THE DEVELOPMENT OF A LABORATORY TEST TO SIMULATE POLISHING OF PAVING SURFACES BY PEDESTRIANS AND VEHICLES.

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ABSTRACT

The aim of this paper is to provide a summary of the testing undertaken in the Laboratory in providing what is now known as the Polished Paver Value. In particular it is concerned with research, in which the test itself has been modified or in which 'special case' testing has been carried out, outside of the scope of routine testing.

This paper provides an overview of the knowledge built up of the polishing and slip/skid characteristics of a range of products in a variety of different laboratory conditions and the relevance of such results is considered.

The result of this work has formed the basis of the European Standard prEN12633[1].

1. EVALUATION OF THE TEST METHOD OF POLISHING SPECIMENS TO DETERMINE THE PENDULUM VALUE (POLISHED PAVER VALUE)

1.1 Introduction

In 1971, the Greater London Council recognised the need to measure and recommend levels of slip resistance for safe walking and used the pendulum apparatus to evaluate all surfaces. They determined the pendulum value of a variety of surfaces located at ticket desks and other areas where the foot traffic was extremely high.

Based on this research there was a need to artificially polish the surface to predict the 'performance in practice' level. In the early 1980's, an aggregate abrasion machine was modified into an apparatus suitable for imparting an accelerated polishing mechanism to flat bed polishing. This became a British Standard Draft for Development DD155 1986[2].

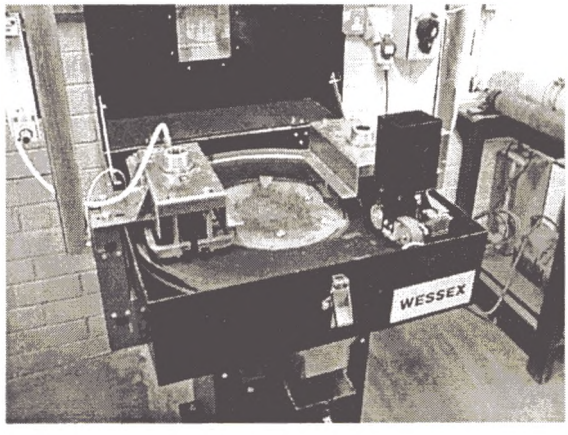
At this time, the concrete industry had limited the use of acid soluble aggregates in the concrete block paving.

In 1998, a British Standard BS 7932[3] was produced based on the DD155, but with improvements. At the same time, the European Standard for concrete block paving, clay and natural stone was being written and one essential requirement for all products was 'safety in use'. This paper examines the various influence of variation in test methods on the final result . The result of these investigations has been used in the drafting of the European Standard prEN12633:1999.

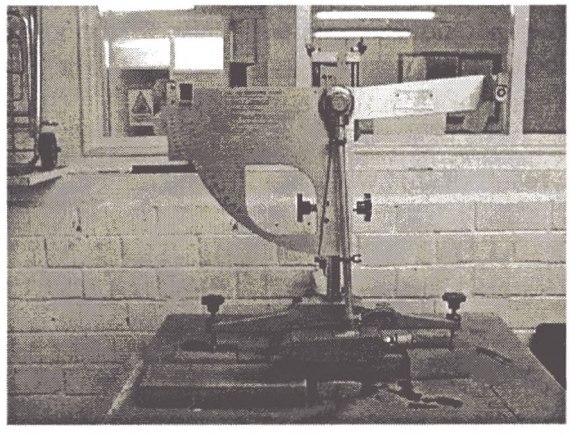
1.2 Description of test.

Flat bed polisher

The flat bed polisher shall consist of a machined circular steel disc fitted with a smooth surfaced styrene butadiene rubber annulus rotating in the horizontal plane at a speed of 29 ± 1 revolutions per minute. The specimens, 92 x 54 mm are located in two adjustable holders and are held on to the annulus with a contact stress of 2276 ± 10 N/mm^2 . Corn emery and water are fed onto the annulus just in front of each specimen at a set rate, 700 ± 10 revolutions. After completing the 700 revolutions the specimens are removed and all traces of corn emery is removed by washing with water. The specimens are then subjected to the emery flour for the same number of revolutions. The specimens are stored in water for at least 2 hours and then the pendulum test is carried out in a standard way. The apparatus is shown in Photograph 1 and the Pendulum Test Apparatus is shown in Photograph 2.



Photograph1. Flat bed polishing machine



Photograph 2. Pendulum apparatus

The test method requires a control stone to be made and tested, as above, to obtain a polishing regime. However, this control stone is difficult to manufactured, an example is shown in Photograph 3.



