Controlling Quality in Concrete Segmental Paving Units

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SUMMARY

The control of quality of concrete segmental blocks was studied using criteria from the Australian Concrete Masonry Association's Specification for Concrete Segmental Paving Units (MA20). The study concentrated on the use of compressive strength and abrasion resistance as block quality indicators and an attempt was made to correlate abrasion index with compressive strength. The results of the study indicated that the MA20 abrasion resistance test had limited applicability in the evaluation of segmental units. It was found that the limitations were due in part to variability in areas of the test method such as water flow rate and time allowed for bedding-in. There was a general correlation found between compressive strength and abrasion index although the trend within any lot was weak. Block compressive strength was found to provide a measure of total block (macro) quality but did not appear useful for evaluation of surface durability. The MA20 specifications appear to be in need of revision with respect to consistency and adequacy of strength and durability requirements.

INTRODUCTION

Over the last 10 years the use of segmental concrete paving units as wearing surfaces on pavements in Australia, has greatly increased. Applications range from extensive use in pedestrian malls and lightly loaded road pavements to heavy industrial roads and storage areas. Initially very little was understood of either the degrading processes of concrete paving units or of the mechanisms causing the degradation. The lack of knowledge has been instrumental in the premature failure of many pavements due to inadequate paving unit durability. A major problem has been the lack of an appropriate test procedure for evaluation of paver quality with respect to durability quality.

The Concrete Masonry Association of Australia (CMAA) published the Interim Specification for Interlocking Concrete Paving Units (MA15) in 1980 which provided some guidelines for sampling and testing. The MA15 document did not provide any information on the evaluation of unit abrasion resistance or durability. Guidelines for the evaluation of abrasion resistance (durability with respect to surface abrasion) did not appear until 1986 when the CMAA published the Specification for Concrete Segmental Paving Units (MA20). The MA20 abrasion test is not described as a test for evaluation of durability quality, but as the "Interim Guide for Abrasion Resistance". The test is however, used extensively and perhaps incorrectly, to quantify the quality of paving units.

QUALITY CONTROL

Quality control in the production of a successful segmental pavement involves all phases from raw materials, mixing, paver production, paver dimensions, mechanical strength, durability, transportation and laying. A full treatment of quality is beyond the scope of this paper which is limited to the mechanical strength properties of pavers. Concrete products are commonly based on a specification where 95% of the product will exceed some minimum set strength. This infers that an average strength must be achieved which is above the minimum, and this concept is discussed later.

MEASUREMENT OF QUALITY IN AUSTRALIA

In Australia two main tests used for gauging block quality have been compressive strength and abrasion resistance as specified in MA20 (see Table 1). Other tests such as salt attack (AS1226.10) [1], efflorescence (AS1226.6) [1] and water absorption (AS1226.9) [1], have been suggested as measures of quality but research has shown that the test results do not correlate well with each other and are not as reliable as compressive strength and abrasion resistance.

Compressive Strength

The compressive strength does not provide any direct measure of paver durability but does provide a simple and useful method for gauging overall quality of a paving unit [2]. Once compressive strength is corrected for paver aspect ratio and shape it may provide a quantitative measure of unit quality. It is reasonable to accept the premise that a lot of paving units with a characteristic strength (C_k) of, say 60 MPa, has better ability to resist applied surface loads than a lot of paving units with a characteristic strength of say, 20MPa. Areas subjected to heavy pedestrian traffic have a MA20 recommended characteristic compressive strength of 30MPa [2] but research has shown however, that loads under high heeled shoes often exceed 50MPa [3]. It is interesting to note that MA20 specifies the lower characteristic compressive strength (C_k) for heavy trafficked pedestrian areas but also (contradictorily) species the highest abrasion resistance.

Abrasion Resistance

The MA20 abrasion resistance test is derived from driving steel ball bearings, within a rotating ball-race, into the paver under a constant load [2]. The test has been utilised extensively in Australia for the evaluation of paver durability since its inception. The test does not claim to be a measure of durability but of abrasion resistance. Advocates of use of the test to measure durability suggest that surface abrasion equates to surface durability, which in turn indicates use of the abrasion test. The abrasion test does not measure impact loads which are the major cause of paving unit failure in pedestrian malls and there have been a number of pavements around Australia which have been replaced due to excessive loss of paver surface material. MA20, by specifying a minimum value of abrasion index (I_a) for heavy pedestrian traffic provides a de facto durability specification. Some of the pedestrian mall areas replaced originally met the MA20 abrasion resistance specification.

