

Chapter 11

Critical Evaluation of ASTM C418

Abrasion Test

11.1 Introduction and Overview

In this chapter, the ASTM C418 abrasion test, the last of the three abrasion tests, is considered.

Only one method of measuring wear is prescribed in the ASTM C418 test, and the chapter is therefore much shorter and simpler than its rivals described in the two preceding chapters.

The results of the 1987 laboratory tests, including those of the ASTM C418 test, were analysed in some detail in chapter 6, and therefore only the main conclusions will be repeated here. This chapter focuses more on the test itself, as a practical means of measuring the resistance of concrete pavers to abrasion. The relevance and variability of the results are considered. The limiting criteria are discussed. Finally the various strengths and weaknesses of the test are assessed.

In chapter 12 the various strengths and weaknesses of this test are evaluated against those of the two other abrasion tests.

Finally, in chapter 14, the 28-day laboratory results referred to in this chapter will be correlated with actual wear measurements after six years of traffic.

11.2 Historical review

Smith(1958) described the Ruemelin shot blast abrasion test, involving steel shot being propelled pneumatically against the surface of concrete, (see appendix U.5.20). In 1958 the test was modified by substituting the shot blast with either silica sand or carborundum as the abrasive, and the test became an official ASTM test; 'ASTM C418-58 Test Method for abrasion resistance of concrete by sandblasting' (appendix U.5.21). The procedure was revised in 1964 calling for explicit use of sand. The 1976 revision calls for the use of oil-based modelling clay of known specific gravity for filling of the craters. There appear to be no further changes of any significance in the 1982 and 1990 publications.

Meanwhile, following the severe winter of 1962/63, abrasion research was started in The Netherlands on concrete pavers using a different sandblast test. The apparatus and test are more fully described in appendix U.5.19. This test had been 'in force for years' for concrete flags [Dreijer(1980)]. In 1966 the test was incorporated into the paving specification NEN 7000 (1966). Following a thorough investigation that spanned the years 1970 through 1978, Dreijer(1980) recommended that the quantity of abrasive be reduced from 3500g to 1000g, so that the test would become a measure of surface quality rather than that of the deeper zones. With this proviso, correlation between freeze/thaw testing and abrasion resistance was much improved, to the extent that adequate abrasion resistance was accepted as an indication of adequate freeze/thaw resistance.

Returning to the USA: In March 1982 the standard specification for 'Solid Concrete Interlocking Units', ASTM C936 - 82 was published. It makes provision for checking the abrasion resistance in terms ASTM C418.

The long history of this test and the fact that it was selected as the standard for ASTM C936 instead of other ASTM abrasion tests also in use at the time, such as ASTM C779 - proc. C (originally published in 1974), and ASTM C944 - 80 (a test involving a rotating dressing wheel), suggests that the committee that decided on the test considered it the best of the three for testing abrasion wear in pavers.

Furthermore, the test has withstood a degree of criticism through the years. For example in 1988 the NCMA conducted tests using ASTM C944 as a possible alternative. Other researchers in the USA such as Ghafoori(1992) and Sukandar(1993) have preferred ASTM C779 Proc C. Nevertheless, the latest revision of the paving specification, ASTM C936 – 96, has retained the sandblast test.

In 1987, when this work commenced, the SABS were already using this test when called upon to investigate wear related problems in concrete pavers. This meant that results were on hand for reference purposes, and that qualified technicians had experience with the test, and that the apparatus could be loaned if necessary.

All in all the test seemed to conform to all the stipulated prerequisites mentioned in 2.5.2, and was accordingly selected as one of the three abrasion tests for this investigation.

11.3 Description of the Test

This test method is fully described in ASTM C418, discussed in some detail in 4.7, and briefly summarised below.

11.3.1 Test procedure and apparatus

The test involves subjecting the surface of the specimen to the impingement of air-driven silica sand. Accordingly 600g of sand is blasted onto the face of the paver at a pressure of 414 kPa. This procedure is repeated eight times until eight distinct craters are formed. These are filled with clay (of known specific gravity) and the abrasion wear is calculated from the volume of the craters.

In order to speed up the testing (eight craters had to be sand blasted in 240 specimens) an apparatus was developed that could abrade two specimens simultaneously, and may be seen in figure 4.9.

The wear pattern produced on the surface of the blocks is that of a circular crater, of diameter 28,7 mm. (Such a precise dimension is achieved by clamping the block beneath a thin plate which has a hole of this diameter.) Typical craters are shown in figure 11.1.

