0 mm, N = 2.8 mm, S = 3.2 mm, T = 2.8 mm: Mean crater depth = 2.56 mm.
Figure 8.48  Fourth-degree abrasion at Lifestyle garden centre. Very extensive loss of the coarse aggregate. Visible wear = 53.5 ml, mean visible depth = 3.59 mm. (Surface area, excluding bevelled area = 14900 mm²).

Figure 8.49  Enlarged view of 50 mm x 30 mm framed area. Typical crater depths: A = 3.5 mm, E = 2.4 mm, N = 4.0 mm, S = 4.2 mm, T = 4.2 mm: Mean crater depth = 3.66 mm.
8.2.6 Acceptable distribution of degrees of wear

Generally it will be possible to identify all five degrees of abrasion on cbp sites as follows:

a. Zero degree abrasion will be seen in remote areas of the site, where blocks are subject to virtually no traffic, e.g. directly adjacent to shop windows in shopping malls, remote corners of large parking areas in shopping complexes.

b. First-degree abrasion will generally be found in lightly trafficked areas.

c. Second-degree abrasion in areas that have been heavily trafficked for some years is normal, and where abrasion is generally limited to second-degree, this is an indication of good quality. However if second-degree abrasion occurs in lightly trafficked areas this may be regarded as an indication of poor quality.

d. Third-degree abrasion should only occur in a few of the most heavily trafficked areas, such as where funnelling occurs in shopping centres, on tight corners in roads etc. Where third-degree abrasion occurs in significantly large areas on a cbp site, this is an indication of poor quality.

e. Fourth-degree abrasion should be limited to just a few blocks in the most heavily trafficked areas. If fourth-degree abrasion occurs in significantly large areas, this is an indication of very poorly made blocks.

It would be unreasonable to make no allowance for third and fourth-degree abrasion, particularly in very heavily trafficked areas. In a normal manufacturing environment approximately 2½ % of the blocks will be at least two standard deviations lower than the mean, while ½ % can be expected to be three standard deviations lower Moroney(1951).
8.3 Binder Strength

8.3.1 Weak binders

The degrees of wear as described in third and fourth-degree abrasion are typical for blocks where the strength of the binder is inadequate. A clear pattern of wear can be identified. The main feature of this pattern is that the mortar component abrades significantly faster than the aggregate, until eventually the aggregate particles come away altogether.

Fine aggregates

In the four case studies described in 8.2, the maximum size of the coarse aggregate was approximately 8 mm. The coarse aggregate was therefore able to protect the softer mortar component to a considerable degree before sufficient mortar had been removed for the stones to be dislodged.

Some manufacturers however, use relatively fine sands with a maximum particle size of less than 5 mm. In such cases it will still be possible to identify third and fourth-degree abrasion, but the aggregate protrusions will be less and hence the protection afforded to the mortar component will be less.

8.3.2 Strong Binders

By increasing the quantity of binder in the mix, aiming at a well lubricated mix, correct curing, etc. it will be both wear resistant and bond strongly to the aggregate. Consequently third and fourth-degree abrasion should only occur in a few instances.

Blocks made from strong binders may have less visible wear, and more absolute wear, particularly for sites that have been subjected to significant traffic volumes. In effect the aggregate is abraded away at approximately the same rate as the mortar component. Thus the mcd and the mvd remain essentially constant, and the absolute wear increases with time.
8.4 Measurement of Abrasion

In order to quantify the five degrees of abrasion, two methods of measuring the visible abrasion will be considered.

8.4.1 Depth gauge method

The method is fully described in 5.3.2 and only the basic principles are discussed here.

This method uses a depth gauge with a vernier scale to determine the depth of five typical craters relative to the surface of the block. This may be done for one or more blocks. The mean crater depth (mcd), illustrated in figure 8.41, is the average depth of the five craters, where the depth of a crater is taken as the distance between the trough of a crater and the upper abraded surface.

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. Taking five measurements in such a confined area reduces the risk of measuring untypical craters. It also makes it possible to illustrate these craters by magnifying the framed area as in the photographs of section 8.2.

8.4.2 Syringe method

This method is fully described in 5.3.3 and once again only the basic principles are discussed here.