Table 1. MA20 compressive strength and abrasion quality specifications

Category	Vehicles<3 tonne	Other traffic	Heavy pedestrian	Other footpaths
Minimum I_a	30 MPa	45 MPa	30 MPa	30 MPa
Minimum C_k	1.2	1.5	2.0	1.2

PAVER SELECTION

Besser (Queensland) Limited, provided the paving units used throughout the project. The total plant production for two days was sampled where a production run was defined as the total number of pavers produced in one day from the same mould. Several production runs would be required to produce enough pavers for any major paving project. Each production run consisted of approximately twenty batches where a batch was defined as the total pavers

produced from one batch load of concrete mix. A number of drops were produced from each batch where a drop consisted of one cycle of the paver machine which produced sixteen pavers. The sampling procedure was to randomly select 4 pavers from each of 40 drops (also selected randomly), during one day production run. The sampling technique provided a total of 160 pavers to represent a single days production which were then used for testing of compressive strength and abrasion index.

TESTING PROGRAMME

The aim of the testing programme was to determine the variability in paver quality using compressive strength and abrasion resistance as indicators. The MA20 abrasion test was considered to warrant the most attention as the processes involved in compressive strength testing have been fully proven and documented. The special attention devoted to the abrasion resistance test stemmed from the apparent problems inherent in the test procedure. Variables such as age of the ball race, ball race seating time, sample levelling, aggregate particulate problems and rate of water flow to the ball race all were thought to be possible contributors to testing errors.

The MA20 document recommends that 5 pavers be tested for abrasion resistance and compressive strength. It was decided early in the project that such a small sample size may not be representative of the lot of pavers and that it was more appropriate to expand the test sample to 10 pavers based on quality control operating characteristics (Tables 3 and 4). The test programme was designed to test the following hypothesis

> *Paver quality is related to both paver compressive strength and abrasion resistance. A correlation should exist between paver compressive strength and abrasion index for a lot of pavers produced during the same production run from identical concrete mixes.*

TEST RESULTS

The effect of compressive strength of abrasion index was investigated by carrying out compressive strength tests and abrasion index tests on pavers at various ages after manufacture. A total of 10 pavers were tested at 8, 13, 21, 28 and 35 days after manufacture and initial curing, and the results are summarised in Table 3. The pavers were stored in a standard concrete curing environment. The abrasion testing used a calibrated flow meter in the water supply line to the ball-race. The effect of ball-race seating was minimised by using a constant seating time of 3.0 +/- 0.1 seconds. A constant flow rate of 0.076L/sec was used, as per MA20, to "ensure water is flowing at a sufficient flow rate to clear grinding debris" . These test conditions were adopted as a consequence of the investigation of the effect of operating variables on abrasion index, which has been reported elsewhere [4].

The data in Table 2 is also presented graphically in Figure 1 to illustrate any, overall correlation between compressive strength and abrasion index. The data from the testing has been superimposed on other later information on the relationship between compressive strength and abrasion index [5]. The information in Table 3 is the characteristic strengths and abrasion indices of the pavers tested in groups of 10 units. The characteristics values for the 10 pavers are presented as two sub-samples of 5 units each and as a combined single sample of 10 units.