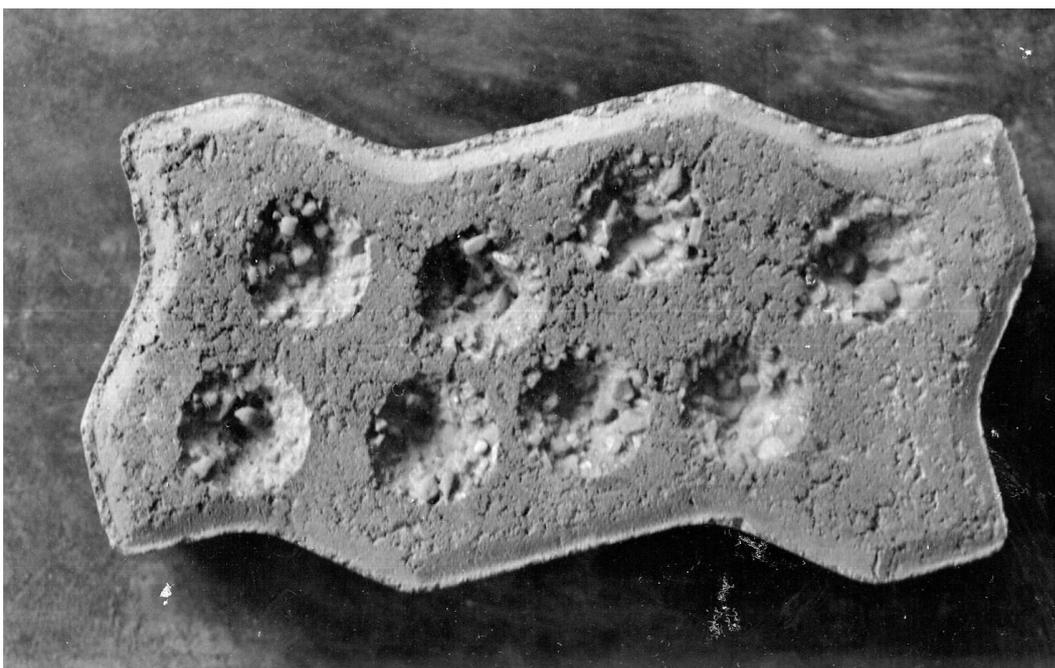


Figure 11.1 Typical craters of the ASTM C418 test

11.3.2 Abrasion Index

The abrasion coefficient A_c , is expressed as:

$$A_c = V / A \dots \dots \dots (11-1)$$

where

V = volume of clay required to fill the eight craters, expressed in cm^3
 A = area of surface abraded, in cm^2

Expressing abrasion-wear by volume is a useful for a number of reasons:

- a. It is an easy concept to understand.
- b. Comparison with other abrasion tests used in this programme becomes a simple matter, since abrasion wear can also be expressed in terms of volume loss for both the MA20 and wire-brush tests (see figure 9.17). In chapter 12 a comparison of the three abrasion tests is done on just such a volume basis.

11.3.3 Limiting Criteria

ASTM C936 has established a relatively simple limiting criteria, i.e. the average loss in depth (ηA_c) shall not exceed 3 mm. For eight craters of diameter 28.7 mm this can be equated to a volume loss of approximately 15 cm^3 .

No provision is made in ASTM C936 for the various traffic regimes, as is the case in the MA20 and wire-brush tests, where different indices are adopted for heavier or lighter traffic loadings. The most likely explanation for this is that the freeze-thaw conditions, which prevail in many parts of the USA, has resulted in a specification (ASTM C140) calling for a compressive strength of 55 MPa. Accordingly, Ghafoori(1992) mentions that cement contents of 16% and more are 'common practice' in the USA, resulting in a 'satisfactory surface resistance'. At these cement contents the compressive strength / abrasion resistance should be very good, even for severe traffic conditions.

11.4 Wear Mechanism of ASTM C418 Abrasion Test

In order to arrive at an understanding of the way the silica sand particles abrade the test specimen it will be useful to magnify the two surfaces that come into contact with each other, i.e. the sand particle (with grading limits between 0.6 mm to 0.85 mm) and the surface of the concrete block. If the two surfaces are sufficiently magnified it can be expected that both the sand particle and the surface of the concrete paver will be relatively rough, as illustrated in figure 11.2.

When these two surfaces come into contact with each other, the sand particles will crush and shear the protruding asperities of the surface of the softer paste at the points of contact. The concentration of loading at these peaks significantly increases the stresses resulting in localised wear, albeit on a microscopic scale.

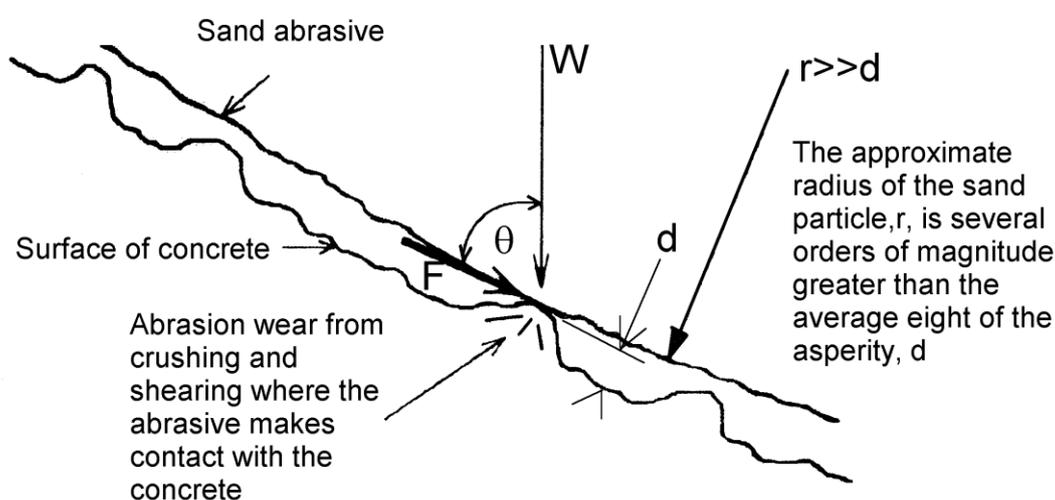


Figure 11.2 Localised crushing of paste by silica sand particle.