This method uses a syringe to apply modelling clay of a suitable consistency to fill up all the craters. The resulting appearance is an even surface, as if no visible wear had taken place. When correctly applied, the upper surface of the modelling clay should coincide with the upper abraded surface.

The mean visible depth is determined by dividing the visible wear (the volume of the applied clay) by the surface area covered with the clay.

8.4.3 Calibration of depth gauge and syringe methods

In order to calibrate the test methods described in 8.4.1 and 8.4.2 with the various degrees of abrasion, five blocks (one for each degree of abrasion) from each of the four sites described in 8.2 were measured for wear using these two methods. The mcd and the mvd values so obtained are summarised in table 8.1.

Figure 8.50 plots the mcd and mvd against the corresponding observed degrees of abrasion. The visual presentation in figures 8.6 through 8.49 are thus illustrated in graphical form.
<table>
<thead>
<tr>
<th>SITE</th>
<th>DEGREE OF ABRASION</th>
<th>MVD mm</th>
<th>MCD mm</th>
<th>REGRESSION LINE mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM</td>
<td>0</td>
<td>0.27</td>
<td>0.52</td>
<td>0.70</td>
</tr>
<tr>
<td>RM</td>
<td>1</td>
<td>0.32</td>
<td>0.68</td>
<td>0.74</td>
</tr>
<tr>
<td>RM</td>
<td>2</td>
<td>0.51</td>
<td>0.68</td>
<td>0.94</td>
</tr>
<tr>
<td>RM</td>
<td>3</td>
<td>1.06</td>
<td>1.82</td>
<td>1.49</td>
</tr>
<tr>
<td>RM</td>
<td>4</td>
<td>1.96</td>
<td>2.08</td>
<td>2.39</td>
</tr>
<tr>
<td>FE</td>
<td>0</td>
<td>0.39</td>
<td>0.62</td>
<td>0.81</td>
</tr>
<tr>
<td>FE</td>
<td>1</td>
<td>0.32</td>
<td>0.72</td>
<td>0.75</td>
</tr>
<tr>
<td>FE</td>
<td>2</td>
<td>0.58</td>
<td>0.86</td>
<td>1.00</td>
</tr>
<tr>
<td>FE</td>
<td>3</td>
<td>1.15</td>
<td>2.08</td>
<td>1.58</td>
</tr>
<tr>
<td>FE</td>
<td>4</td>
<td>2.95</td>
<td>3.32</td>
<td>3.39</td>
</tr>
<tr>
<td>RR</td>
<td>0</td>
<td>0.19</td>
<td>0.08</td>
<td>0.62</td>
</tr>
<tr>
<td>RR</td>
<td>1</td>
<td>0.25</td>
<td>0.44</td>
<td>0.68</td>
</tr>
<tr>
<td>RR</td>
<td>2</td>
<td>0.42</td>
<td>0.94</td>
<td>0.84</td>
</tr>
<tr>
<td>RR</td>
<td>3</td>
<td>0.89</td>
<td>1.86</td>
<td>1.32</td>
</tr>
<tr>
<td>RR</td>
<td>4</td>
<td>1.52</td>
<td>2.56</td>
<td>1.95</td>
</tr>
<tr>
<td>LS</td>
<td>0</td>
<td>0.40</td>
<td>0.64</td>
<td>0.83</td>
</tr>
<tr>
<td>LS</td>
<td>1</td>
<td>0.40</td>
<td>0.68</td>
<td>0.83</td>
</tr>
<tr>
<td>LS</td>
<td>2</td>
<td>0.34</td>
<td>0.82</td>
<td>0.76</td>
</tr>
<tr>
<td>LS</td>
<td>3</td>
<td>0.71</td>
<td>1.74</td>
<td>1.14</td>
</tr>
<tr>
<td>LS</td>
<td>4</td>
<td>3.59</td>
<td>3.66</td>
<td>4.03</td>
</tr>
</tbody>
</table>

Regression Output:

- Constant: 0.425
- Std Err of Y Est: 0.350
- R Squared: 0.883
- No. of Observations: 20
- Degrees of Freedom: 18
- X Coefficient(s): 1.004
- Std Err of Coef.: 0.086
8.4.4 Interpretation of abrasion-wear in terms of mvd (figure 8.50)

Zero degree

It is important to note that the mvd values for zero degree abrasion are not zero. This is because most blocks are made with a surface texture that has a finite roughness. Whenever a site investigation is carried out, it may be advisable to establish these values for zero degree abrasion, particularly for rough textured blocks. This can be done by measuring blocks at remote areas of the site, which have not been subject to traffic. First, second, third etc. degree abrasion measurements should be interpreted in the light of the zero degree measurements.