Photograph 3. Face of control stone

1.3 Alternative reference control stone

The use of Natural Stone as a reference material to replace standard control stone in the calibration of polishing was evaluated using a 92 x 54mm sample of natural granite, marble and a reference stone. All were taken and subjected to the standard procedure as given in BS7932, it was then tested using the pendulum. Table 1 shows the values obtained using alternative material to the control stone.

Table 1. Comparison of reference material

Reference material	Pendulum value (average)
Control stone 1	45
Control stone 2	43
Control Stone 3	46
Granite	45
Marble	11
Marble	15

1.4 The Effect of grinding the Control Stone flat before use.

When making a control stone, it is not uncommon for it to be uneven and when tested, the value can be too low for the stone to be used. In this investigation, one stone was ground flat using the flat bed polisher and the steel annulus with emery corn only and then measured with the pendulum. It was then polished using the rubber annulus with corn and the pendulum value obtained.

Using BS7932 method of measuring, the pendulum results were 43 (out of spec.– too low) and 50 (out of spec.- too high) for the two regimes respectively.

1.5 The effect of variations in the amount of emery corn and flour delivered onto the rubber annulus.

Four 92 x 54mm samples were taken from a secondary processed flag and subjected to polishing. However, instead of two hoppers dispensing the emery corn or flour, only one was used in each case. Another variation to the standard test was that pendulum readings were taken after the first polish, using the corn emery. A further pendulum value was obtained after the polishing phase as shown in Table 2.

Table 2. The effect of reduced levels of corn and flour

Ref		Pre-Polish	After Corn	Post Polish
Concrete	1	55	60	55
flag(ground)	2	55	58	55
Concrete	3	55	58	55
standard finish	4	55	58	55

This can be compared with the standard PPV test on the same product as shown in Table 3.

Table 3. Standard rate of application of corn and flour

Ref		Pre-Polish	After Corn	Post Polish
Concrete	1	55	58	53
flag(ground)	2	55	57	55
Concrete	3	55	55	53
Standard finish	4	55	55	55

1.6 The effect of each abrasive in isolation on Slip/Skid resistance.

To understand more fully the function of the polishing procedure it was felt that slip skid readings should be taken after the first polish with the emery corn, Table 4.

Table 4. Values obtained after corn and flour application

Ref		Pre-Polish	After Corn	Post Polish
Concrete	1	66	50	48
block paving	2	66	50	50
50mm.	3	67	50	46
	4	66	50	50

1.7 The effect on Slip/Skid resistance of polishing a sample more than once.

Following on from the results outlined previously, trials were carried out in which samples were re-polished with flour after the standard procedure, Table 5

Table 5. Effects of polishing twice

Reference material	Pre-polish	After corn	Post polish	Post re-polish
Concrete 1	66		48	50
Concrete 2	66		50	50
Concrete 3	67		46	47
Concrete 4	66		50	50
CBP Granite agg.	50	47	43	50
CBP Granite agg.	53	47	43	48
Natural granite	46	40	36	36
Natural granite	50	42	38	38

1.8 The effect of wear on the rubber annulus.

As tests progressed, the rubber annulus became worn and to determine the effectiveness, specimens were polished in accordance with BS 7932 and measured with the pendulum apparatus. The test was repeated using a new rubber annulus, and specimens from the same source, and the pendulum values were compared as shown in Table 6.

Table 6. Effects of rubber annulus

Reference material	Pre-polish	Post polish
Worn rubber	60	35
	60	35
	55	33
	60	45
New rubber	53	47
	55	47
	55	40
	55	42

1.9 Comparison between polishing full size units to standard 92 x 54mm specimens.

In this evaluation of comparisons between the specimen sizes, the standard as written, was applied in all the tests, for example, there was no increase in the amount of abrasive dispensed during the polishing, Table 7

Table 7. Comparison between the small and large specimen

		C scale		F scale Readings	
Reference	Number	Pre-Polish	Post-Polish	Pre-Polish	Post-Polish
		Average	Average	Average	Average
Full size unit	1	75	53	-	55
	2	75	55	-	52
	3	75	55	-	55
	4	75	55	-	52
Small size unit	A	-	-	65	50
	B	-	-	65	50
	C	-	-	65	50
	D	-	-	65	50