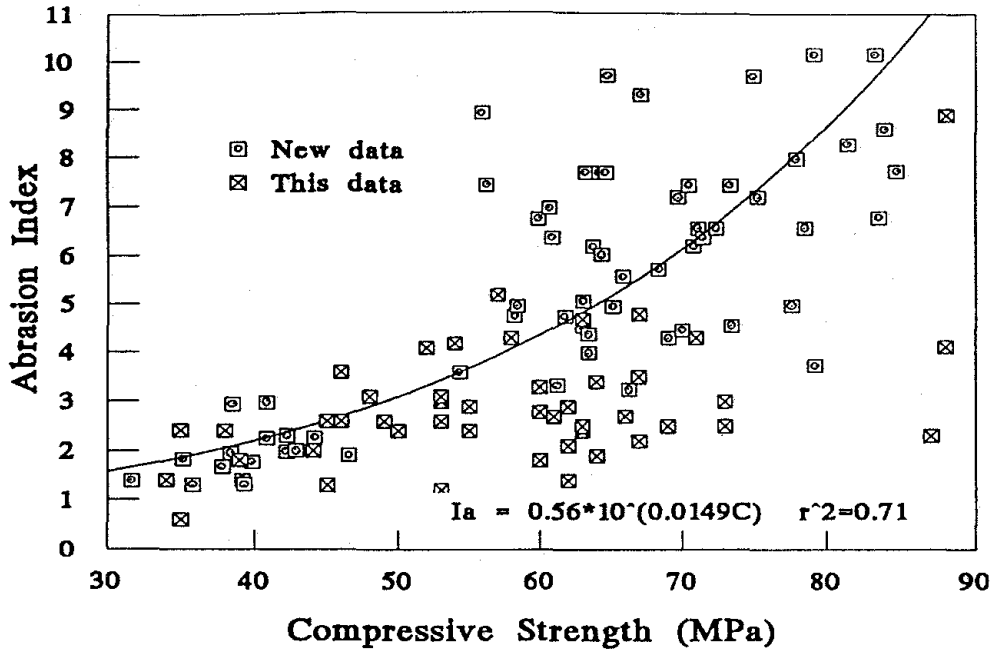

Figure 1. Compressive Strength versus Abrasion Index

Table 2. Compressive strength and abrasion index

Identity and Statistics.	8 days		13 days		21 days		28 days		35 days	
	I_a[1]	CS[2]	I_a	CS	I_a	CS	I_a	CS	I_a	CS
1	1.2	53	2.4	35	4.1	52	2.4	63	2.7	66
2	1.4	62	2.6	53	2.7	61	2.6	49	2.5	63
3	0.6	35	2.6	49	-	-	2.5	69	2.3	87
4	1.4	34	2.8	60	4.1	88	2.5	73	2.1	62
5	1.3	45	2.5	63	4.3	71	1.8	39	3.1	53
6	1.9	64	3.3	60	3.4	64	3.5	67	5.2	57
7	2.2	67	4.7	63	2.6	45	3.6	46	8.9	88
8	2.4	50	2.4	55	4.8	67	2.4	38	4.2	54
9	1.8	60	2.9	55	2.0	44	4.3	58	2.8	60
10	3.0	73	3.1	48	2.9	62	3.0	53	2.6	46
Average	1.7	54	2.9	54	3.4	62	2.9	55	3.6	64
Std Dev	0.7	13	0.7	8	0.9	14	0.8	13	2.1	14
% Var.[3]	40%	25%	24%	16%	27%	22%	26%	23%	58%	22%

1. I_a - Abrasion Index
2. CS - Compressive Strength
3. Coefficient of Variation

Table 3. Characteristic Strengths and Abrasion Indices

Sample Age (days)	Samples 1-5		Samples 6-10		Samples 1-10	
	I_a [1]	C_k [2]	I_a	C_k	I_a	C_k
8	0.56	26.1	1.47	48.7	0.58	32.2
13	2.34	34.3	1.86	46.6	1.79	40.1
21	2.58	42.7	1.40	38.3	1.88	39.2
28	1.83	35.1	2.19	33.8	1.64	38.8
35	1.91	45.9	0.52	34.6	0.21	40.9

1. I_a - Characteristic Abrasion Index
2. C_k - Characteristic Compressive Strength

SAMPLING STATISTICS

The MA20 specification for compressive strength is based on the characteristic strength of 5 paving units where equation 1 is used to determine the reported value. Such a sampling scheme is commonly termed a "variables" sampling scheme as acceptance is based on the variation in property values which are assumed normally distributed.