Zero and first-degree

Figure 8.50 shows that the mvd differs little from degree zero to first-degree, i.e. the visible wear for these degrees is essentially the same. This is to be expected since the only difference between degree zero and degree one is the removal of a thin skin of paste above the topmost aggregate particles.

Second-degree abrasion

The mvd corresponding to second-degree abrasion is only slightly more than that of first-degree abrasion, as may be seen figure 8.51. This is because the paste / mortar component is strong enough to hold both the coarse aggregate as well as the larger to medium fine aggregate particles firmly in the matrix. In return, the aggregate particles will stand slightly proud of the finer mortar component, affording a significant measure of protection. The absence of any significant holes representing loss of medium to larger aggregate (say > 1mm) is the reason for the low mvd. Therefore it may be said that if wear is limited to second-degree abrasion in cbp that has been trafficked for some years, this is an indication of good quality.
Third-degree

The graph shows that a significant rise in the roughness of the surface texture occurs from degree two to three. This rise is associated with the increase in the recorded volume of clay infill associated with the loss of the fine aggregate particles. Blocks exhibiting third-degree abrasion are generally borderline in quality (unless severe traffic conditions exist).

Fourth-degree

Generally the four bar lines in figure 8.50 are contained in a relatively tight envelope from zero to third-degree abrasion. However in fourth-degree abrasion these lines diverge considerably. This is a feature of fourth-degree abrasion, which may be relatively mild with only a few patches where the coarse aggregate particles are coming away such as in RM and RR (see figures 8.42 and 8.46), or it may be severe where a great deal of the surface has come away as in FE and particularly LS (see figures 8.44 and 8.48).
8.4.5 Interpretation of wear in terms of mcd (figure 8.50)

Generally the mcd values follow the same trend as the mvd values. However the transition from one degree of abrasion to the next is less predictable and somewhat jerky. This is because the mcd is the average of only 5 craters, whereas the mvd represents the whole upper surface of the block.

For this reason it is preferable to use the mvd as the measure of wear.

Nevertheless it is evident that a meaningful relationship exists between the different degrees of abrasion (as defined by the criteria set in 8.2) and the mcd and mvd values.

However, it should be noted that both mcd and mvd are, strictly speaking, a measure of the roughness of the blocks, and should not be confused with the total or ‘absolute wear’, i.e. they give no indication of the amount of invisible wear that has taken place. They are an indication of the height of the protruding aggregate particles relative to the troughs in between them. Nevertheless, they are still most useful indications of abrasion resistance and abrasion wear, and are widely used in chapter 14. If a block remains smooth (i.e. one with a low mcd and mvd) after many years of heavy traffic, this is an indication of high abrasion resistance, even though it may have a significant amount of invisible wear. Being smooth it will still be comfortable to walk or ride on. Thus the degree of roughness (i.e. mcd, mvd) is a useful indication of abrasion resistance.

From figure 8.50 the following criteria for mcd and mvd may be established:

<table>
<thead>
<tr>
<th>TABLE 8.2 QUANTIFYING DEGREES OF ABRASION IN TERMS OF MCD AND MVD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DEGREE OF ABRASION</strong></td>
</tr>
<tr>
<td>Zero to second</td>
</tr>
<tr>
<td>Third</td>
</tr>
<tr>
<td>Fourth</td>
</tr>
</tbody>
</table>

In chapter 14 (which deals with the mvd and mcd values at Westgate) these limits are expressed slightly differently, to accommodate for transitional zones between second and third-degree, as well as between third and fourth. (See table 8.3 for modified mvd values). Nevertheless the limits in table 8.2 correspond well with the Westgate results.