When viewed microscopically the surface of a leather sole or rubber tyre will also be relatively uneven, and when in contact with the paving block the interface will be similar to that shown in figure 11.2. The only difference is that this contact will be softer and hence the rate of abrasion therefore a few orders of magnitude slower [Hutchings(1992)] than in the case of the sharp silica sand of the ASTM C418 test. On the other hand when a grain of sand is trapped between the heel of a pedestrian's shoe and the paving block, the microscopic crushing will be greatly multiplied, probably exceed that of an impacting silica particle.

The 'microscopic crushing' effect in this test may be attributed to the velocity of the individual sand particles impacting on the surface. Although the individual particles have little mass, their considerable velocity means that the degree of kinetic energy imparted to the surface of the block results in measurable wear for even strong concretes. Whereas the wear caused by a single impingement of one grain is infinitesimal, after many thousands of particles have attacked the surface, a clearly noticeable crater of a few mm in depth can be seen.

Once the test has been in progress for some time, the aggregate particles will protrude from the matrix, and if the matrix strength is inadequate, a relatively deep crater will result. This means that the surface under attack is no longer a horizontal plane, but more like an inverted dome or cone (see figure 11.1). The sand particles, which are being blasted

vertically from above, will therefore strike this surface at an angle, and thus there will be both a normal and tangential impact component. The normal component leads to 'microscopic crushing' and has already been discussed. The tangential component in figure 11.2 (F), on the other hand, will give rise to shearing and shaving effects. On a microscopic scale this will abrade on the same basis as the tangential attack of the wire bristles in the wire-brush test, as illustrated in figure 10.4A.

According to Hutchings (1992) and from the foregoing arguments, it follows that the abrasion wear, Q_{impact} , will be proportional to the kinetic energy of the sand particle ($\frac{1}{2}mU^2$). It is also a function of the angle of attack, η . Finally it is inversely proportional to the hardness of the surface, H . (Note that hardness is defined and its effect discussed in 3.2.3 of volume 2):

$$Q_{\text{impact}} \propto f(\theta) \cdot mU^2 / H \quad (11-2)$$

Where m is the mass of a single particle of sand abrasive, and U is its velocity.

Note that $f(\theta)$ is a maximum when $\theta = 90^\circ$, i.e. when the sand abrasive strikes the surface normally (crushing effects), but gradually decreases to zero as $\theta \rightarrow 0^\circ$. In the brittle materials this means that the cutting/shearing effect of the impacting sand particle is not as severe as the crushing aspect. (The effect of $f(\theta)$ on Q_{impact} is shown in figure 4.3 of volume 2).

It may be said that for blocks made with a strong matrix, the depth of the crater will be limited, and its surface will not deviate much from the horizontal. Thus the attack will essentially remain normal to the surface for the duration of the test, and microscopic crushing will be the predominant means of abrasion.

However, when intermediate and weak strength matrices are subjected to this test, a transition will take place from purely crushing effects to a combination of crushing and shearing effects.

Thus the ASTM test simulates different effects depending on the strength of the matrix. For weak and intermediate strength binders this test will simulate virtually all wearing mechanisms that occur in cbp surfaces, i.e. both localised microscopic crushing *and* shearing.

In Table 4.2 of volume 2, ASTM C418 is classified as having an abrasion wear code R0 S2 I3, indicating that no rolling (R) under pressure takes place, while crushing from impact (I) is relatively severe. Shear (S) effects are mild, but may extend to sub-asperity depths. (See chapter 4 of volume 2 for a fuller treatment of these concepts).

The crushing and shearing effects of this test also occur in practice. Compression effects occur from the vertical pressure of normal traffic, either pedestrian, or vehicular. (The resultant vertical stresses are significantly magnified if sand or grit particles are present). Shearing effects occur from slewing, cornering, braking and traction in the case of vehicles, and from traction, dragging of the feet etc., in the case of pedestrians. (Again the resultant shear stresses are significantly magnified if sand or grit particles are made to slide under load).

Finally, a distinction should be made between the microscopic impact effects of ASTM C418 and impact on a macro scale from much larger loads, which would result in large cracks developing and the eventual disintegration of the block. An example would be at off-loading zones at harbour docks where surfaces are subjected to iron ore being dropped on them by the off-loading rigs of ships.

What other authors say

Alexander(1984) states that amongst other things this test simulates 'the action of abrasives under traffic on concrete surfaces'. He suggests that the ASTM C418 can be used for testing concrete floors subject both to light and heavy traffic as well as concrete roads where abrasive grit is present on the surface.