The abrasion index is determined by the lowest value from a set of 5 paving units. Such a scheme may be compared to an attributes sampling scheme where the paver is deemed acceptable if its attribute of abrasion index exceeds the minimum value set in the specification. The operating characteristics are calculated using the cumulative binomial distribution function and are readily available in tabulated form [6]. It is important to note that the MA20 specification for determination of the abrasion index of a lot of pavers is independent of the distribution of abrasion indices for the individual pavers.

$$C_k = C - 1.65*s \qquad \ldots . 1$$

where
C_k characteristic compressive strength of the lot under test.
s unbiased standard deviation of 5 pavers.
C average compressive strength of 5 pavers.

The operating characteristics of the quality procedures used are provided in Table 4, where "n" represents the sample size and "r" the allowable number of defective units [4]. The characteristic values for the "variable" schemes are based on a single sided specification, unknown variability scheme with "K", the acceptance constant, being a function of sample size, proportion of defective units and of the assigned probability of acceptance [4]. In the "attributes" scheme the allowable number of rejects has been assumed as nil, to agree with the MA20 specification that the lowest value of abrasion index be adopted to represent the sample "n", and exceed the minimum requirement. The attributes scheme also requires that a process variability target be specified to enable a target mean to be calculated which will achieve the sampling scheme.

Table 4. Operating Characteristics of Sampling Procedures

Operation Characteristics - Probability of Acceptance									
Sampling Method	Sample Size n	K[1] or r^2	Percentage Defective Material						
			1	3	5	10	20	30	40
Variables	5	1.65	85.5	68.5	56.5	36.5	16.5	7.0	3.0
	10	1.65	92.5	71.5	54.0	26.0	6.0	1.0	0.0
Attributes	5	0	95.1	85.9	77.4	59.0	32.8	16.8	7.8
	10	0	90.4	73.7	59.9	34.9	10.7	2.8	0.6

1. K - acceptance constant in the variables scheme
2. r - allowable defect level in the attributes scheme

The benefit of increased sample size is well established and is illustrated in Table 4. For a variables scheme, there is little effect on the probability of accepting defective material until the level of defective material becomes more than about 5%. For example at a level of 20% defective material (quite significant) the probability increases from 6.0% for a sample size of 10, up to 16.5% for a reduced sample size of 5.

The attributes scheme is much more sensitive to change in sample size as is seen when the number of samples is increased from 5 to 10. The change is important at percent defective material levels as low as 3%. At a level of 20% defective material the probability increase from 10.7% for 10 samples, up to 32.8% for 5 samples. The variables method has a slightly more attractive probability values for accepting defective material.

DISCUSSION OF RESULTS

Compressive Strength

Comparison of Tables 1 and 5 show that the Australian specifications for compressive strength are low compared with those from the northern hemisphere where absolute minimum compressive values are typical 45 MPa to 50 MPa. This can be attributed to the high strength requirements which are set to ensure durability with respect to freeze/thaw problems in the north. The high strengths then mean that little problems are encountered with abrasion.

The data from compressive strength testing showed that based on 28 day strength criteria, lot 1 (samples 1-5), lot 2 (samples 6-10) and lot 3 (samples 1-10) would pass the minimum characteristic strength requirement of 30 MPa for pedestrian mall areas. The benefits of using a larger sample size are self evident when the C_k values for the different lots are compared in Table 4.

Table 5. Strength requirements for pavers.

Country	Compressive Strength	Flexural Strength
Canada	50 MPa min average 45 MPa absolute min	NA
GFR	60 MPa min average 50 MPa absolute min	NA
Japan	NA	4.9 MPa
Netherlands	NA	5.9 MPa min C_k
New Zealand	40 MPa min C_k	NA
South Africa	35 MPa min average 30 MPa absolute min	NA
USA	55 MPa min average 50 MPa absolute min	NA

Abrasion Resistance

If abrasion resistance is used to evaluate the pavers at 28 days then lot 1 would fail, lot 2 would pass and lot 3 would fail, based on a minimum I_a value of 2.0. Using a minimum characteristic abrasion index (sampling by variables) instead of the present absolute minimum method (sampling by attributes) seems attractive.

Compressive Strength and Abrasion Index

The possibility of a relationship between paver compressive strength and abrasion index, with increase in paver age was investigated [7]. Although there were no more than 10 pairs of observations of strength and abrasion index for each curing time, a regression analysis was done for each curing time to indicate the effect of time. Only the regression coefficients for the first group (8 days) was significant at the 5% level and that of the third group (21 days) at the 10% level. The correlations ranged from near zero to 0.73 and there was no indication of pattern with time.