In this section a means of quantifying wear has been attempted. The degrees of abrasion for a number of cbp sites, involving three of the major producers, are thus quantified. These results are taken into consideration in the classification given in table 8.3.

It is appreciated however that it would be unwise to assume that the five degrees of abrasion would be the same for every cbp site. For example, the mean visual depth associated with third-degree abrasion will be dependant on the size of the coarse aggregate; the larger the aggregate particles the greater the value since much fine aggregate may be dislodged before the onset of 4th degree. Nevertheless the values in table 8.2 seem to be a fair representation the paving industry.
Comparison of mcd and mvd

It is apparent from Table 8.1 that the mcd values are generally twice that of the mvd values. This is logical, since the mcd generally represents the difference in height between the crest of an aggregate particle and an adjacent trough, which should be exactly equal to twice the mvd for the case where the volume of the crests is equal to the volume of the troughs. An illustration of such a case would be a sine wave, where the volume of the crests will be equal to the volume of the troughs. However, in severe cases of fourth-degree abrasion, where the upper abraded surface is no longer planar, the mvd may be much closer to the mcd, particularly where only a few coarse aggregate particles are left protruding as in figure 8.48.

In table 8.1 the average ratio of mcd/mvd = 0.95/0.51 = 1.86, if fourth-degree abrasion is ignored. If fourth-degree abrasion is included the average ratio is reduced to 1.47. The average ratio of mcd/mvd for fourth-degree abrasion is 1.16. These figures illustrate how a few isolated coarse aggregate particles as may be found in 4th degree abrasion, can raise the level of the upper abraded surface to an extent that there is little difference between mvd and mcd.

Figure 8.52 illustrates the relationship between mvd and mcd. A total of 20 points are used (4 sites x 5 degrees per site). An $R^2$ value of 0.9394 in the regression analysis indicates a good correlation between mcd and mvd.

![Figure 8.52](image)

The mvd and mcd wear indicators that have been developed in this chapter are used extensively in chapter 14 to correlate the wear at Westgate bus terminus with the laboratory tests of chapter 4, in particular the abrasion tests.
8.5 Classification of Cbp in terms of Degrees of Abrasion

There are many applications for cbp where the emphasis is on serviceability / durability / aesthetics, and the structural element (which is the whole rationale behind the current SABS specification) is superfluous. However, there is no classification in South Africa for measuring and evaluating in situ wear. Table 8.3 addresses this need. It is aimed at defining and quantifying wear, thus providing limiting criteria that designers and specifiers can use in their specifications. It summarises the main characteristics of the five degrees of abrasion and it classifies typical cbp applications in terms of these degrees of abrasion.

Certain changes have been made to the mvd limits, in order to allow for transitional zones between degree two and three, and between three and four, in line with the extensive measurements at Westgate (see chapter 14). The values expressed in table 8.2 nevertheless fit into the mvd parameters established in chapter 14 and shown in table 8.3.

Mvd measurements are not included in table 8.3, and this is also explained in chapter 14.

8.5.1 Interpretation of the Classification

The classification shown in table 8.3 applies to cbp subject to heavy volumes of either pedestrian or vehicular traffic. Where extreme conditions exist however, the engineer will have to use his judgement. For example, a surface showing fourth-degree abrasion which is in an area subject to frequent and excessive slewing of heavy vehicles, or an area where funnelling of pedestrian traffic occurs, or an area subjected to the spikes of golfer’s shoes, etc. may have remained at third or second-degree abrasion under normal conditions.

Therefore engineers, architects and specifiers who are called upon to make an assessment of wear in a paved surface should in fairness to the supplier / manufacturer not condemn an entire area where there are only isolated failures. It is important to walk over the whole surface to establish a visual appreciation of what the average degree of abrasion is. It is very likely that more than one degree of abrasion will be identified. Only if the degree of wear is unacceptable on a large scale should the area be condemned. The supplier should be given the opportunity to replace isolated pockets of unacceptable wear.