1.10 Tests to study the effect of various swept lengths and slider widths using measurements taken on the C and F Scale.

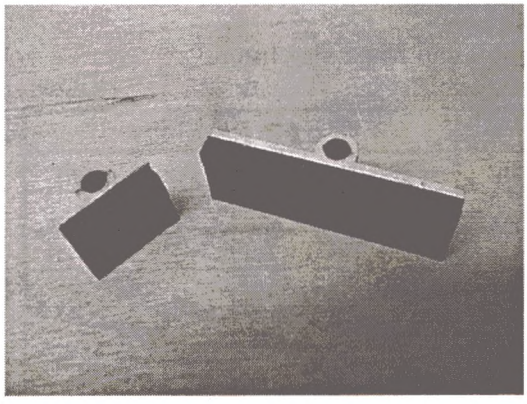
To provide a range of high to low slip/skid values, samples of concrete block paving from three different aggregate sources and production locations as well as clay paving, were selected.

The results shown in Table 8, compares the use of the C scale, wide slider and 126mm swing with the F scale, narrow slider over a 76mm swing. A factor of 1.15 was determined for a wide/narrow slider over the same swing length of 126mm. A similar factor of 1.45 was determined for a 126/76mm swing length using the same narrow slider.

Table 8. Comparison between small and large slider and small and normal swing

Scale	C Scale	C Scale	C Scale	F Scale	C Scale	C Scale
Slider	Wide Slider	Narrow Slider	Narrow Slider	Narrow Slider	126mm swing wide/narrow slider	126/76mm swing
Swing	126mm.	126mm.	76mm.	76mm.		
Product						
CBP-1	65	56	42	70	1.16	1.33
60mm.						
CBP -2	76	68	48	80	1.12	1.42
60mm.						
CBP -3	83	75	50	83	1.11	1.50
60mm.						
Clay Paving	77	70	45	75	1.10	1.56
Mean					1.12	1.45

Photograph 4 illustrates the small and standard slider used in the pendulum test.



Photograph 4. The sliders used in the test

1.11 Reproducibility of Polished Paver Values between different laboratories.

As a confidence measure and in order to check results, a comparative test was undertaken with CERAM research and Marshalls Mono. CERAM have a renowned reputation within the industry for independent testing of slip/skid. Duplicate samples of natural stone and concrete block paving were selected. Table 9 shows the results of the unpolished skid resistance value(USRV) and the Polished Paver Value (PPV).

Table 9. Comparison of results between laboratories

Product type	Lab 1	Lab 1	Lab 2	Lab 2
	PPV	USRV	PPV	USRV
200x100x600mm	60	69	57	73
200x100x65mm	65	76	65	76
Stone sett	70	84	69	83
Clay	61	74	66	75

1.12 Variation of paver thickness on the pendulum result

The aim of this study was to evaluate the effect, if any, on the Polished Paver Value using different thickness of concrete block paving units, manufactured at the same works.

Samples of 80mm and 50mm concrete block paving were submitted for Polished Paver values at 7 days. At the same time the similar representative samples were tested for routine strength requirements, Table 10

Table 10. Effect of thickness on pendulum test

Test Method	80mm.Blockpaving	50mm Block paving
Batch Code	FKE29217	FKE29227
7 day strength	49N/mm^2	49N/mm^2
s.d. strength	3.41N/mm^2	2.39N/mm^2
Density	2212kg/mm^2	2125kg/mm^2
USRV	60	60
PPV	73	72

1.13 Variation of Polished Paver Value with age.

This investigation was carried out to study any variation in results due to age. The same family of samples were tested after 7 days and 72 days, Table 11.

Table 11. The effect of age on the pendulum results

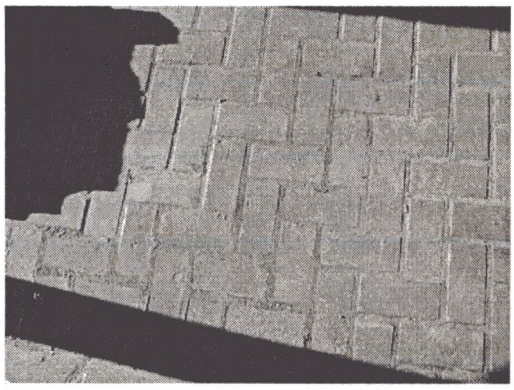
Product Thickness	Batch Code	USRV		PPV	
		7 days	72 days	7 days	72 days
50mm.	FKE29227	60	62	72	75
80mm.	FKE29217	60	64	73	78

2. EVALUATION OF CONCRETE PRODUCTS UNDER DIFFERENT TRAFFIC CONDITIONS AND COMPARISON WITH FLAT BED POLISHER

2.1 The Measurement of Polished Paver Values as an indicator of wear in service.

The main objective for the laboratory test was to attempt to simulate the way in which a product may polish when subjected to wear in service. The pendulum test apparatus was used to determine the insitu slip/skid value in areas of known usage in the different applications . Samples, were taken from these areas, where the units had had minimal use and were tested in the laboratory using the flat bed polisher to compare results, Table 12.