In the overall regression of abrasion index on strength, although strength was highly significant in its effect on abrasion index, with a correlation of approximately 0.5, there were a number of data pairs which had considerable effect, either through their strength or abrasion value. These data pairs caused a high estimate of standard deviation of abrasion index of over 1.1, after fitting strength. Omitting the data pairs whose influence or effect were questionable resulted in a decrease in correlation to less than 0.4, and raised queries about further points. The overall impression from the analysis was that although there was evidence of a link between strength and abrasion, experimental or inherent variation tends to hinder analysis of the link and its connection with time.

CONCLUSIONS

The measurement of abrasion resistance of concrete paving blocks is at present best described as an inexact science. The MA20 test could be made more effective if its methodology was reviewed and test variables, such as ball-race seating time and water flow to the ball-race, better specified. A minimum characteristic value of abrasion index is recommended to replace the existing method.

The use of abrasion index as a measure of paver quality is only appropriate with respect to abrading surface loads. Its use in any other situation should be with great care (even actively discouraged) particularly for pedestrian mall areas where degradation due to impact/skew forces is the governing criteria. The use of a minimum characteristic compressive strength appears to remain the best method to evaluate paver quality, but an increase in sample size from 5 to 10 is recommended.

A simple statistical analysis found that trends existed for increase in paver abrasion resistance with increased compressive strength but that those trends were not highly significant. No good correlation could be established due to inherent errors caused by MA20 test method or by variability within the pavers themselves. The MA20 specification should be modified to recognise the general trend of increase in abrasion index with compressive strength.

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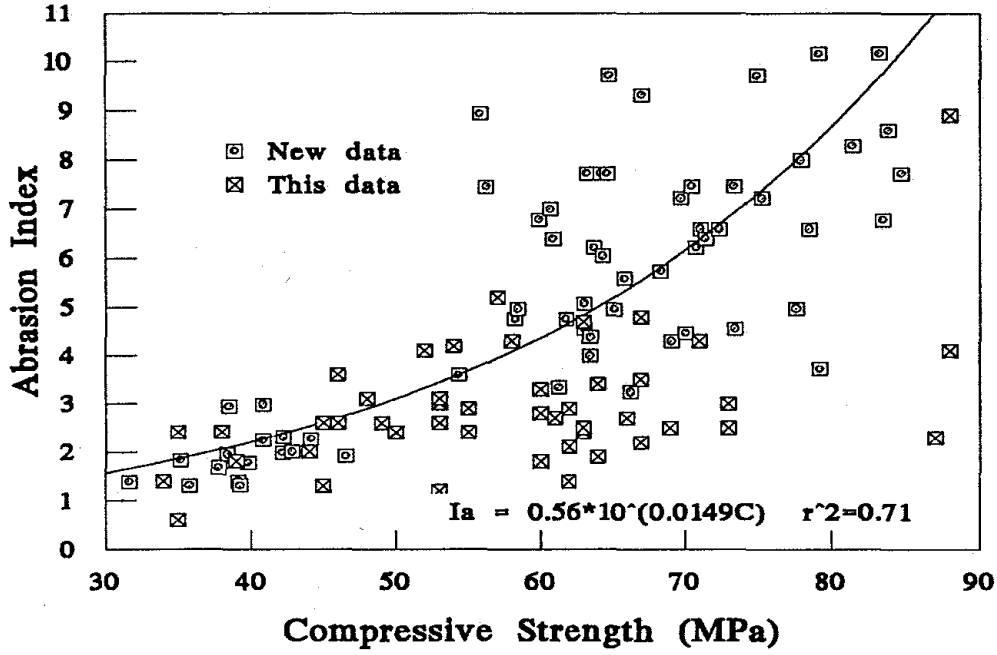
Abrasion Index
Compressive Strength (MPa)
New data
This data
Ia = 0.56*10^(0.0149C) r^2=0.71
0
1
2
3
4
5
6
7
8
9
10
11
30
40
50
60
70
80
90