Consideration must also be given to what information the supplier was given at the time the order was placed, i.e. was the supplier told that the blocks were to be installed in an area subject to very heavy abrasion. The current situation is that the manufacturer/supplier is in a strong position. Providing he can show that in terms of SABS 1058 the average compressive strength complies to either 25 MPa (or 35MPa if heavy duty pavers were ordered), he cannot be held accountable for pavers that wear excessively.
<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>ZERO DEGREE</th>
<th>FIRST DEGREE</th>
<th>SECOND DEGREE</th>
<th>THIRD DEGREE</th>
<th>FOURTH DEGREE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour shift in direction of aggregate (see note 1)</td>
<td>Nil</td>
<td>Slight</td>
<td>Moderate</td>
<td>Pronounced</td>
<td>Pronounced</td>
</tr>
<tr>
<td>Surface texture</td>
<td>Unchanged</td>
<td>Smooth</td>
<td>Moderate</td>
<td>Rough</td>
<td>Very rough</td>
</tr>
<tr>
<td>mvd (mm) (see note 4)</td>
<td>mvd&lt;0,5</td>
<td>mvd&lt;0,5</td>
<td>mvd&lt;0,5</td>
<td>0,75&lt;mvd&lt;1,0</td>
<td>1,25&lt;mvd</td>
</tr>
<tr>
<td>visible wear</td>
<td>nil</td>
<td>very slight</td>
<td>slight</td>
<td>moderate</td>
<td>significant</td>
</tr>
<tr>
<td>invisible wear</td>
<td>nil</td>
<td>very slight</td>
<td>slight to significant</td>
<td>slight to significant</td>
<td>significant to very severe</td>
</tr>
<tr>
<td>Distinguishing characteristics</td>
<td>No wear, surface aggregate still covered by binder paste</td>
<td>Surface aggregate just exposed</td>
<td>Surface aggregate slightly prominent, and protecting matrix. Minimal loss of fine aggregate. Aggregate may be Smooth and polished</td>
<td>Loss of fine aggregate</td>
<td>Loss of coarse aggregate, in severe cases the upper abraded surface is no longer planar</td>
</tr>
<tr>
<td>Comment on quality</td>
<td>(see note 2)</td>
<td>(see note 2)</td>
<td>(see note 2)</td>
<td>borderline quality</td>
<td>poor quality</td>
</tr>
<tr>
<td>Typical Applications</td>
<td>Applications where aesthetics is important, e.g. shopping malls, prestigious buildings</td>
<td>Applications where aesthetics is not crucial, i.e. Where small craters in the surface are acceptable, e.g. Industrial hardstandings, public roads, car parks, canals and waterways (see note 3)</td>
<td>Applications where aesthetics and durability are of no concern, riding quality is unimportant, e.g. farm dams, as a covering to prevent dust or erosion, for temporary roads and surfaces</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Concrete pavers which are initially grey, may appear greenish or bluish (depending on the aggregate colour) once a significant proportion of the aggregate is exposed.
2. If wear is limited to zero or first degree abrasion, this is generally an indication that the blocks have not been heavily trafficked. It is not necessarily an endorsement of good quality. On the other hand, blocks that have had significant traffic and only manifest 2nd degree abrasion or less, may be considered as good quality.
3. Where CBP is used in canals and waterways, caution must be exercised to ensure that the velocity and turbulence of the flow do not result in the blocks being uplifted.
4. Transitional zones exist between mvd limits, which provide a degree of flexibility for interpretation of results. Concrete pavers with such intermediate values must be assessed in terms of the visual criteria in this table, e.g. colour shift, surface texture etc.
8.5.2 This classification will be useful to:

a. Architects and specifiers who wish to be sure that the long term aesthetics of their projects will not be compromised;

b. Engineers involved in the specification of structural roads and hardstandings where abrasion resistance may be the primary concern;

c. Manufacturers in assisting them in the selection of the correct mix designs. Often the manufacturer is held responsible for excessive wear, when in reality the blocks meet all the requirements of SABS 1058. In such cases the manufacturer simply points out that the client is welcome to uplift some of the blocks and have them tested. Invariably the test results show compliance to SABS 1058. The manufacturer is absolved, but the specifier may go away disillusioned with cbp. This does not improve the image of cbp in the market place. Such scenarios are quite unnecessary since it is not difficult to make concrete paving blocks with excellent wear resistance.
8.6 CMA Abrasion Program

In 1990 the Concrete Masonry Association embarked on an exercise that involved monitoring wear at various sites around South Africa. In Johannesburg three sites were under observation; Crown Mines Golf Course, an interchange in Yeoville and a shopping complex in Randpark ridge.