Alexander(1987) makes reference to the abrasive action of the ASTM C418 test being that of 'impinging and impacting forces'.

ASTM C418 - 90 describes this action as a cutting action that tends to abrade more severely the less resistant components of the concrete.

Dougerous(1995) describes the abrasive action as 'one of micro-crushing and cutting as the projected sand particles impact against the surface of the concrete. The test is essentially attacking the weaker cementing matrix ...'

Robertson(1991) concurs that the abrasion mechanism of ASTM C418 is 'sandblast erosion of weaker components by way of high velocity direct impact of small particles influenced by aggregate and paste hardness'.

11.5 Results of Laboratory Tests done in Sept. 1987

A total of 240 blocks were subjected to the ASTM C418 abrasion test, and the results recorded in appendix I.1 through I.8. These results are summarised in column I of Table 6.2, where each entry is the average of five blocks tested for each of 48 mixes.

The results of this abrasion test are fully discussed in chapter 6. The main findings are briefly summarised here; namely that the abrasion index of the ASTM C418 test is primarily a function of:

- the density of the block (a function of the quantity of water in the mix)
- the cement content.

These relationships are demonstrated graphically in figure 11.3.

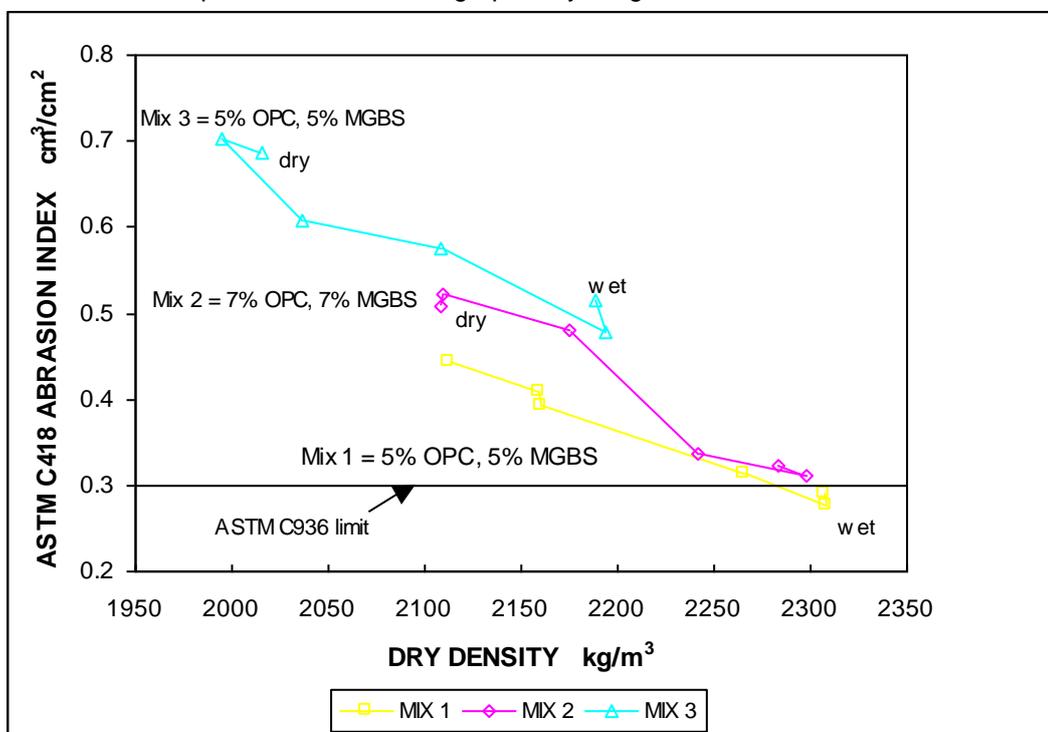


Figure 11.3 Relationship between ASTM C418 abrasion index and dry density

Figure 11.3 clearly shows that *wet* and *rich* mixes have significantly lower indices, i.e. lower average crater depth. (Increasing the water in the mix lubricates the mix and thus facilitates compaction and hence greater density. Increasing the cement content increases the cement / water ratio, for a given workability. These principles are fully discussed in chapter 6).

To a lesser extent, the ASTM abrasion index is also affected by the type of binder used, e.g. OPC, MGBS, FA, SF. This aspect has also been covered in chapter 6.

Suffice it to say that ASTM C418 is capable of discerning changes in surface hardness from mix design variations.

11.6 Variability

The repeatability of the ASTM C418 test is by far the best of the three abrasion tests examined in this investigation. The average of 48 coefficients of variation (5 specimens per mix) was 7.7%, compared to the 15.1 % of the wire-brush and the 24.3% of the MA20. This coefficient is even less than that achieved in the three compression tests (i.e. 10,4% for SABS, 9,2% for ASTM, 8,7% for MA20).

Holland(1991) also reported an average of 7,7%, from six coefficients representing blocks that had been in service for some years. (His seventh result is discounted here as an average coefficient of 49,2% was obtained for those blocks. He explains that the 'spread of the results for the J blocks could be due to the badly pitted surface being vulnerable to aggregate loss in the test'. In all probability some of the blocks were pitted while others were not. Thus his working calculations show that some of the abraded volumes are 200% more than others).