The areas ranged from Pedestrian use, Photograph 5, to Light traffic use, Photograph 6, to Heavily trafficked use, Photographs 7 and 8.



Photograph 5. Pedestrian use



Photograph 6 Light traffic use



Photograph 7 Heavy Traffic Use



Photograph 8 Typical use of traffic lane

Using the Pendulum apparatus, tests were carried out in the trafficked areas and the values were obtained from numerous locations.

Eight samples were uplifted from the areas where they had received little or no traffic in the three locations. These samples represented the blocks that had been tested insitu. All the samples were polished using the flat bed polishing machine.

Using the C scale, pendulum values were measured in two directions before the laboratory polishing procedure began and the results are reported as the Unpolished Skid Resistance Value.

On completion of the polishing procedure on four samples, pendulum readings were taken using both C scale and F scale readings. These samples are referenced 1 to 12 in the Table 12.

The remaining four samples were taken and the Unpolished Skid Resistance Value was determined. The samples were then cut in to the standard 92 x 54mm size for the Polished Paver Value test and polished in the standard procedure. These samples are referenced A to L in Table 12.

Table 12. Comparison of in-situ and laboratory tests

	C scale Direction A		C Scale B	F scale Readings	
Ref.	**Pre-Polish**	**Post-Polish**	**Pre-Polish**	**Pre-Polish**	**Post-Polish**
Heavily trafficked					
1	53	45	50	-	45
2	57	52	53	-	55
3	55	50	55	-	53
4	53	50	53	-	50
A	53	-	53	50	50
B	53	-	53	50	46
C	53	-	53	50	50
D	53	-	53	50	48
Pedestrian trafficked					
5	48	42	46	-	45
6	47	40	46	-	43
7	48	42	48	-	47
8	47	45	47	-	48
E	50	-	50	46	40
F	53	-	52	46	40
G	50	-	50	45	42
H	50	-	50	45	40
Lightly trafficked					
9	52	53	50	-	60
10	55	53	55	-	55
11	46	48	46	-	55
12	50	49	50	-	55
I	48	-	48	45	50
J	45	-	45	45	43
K	53	-	53	50	50
L	47	-	46	45	45

3. CHANGES IN RESISTANCE VALUE AS A RESULT OF LAYING PROCESS.

This ad-hoc test was to observe any differences between the declared value and an unpolished value after laying. The results are shown in Table 13 of five blocks taken from a batch before laying, compared with after laying. Photograph 9 show the site of this evaluation.



Photograph 9. Newly laid road

Table 13. Comparison of pendulum result on blocks before and after laying

Reference.	Pendulum result
Laboratory	75
Test	75
Before	75
Laying	75
	76
On site	63
Test	65
After	68
laying	65
	65

4 CONCLUSIONS

The flat bed polishing test method produces slightly lower pendulum values than those that occurred in practice. This has been verified on samples from other sites throughout Europe using the same selection procedure and tested with apparatus in the author's laboratory. This confirmed that the flat bed testing polishing test method gives a good correlation to practice.

Full size units 200 x 100mm are recommended in the prEN12633 using the large slider and full swing. Although a relationship has been developed between the two different swings and slider size these have been rejected. If the specimen is not flat, then a suitable size of specimen may be taken to allow the large slider and the long swing to be used.

The flat sample of granite polishes to a similar degree to a control stone prepared in accordance with BS 7932. These results suggest that although the marble is consistent in its polishing behaviour, values given are too low to provide an acceptable alternative

The difference between acceptable wear of the annulus needs to be defined and requires a revision of the definition of acceptable wear. This difference will not be obvious by the use of control stones to calibrate the polishing, unless another factor changes (e.g. new batch of abrasive).

Both of these are currently being investigated.

The corn serves only to roughen the surface of the sample as in the road application and the flour polishes the surface.

REFERENCES

1. Determination of Polished Paver Value', prEN 12633 : 1997
2. British Standards Draft for Development DD155 1985
3. Determination for Polished Paver Value', BS 7932 : 1998

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