Blocks from the same batch as those installed at these sites were also subjected to the three abrasion tests referred to in this dissertation, as well as the SABS 1058 compression test and the ISO 4108 tensile splitting strength test. In addition, the ASTM C944-80 abrasion test was used. These tests were analysed in an attempt to try to determine the most suitable test for the cbp industry. Special attention was given to statistical indicators [Robertson(1991); see also appendix A.8].

The blocks at the various sites were visually assessed after a period of one year, and again after two and a half years. A number of referees (between 3 and 5) with a wide range of experience in cbp and related fields were used to make the assessments in terms of various visual criteria (reproduced in table 8.4). The equivalent degrees of abrasion used in this investigation, are placed alongside the CMA criteria.

The CMA indicators range from 5.0 down to 0. Thus with each referee assigning a number to each site, it is possible to obtain an average value for each site after each successive assessment, and in this way keep track on abrasion as time passes.

Unfortunately, various kinds of problems were experienced at the three test sites:

- In the first instance it appears that most of the blocks at the Yeoville interchange have subsequently been replaced.
- Secondly, the blocks installed at crown mines have been subjected to the spikes associated with golf shoes, and generally all show signs of fourth-degree abrasion. This site is therefore not ideal for checking the five degrees of abrasion. Furthermore such unusual traffic loadings are not helpful when setting specifications for acceptable abrasion-wear.
- Finally the CMA blocks under observation at the Randridge Mall do not generally show all of the five degrees of abrasion. The wear in the blocks is limited to first, second and third-degree abrasion. Consequently it was not ideal to photograph the exact CMA blocks and include them as part of 8.2, where the five degrees of abrasion are illustrated. Instead five other blocks at the access road's entrance to the parking area of the mall were selected, which are in the same general area as the CMA blocks, but have clear-cut features with respect to the respective degrees of abrasion. (They are shown illustrating the five degrees of abrasion in figures 8.10, 8.11; 8.19, 8.20; 8.28, 8.29; 8.37, 8.38; 8.46, 8.47).

Future work. It is clear that the traffic conditions at the different CMA sites varied widely. It was therefore not meaningful to compare the results of the various sites. Consequently it decided to install a set of blocks (from the same batch as those installed at the various sites) in a busy sidewalk, so that they would all be subjected to the same traffic. (This approach is similar to what was done in the sidewalk at Westgate bus terminus, as described in chapter five). This was possible since additional blocks from the various sites had been stored at Portland Park. The wear in the blocks was to be monitored periodically. However, given the difficulties already encountered, together with the emigration of the then CMA director, as well as funding constraints, this program has been discontinued.

Chapter 16 includes a full discussion of other sponsored work on abrasion resistance in cbp that was envisioned by the CMA at the time.
<table>
<thead>
<tr>
<th>RATING</th>
<th>DESCRIPTION</th>
<th>SIMILAR TO OF ABRASION (not in CMA form)</th>
<th>CORRESPONDING DEGREES</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>Perfectly smooth and plane surface</td>
<td>Glass</td>
<td>0</td>
</tr>
<tr>
<td>4.8</td>
<td>Loss of laittance</td>
<td>Rough steel trowel finish</td>
<td>1</td>
</tr>
<tr>
<td>4.7</td>
<td>Minor loss or absence of cement sand matrix</td>
<td>Fine sand paper</td>
<td></td>
</tr>
<tr>
<td>4.4</td>
<td></td>
<td>Wood float finish</td>
<td></td>
</tr>
<tr>
<td>4.0</td>
<td>Major loss or absence of cement sand matrix</td>
<td>Very coarse sand paper</td>
<td>2</td>
</tr>
<tr>
<td>3.7</td>
<td></td>
<td>Deep pitting</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>Coarse aggregate particles becoming exposed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>Considerable number of aggregate particles exposed</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>2.5</td>
<td>Coarse aggregate particles becoming rounded and polished</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0</td>
<td>Aggregate particles being plucked out</td>
<td></td>
<td>3 &amp; 4 *</td>
</tr>
<tr>
<td>1.0</td>
<td>Loss of surface layers</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>0.5</td>
<td>Major loss of surface layers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Disintegration of surfaces and pavers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overlapping of the time of occurrences of the various signs of wear detailed above is likely