Robertson(1991) found that the sandblast test had the lowest variability of all the tests used in his experimental work. He measured a coefficient of variation of 5,1% for ASTM C418, relative to 12,3% for ISO4108 tensile splitting testing, 13,4% for compression testing, 26% for the ASTM C944 rotating cutter, 18,6% for the wire-brush test, and 29,2% for the MA20 test.

The low coefficient of the ASTM C418 test can be largely attributed to the fact that eight holes are made in each block, compared to the single groove or crater of the MA20 and Wire-brush tests respectively. As a separate exercise the writer re-measured just one hole (as opposed to eight) of six test lots of the original test specimens. The result was an increase in the coefficient of variation, to 15%.

Nevertheless, the low coefficient of variation (assuming eight holes are made) is a positive attribute of this test.

11.6.1 Correlation of ASTM C418 with compressive strength results

In table 11.1 the abrasion index has been correlated with the 'average' compressive strength, for the 48 mixes. The 'average' refers to the average of the three compressive strength tests, and represents an average of 18 blocks, and is thus a good indication of the quality of the mix. As stated in the previous chapters, the compression tests in this investigation can be considered a good yardstick for abrasion resistance as well, owing to the careful controls on curing etc.

Although each entry in the 'ASTM C418' column is only the average of 5 blocks tested, each block received eight craters, and thus effectively each entry in table 11.1 represents 40 tests.

From the values in table 11.1 a linear regression analysis was performed to determine the degree of correlation between ASTM C418 and compressive strength, as shown in figure 11.4.

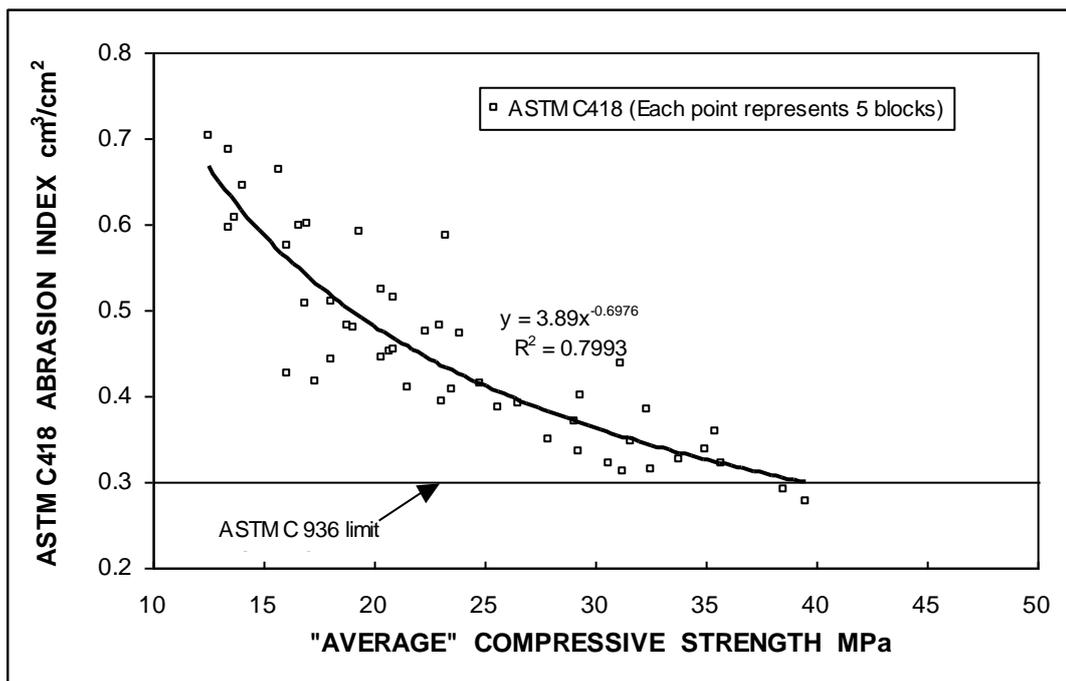


Figure 11.4 Correlation of ASTM C418 abrasion index with 'average' compressive strength

Observations on Table 11.1

The R^2 coefficient of 0.74 indicates that there is a reasonably good correlation between the abrasion index and compressive strength in general. It does not however correlate as well as the $R^2 = 0.82$ of the MA20 abrasion test. This is somewhat surprising, as the deeper penetration into the block of the ASTM test ought to mean that it corresponds better with compressive strength (an indicator of bulk property) than MA20, which is more of a surface test. The lower than expected correlation coefficient is all the more surprising given that both the compression and the sandblast test have relatively low variability (C of $V < 10$ in both cases).

Limiting criteria: The limit of $0.3 \text{ cm}^3/\text{cm}^2$ (i.e. average depth of 3 mm) given in ASTM 936, is too severe for local conditions. According to this only 2 of the 48 mixes would have adequate abrasion resistance. A correlation between the wear at Westgate and these laboratory results is made in chapter 14, from which it will be possible to obtain more realistic indices.

TABLE 11.1 CORRELATION BETWEEN "AVERAGE" COMPRESSIVE STRENGTH AND ASTM C418 ABRASION TEST					
MIX	COMPRESSIVE STRENGTH			AVG COMPRESSIVE STRENGTH MPa	SAND ASTM C418 cm ³ /cm ²
	SABS 1058 MPa	ASTM C140 MPa	MA20 MPa		
1.2	36.6	36.1	45.8	39.50	0.276
1.1	35.3	35.4	44.9	38.53	0.290
7.1	31.6	33.2	42.3	35.70	0.320
8.3	31.1	31.7	43.6	35.47	0.359
8.2	32.1	30.4	42.4	34.97	0.338
8.1	28.6	32.6	40.2	33.80	0.326
1.3	30.9	27.5	39.3	32.57	0.314
5.1	29.9	29.2	37.9	32.33	0.384
7.2	26.1	29.1	39.8	31.67	0.346
2.2	30.3	27.6	36.0	31.30	0.312
6.1	28.6	30.2	34.7	31.17	0.437
2.1	29.2	27.5	35.3	30.67	0.322
6.2	27.2	28.1	32.9	29.40	0.401
2.3	27.9	24.8	35.2	29.30	0.336
4.2	28.1	26.3	32.9	29.10	0.370
4.1	25.4	26.1	32.3	27.93	0.349
5.2	22.7	27.0	30.0	26.57	0.390
7.3	23.0	21.9	32.0	25.63	0.385
7.4	20.1	23.4	31.0	24.83	0.413
8.4	24.0	18.9	28.8	23.90	0.472
1.5	22.6	20.1	28.0	23.57	0.408
6.3	22.1	23.2	24.4	23.23	0.587
1.4	22.0	19.0	28.4	23.13	0.392
2.4	23.9	18.9	26.2	23.00	0.481
8.5	18.1	21.1	27.8	22.33	0.475
5.4	19.3	20.2	25.0	21.50	0.410
3.1	18.9	18.9	25.0	20.93	0.514
7.5	20.0	16.3	26.3	20.87	0.453
5.3	19.8	18.3	24.0	20.70	0.451
2.5	19.1	17.1	25.0	20.40	0.523
8.6	17.8	18.2	25.0	20.33	0.444
6.4	16.4	19.2	22.6	19.40	0.591
3.2	15.9	18.5	22.8	19.07	0.478
5.5	18.2	17.2	21.0	18.80	0.482
1.6	15.9	16.4	22.0	18.10	0.443
2.6	18.0	14.7	21.6	18.10	0.509
4.3	16.4	15.6	20.2	17.40	0.417
4.5	15.5	14.3	21.3	17.03	0.601
7.6	16.0	13.5	21.1	16.87	0.507
6.5	14.0	16.4	19.6	16.67	0.598
3.3	15.1	14.6	18.5	16.07	0.575
4.4	14.3	14.5	19.4	16.07	0.426
4.6	13.4	14.3	19.5	15.73	0.662
5.6	13.7	12.1	16.5	14.10	0.645
3.4	12.5	12.0	16.6	13.70	0.607
3.6	11.9	11.8	16.6	13.43	0.686
6.6	12.3	11.3	16.7	13.43	0.596
3.5	11.4	11.1	15.0	12.50	0.702
AVERAGE	21.7	21.4	28.2	23.77	0.454
R ²					0.739

11.7 Strengths and Weaknesses of ASTM C418 Abrasion Test

In the USA this test is used in preference to other standard ASTM abrasion resistance tests for testing pavers. Some of the advantages and disadvantages are as follows:

11.7.1 Relatively slow

It is quick enough to allow it to be used as a method of production control, but is slower than the MA20 and wire-brush tests. The test takes about 13 minutes to make the eight craters, including the time to fasten and correctly align the specimen eight times and later remove it. The time taken to weigh out eight quantities of abrasive is four minutes. A further 11 minutes or so is then required to fill the craters with clay, weighing the clay before and after to determine the volume of the abraded material. Thus the total time is 28 minutes. By way of contrast the MA20 test can be done in 7 minutes.

11.7.2 Very severe

The test is sufficiently severe to result in a noticeable crater, thereby yielding a measurable result, even with the hardest pavers tested in this programme. The severity of the test in the initial stages therefore sets this test apart from other abrasion tests such as the ASTM C944 test, where a rotating cutter with a relatively large bearing area is not capable of producing a clear penetration of high strength surfaces Robinson (1991) .

11.7.3 Capital expenditure

It is carried out with inexpensive equipment, and should cost in the order of R3000 to have made up. However if an adequate supply of compressed air is not available, this cost could increase by a further R6000 (1994 costs).

11.7.4 Portable

The equipment is not readily portable, and insitu testing is therefore impractical.

11.7.5 Cost of Abrasive

The cost of the abrasive, i.e. a silica sand within narrow grading limits imported from Philippi in the Cape makes the test somewhat expensive on a test by test basis. At present this is the only known source of sand that falls within the very close limits of the specification. Thus the producers who wish to use this test are also faced with the not inconsiderable inconvenience of having to import the abrasive from the Western Cape.