Note:  
(1) Original surface may be pitted with smooth plane surfaces between the pite/holes/depressions.  
(2) It is intended that photographs be taken of pavers during the various laboratory tests at the 1/4, 1/2, and 3/4 stages of the test to show the change in surface appearance of the pavers.  
* The CMA rating does not differentiate between the loss of fine aggregate and coarse aggregate. Thus there is no clear distinction between 3rd and 4th degree abrasion.
8.7 Abrasion in Other Surfaces

The writer does not want to leave the impression that cbp is a troublesome material which cannot be used with confidence. Providing it is correctly specified for the application, and manufactured accordingly, cbp has proved worldwide to be a most acceptable surface.

Alternative surfacing materials are asphalt, fired clay bricks, insitu concrete, or precast concrete slabs. However, these materials can also show advanced degrees of abrasion if incorrectly specified, poorly manufactured or badly installed. Following are examples of what may be considered ‘fourth-degree abrasion’ in these surfaces.

Note that these photographs are not intended to degrade these materials; they are meant to show that severe abrasion can occur in any surface. The writer acknowledges that they all have a place in the market with respect to economics, aesthetics, serviceability etc., and will all perform admirably providing they have been correctly specified, manufactured, and installed.

Figure 8.53 ‘Fourth-degree abrasion’ in a fired clay brick surface. Notice significant loss of original surface material and unevenness. In this instance it appears that an inferior quality clay paver was used, given that the adjacent exposed aggregate slabs are clearly performing very well.
Figure 8.54 Fourth-degree abrasion in an asphalt surface. Notice significant loss of aggregate. Asphalt surfaces behave similarly to cbp surfaces. Both rely on the wear resistance of the aggregate to protect the weaker component, which in the case of asphalt is the bitumen. (If the bitumen becomes brittle due to excessive UV exposure, or is dissolved by fuel and oil spillages, it loses its ability to bond the aggregate into the matrix.)

Figure 8.55 Fourth-degree abrasion in an insitu concrete surface. Notice significant removal of large aggregate. Virtually no sign of abrasion-wear is evident in the coarse aggregate particles. This suggests that the severe abrasion-wear may be attributed to a very weak mortar that probably had too much water and too little binder.
Figure 8.56 Fourth-degree abrasion in a precast concrete slab. Again notice the significant loss of aggregate. These surfaces behave similarly to cbp surfaces. Both rely on the wear resistance of the aggregate to protect the weaker component, which in this case is the mortar.

Figure 8.57 Close view of fourth-degree abrasion in a precast concrete slab. Notice the holes where the aggregate has been removed.
8.8 Summary and Conclusion

Five degrees of abrasion (strictly degrees of abrasion-wear) are set out to describe wear in cbp, from almost zero to a stage where there is major loss of material. The various degrees of abrasion are fully supported by photographs from five sites.

Two methods of measuring this wear are set out. The first is a method of measurement of the relative distance between the crest of a protruding aggregate particle and an adjacent trough. The average of five of such measurements is the ‘mean crater depth’. The second method uses clay to determine the true value of the ‘visible wear’. This volume value is easily converted to the average depth of visible wear, or the ‘mean visible depth’.

A distinction is made between ‘invisible’, ‘visible’ and ‘absolute’ wear.

These methods of quantifying the visible abrasion-wear are applied to the four sites, representing blocks from three manufacturers, to obtain a relationship between the visually observed degrees of abrasion and the mcd and mvd indicators.

The main characteristics of the five degrees of abrasion are classified in table 8.3. The degree of abrasion occurring in cbp should match the application for which it is intended, and some recommendations are made. Using this classification, the end user is in a position to specify the required long term degree of wear.

In conclusion, a method of identifying and quantifying abrasion-wear in cbp is proposed.

What is now needed is an accelerated abrasion test that will assist both the specifier and manufacturer to predict the long-term performance of a batch of blocks, prior to installation of the blocks. The next four chapters are therefore devoted to an analysis of three different abrasion tests.