The fact that the abrasive can be used for sixty minutes before replacement does however alleviate this cost considerably. In effect this means that 7.5 blocks (i.e. 60 holes) can be tested per 600 g of abrasive. However the writer is not in agreement with this provision on three counts:

- a. Firstly, the nature of the test is such that relatively large aggregate particles (in the order of 6 mm to 9 mm) are dislodged. The sand cuts through the relatively soft mortar component until the larger particles are sufficiently exposed to be blown

away. Thus after even one minute of operation with the sand a number of larger aggregate particles will be present in the residue. These particles are very likely to block the 6,25 mm aperture.

- b. Secondly, a large amount of abraded concrete dust will result from the operation. In this investigation an average of $2,9 \text{ cm}^3$ was dislodged per hole. Thus for 60 holes this would amount to 174 grams. The 600 g sample of silica would therefore be substantially polluted. The end result after 60 minutes would be that only 77,5% of the material being used as an abrasive was silica sand.
- c. Thirdly, the silica sand particles would loose some of their sharp edges if re-used 60 times, the test would thus become progressively less stringent, with a corresponding increase in variability. In a typical crater, there is evidence of exposed coarser aggregate particles that are distinctly rounded. A similar rounding can be expected on the sand abrasive.

For these reasons the sand was never reused in this investigation, i.e. it was replaced after each and every hole.

11.7.6 Standard test

It is a standard test method that has been used over many years. The results may therefore be compared with results in the USA. In this country the Civil Engineering laboratory of the SABS in Pretoria has been using this test for a number of years to test various surfaces including paving blocks, and may therefore be consulted for advice, available data etc. if required.

11.7.7 Reproducibility

The reproducibility of this test has not been confirmed in this work, but the use of the apparatus as a standard in the USA may indicate that the variation between one rig and the next does not present a problem.

The author has discovered that careful attention to the shape and dimensions of the nozzle (see specification) is most important if the correct wear pattern is to be achieved. The nozzle should be changed after every 60 minutes of operation. ASTM C418 is very specific in the way the test is to be done, and careful attention to these details is essential to achieve reproducibility.

11.7.8 Sensitivity

The ASTM test is the least sensitive of the three abrasion tests i.e. does not respond dramatically to mix design changes. The MA20 is far more sensitive. This aspect is discussed further in chapter 12.

11.7.9 Simulation of wear effects

The characteristic appearance of the abraded surface in plan is that of a circular crater of diameter 28,7 mm. A visual examination of the surface texture of the crater reveals a rough abraded surface with the aggregate particles protruding out of the matrix, as shown in figure 11.5.

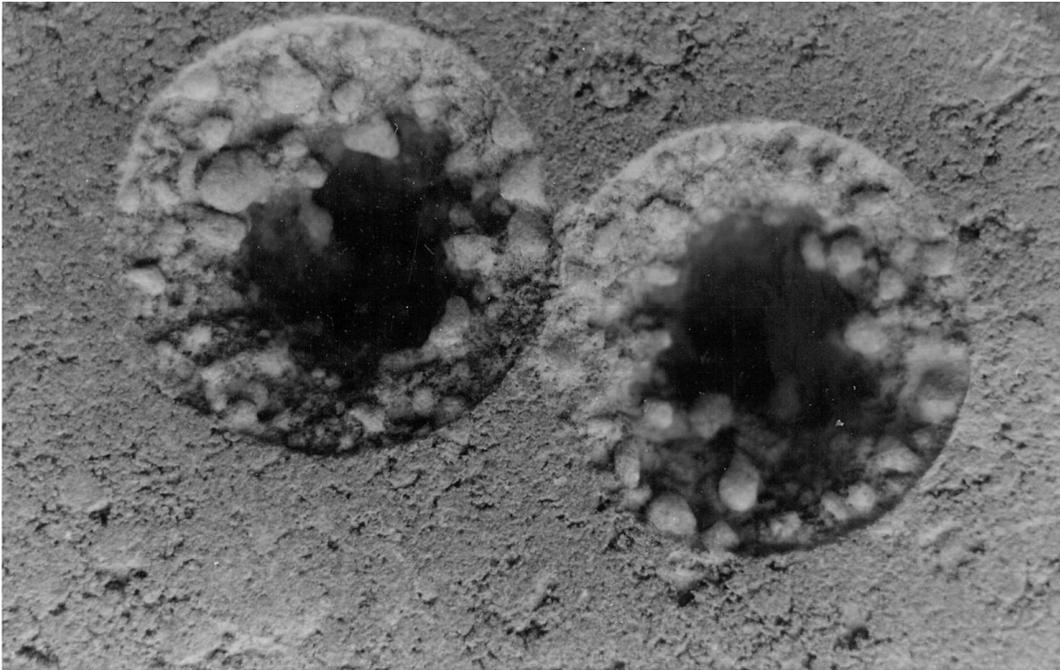


Figure 11.5 A typical close up view of a crater after one minute of sand blasting.

The abrasive attacks the mortar and aggregate particles indiscriminately, but since the mortar is weaker it wears preferentially leaving the aggregate particles jutting out.

Once sufficient mortar component surrounding an aggregate particle is gone, the particle is dislodged and blown away. The aggregate particles therefore only contribute to resisting the sand until such time as they are blown away. Thus this test primarily simulates the wear resistance of the mortar component. The fact that the test only partially measures the contribution of the aggregate component, a major contributor of abrasion resistance, is seen as a serious shortcoming.

It may therefore be said that the ASTM C418 abrasion test is a fair reflection of the mechanism of wear only in cases where weak binders are used (see also wire-brush test), where the strength of the aggregate would be plucked out before it could make a significant contribution.

11.7.10 Effect of aggregate size

Providing the size of the coarse aggregate is of the order of 6mm, the sandblast test is able to dislodge these particles relatively easily as described in the previous section. However, as the size of these particles increases dislodgement becomes increasingly more difficult. The larger particles afford substantially more protection to the underlying and surrounding paste/mortar. It is also evident that the result will be significantly influenced by

the position of the aggregate. A 19mm stone positioned in the centre of the hole and near to the surface will result in minimal abrasion. Conversely should the crater be away from any aggregate particle then a much deeper crater will be formed. Gordon(1991) found that sandblasting abrasion was curtailed by the coarse aggregate to a large degree. (It seems as if he used 19mm stone for 100mm cubes). Furthermore, differing values were obtained on a single cube owing to the 'random' positioning of the aggregate. Seen in this light, the requirement for eight holes per test result may not be sufficient where large aggregate is used.

11.7.11 Surface measurement

Only for concrete pavers with good abrasion resistance (generally the 55 MPa requirement in the USA ensures this) will the crater be confined to the surface layer. For the majority of tests in this investigation, the compressive strength of the material was significantly less, and the resulting craters were relatively deep, up to 20 mm at the deepest points. Clearly in this case the test no longer serves as a measure of the surface. Rather it becomes an indicator of the bulk property of the concrete. This is also seen as a serious shortcoming.

It may be concluded that this test only serves as an indicator of the *surface* properties for very strong concretes.

A logical way of overcoming the deep penetration of this test is by simply using less sand. This was achieved in The Netherlands by reducing the quantity of blasted sand from 3500g to 1000g, for a 64mm diameter hole. Dreijer(1980) states emphatically that 'the one and only way of getting the right idea about the top layer is by blasting less sand'.

The ASTM C 418 test appears to be even more severe than the sandblast test used in The Netherlands, described in NEN 7000. In this test a limit for abraded material of 35g is set corresponding to 3500g of blasted sand, or alternatively, following Dreijer(1980)'s recommendation, 10 grams loss from 1000g of sand abrasive. For a 63,73mm diameter hole, and assuming a specific gravity of 2300kg/m^3 , this equates to an average depth of 1,36mm. The average depth of abrasion for ASTM C418 is 2,9mm, but this is based on 8 x 600 grams of abrasive, or 4800 grams. Assuming linearity, the equivalent depth of 1000g of abrasive is 0,6mm, and it may therefore be seen that ASTM is 2,27 times more severe than NEN. According the Dreijer (1980), the NEN limit of 10g loss for 1000g abrasive, is such that 'it can be assumed with great certainty that these blocks are resistant to frost and de-icing salts'.

It follows that the more stringent ASTM limit should equate to very high abrasion resistance.

11.8 Summary and Conclusion

The ASTM C418 test was first introduced as a means of testing for abrasion resistance in 1958, and was formally prescribed for the cbp industry in the USA in 1982.

Eight holes are sand blasted into each paver, and the abrasion index is determined from the ratio of the volume and the surface area of the holes, expressed in cm^3/cm^2 .

The velocity of the sand particles cause them to impact against the face of the concrete, and on a microscopic scale the high points of an impinging particle 'crush' the surface (for weaker matrixes 'shearing' also occurs), causing an 'infinitesimal' degree of wear at these points. These microscopic effects also occur in the majority of applications where cbp is used, such as vehicular or foot traffic.

The abrasion index, A_c , is inversely proportional to the density, which in turn is a function of the water in the mix. Wet mixes are more abrasion resistant (lower A_c) than dry mixes. Similarly, strong binders (18% binder) are more abrasion resistance than intermediate (14%) or weak binders (10 %).

A reasonably good correlation exists between the ASTM index and compressive strength, $R^2 = 0.74$.

In summarising the strengths and weaknesses of this test, two weaknesses seem to be very serious, and therefore preclude this test as a viable choice as a future abrasion test for the industry. Firstly, the test is so severe that it penetrates deep into the face of the concrete in all but the strongest of mixes. This is not the ideal requirement for a test that is primarily there to determine the condition of the surface concrete. Secondly, the test dislodges the aggregate particles rather than measure their contribution to abrasion resistance. This applies especially to weak concretes.

A comprehensive comparison is made between the MA20, wire-brush, and ASTM C418 test in chapter 12, summarising the relative strengths and weaknesses of the different abrasion tests.