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The Effect of Abrasive Minerals on the Mechanism of Road Stones Polishing

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Abstract

As a road surface comes into contact with the vehicle tire under traffic movements, the exposed aggregates experience a wearing or abrasive effect. By the presence of sand or grit on the road surface this effect is accelerated. If aggregates are of a particular nature, the gradual wearing will result in a loss of aggregate angularity and polishing may occur. This paper presents the results of laboratory tests on physical, mineralogical and mechanical polishing properties of aggregates that are currently employed in asphalt wearing courses. 81 samples of 27 different freshly crushed aggregates from different geological groups were subjected to a program of experiments utilizing Accelerated Polishing Machine (APM) using Corn Emery (as coarse mineral) and Emery Flour (as fine mineral). A 3-hour interrupted one hour test using Corn Emery followed by 3-hour interrupted test using Emery Flour was preformed to obtain the effect of polishing. British Pendulum was used to measure the PN after every one hour. The gradual decrease of Pendulum number (PN) according to geological point of view was also evaluated. It was found that in general that presence of finer materials wears road surface aggregates faster than coarser materials. The results showed that the maximum amount of drop in PN is related to the first hour of polishing with fine abrasive and in the first three hours using coarse abrasive, and little change occurs in PN. Therefore, the data would seem to suggest that PSV is to be calculated using fine mineral abrasive within one hour instead of 6 hours.

Keywords: Aggregates; Polished Stone Value; British Pendulum; Abrasive Minerals.

1. Introduction

The British Polished Stone Value (PSV) test method has been used for many years to measure the polishing properties of aggregates [1]. The PSV is directly related to the tendency of an aggregate to lose its roughness or initial microtexture due to the polishing effect of tires [2]. Recent studies have found that this method is dependent on the test conditions used [3-5].

Road polishing surfaces are complex phenomena, which are obviously strongly related to the energy that polishes the road, and this energy is the one created by the tire with the presence of abrasive materials. It depends on non-linearly of numerous parameters, like materials used, vehicle and road usage, environmental conditions (e.g. temperature) among many [6]. It is essential that the aggregates used in construction purposes to be strong and durable.

Traffic flows and higher speeds on trunk roads, together with concerns about road safety led to study the relationship between road materials and skid resistance. Abrasion of aggregates at the surface could result in particle polishing, and consequently reduction of surface friction[5]. The friction of asphalt pavement surface is a function of the microtexture and the macrotexture. The microtexture is primarily a function of aggregate shape characteristics, while macrotexture depends on aggregate gradation, mix design and compaction. The review of publishing literature reveals that microtexture has been the most difficult to measure and is related to surface friction [7-9]. During the polishing process, the micro-texture of aggregates changes due to a gradual removal of mineral components [10-11].

In 1952, an accelerated wear machine was constructed by the Road Research Laboratory (now Transport Research Laboratory (TRL)) to study different factors that cause wear on a surface dressing. Provisional results suggested that loose grit on the surface might be an important factor contributing to the abrasive wear of aggregates [7]. By 1957, it had become the basis for testing aggregate resistance to polishing. After wearing, the extent of polishing was measured by a pendulum friction tester, and expressed as a 'roughness number'. The roughness number ranged from 0 for specimens that became highly polished, to 10 for specimens that remained rough. Roughness numbers were then compared with the measured average sideway-force coefficient (SFC) at 30mph of surfacing when wet. This led to the development and adoption of the polished stone coefficient (PSC) in 1958 [8].

Soon after, these polished stone coefficients were multiplied by 100, to avoid confusion with SFC, with the results of the test being expressed as Polish Stone Values (PSV). This amended accelerated polishing test was then published by the British Standards Institute as BS 812:1960 [8].

In 1965, changes in test procedure (replacing the pneumatic tire with a solid one) led to an approximately 10% reduction in PSV. Now, this procedure is developed in the world, and retained in subsequent revisions of British Standards BS 812 (BS EN 1097-8: 2000). This British Standard has been adopted and used widely around the world. The Permanent International Association of Road Congresses (PIARC) in conjunction with RILEM and the American Society for Testing Materials (ASTM), recommend the use of BS 812 to determine Polish Stone Values.

The development of the Accelerated Polishing Machine has enabled engineers and highway designers to choose an appropriate PSV of aggregate for each section of the road, since aggregates polish more rapidly at locations where tire forces are relatively high rather than on straight sections [9].

PSV is measured as part of a standard test known as the Accelerated Polishing Machine tests. The BS accelerated polishing test, whilst simple in concept, is time-consuming. It consists of two 3-hours polishing stages using different polishing agents, namely Corn Emery and Emery Flour, with regard to the polishing machine between the stages and measurement of the PSV at the end [9].

However, in recent years this traditional approach has been subjected to investigation. In England, Roe and Caudwell accept that the polished stone value test has its limitations and alternatives that might provide an even better capability to predict performance and help select the most appropriate aggregates [12]. Soleymani pointed out that there are other ways of evaluating the PSV and he has formulated a correlation with Moh's normative hardness [13]. Ahadi suggested that PSV test is very time-consuming and he has demonstrated that the test procedure could be shortened for 3 hours, if only Emery Flour is used [9].

Another study carried out by Wang et al. investigated the behaviors of typical mineral components of the aggregates due to tire-polishing. They were found that a fine mineral structure for granite brings an overall high friction level [14].

In another study Ramirez *et al.* [2] represented the results obtained during the development of a test procedure which has been applied in the laboratory to measure the evolution of the skid resistance of hot mix asphalts through a modified version of an accelerated polishing machine which is normally used to determine the polished stone value of aggregates [2].

2. Methodology

One of the main parameters in this study is the rate of microtexture waning in time in the presence of different sizes of mineral abrasives for which the aggregate PSV is used to measure the pattern of declining PN to reach the final value. This important factor can be accomplished by performing interrupted test (as this research suggests) according to BS 812 part 114 procedure and using the Accelerated Polishing Machine as an apparatus. This research established that to examine different stages of polishing of aggregate, researchers could interrupt the 6-hours test and measure PN to observe the gradual reduction in PN for each individual aggregate.

The polishing process was simulated by means of a laboratory device on laboratory-made specimens composed of aggregates. The same specimen was used to survey the evolution of the microtexture with the polishing time. The extent of this research called for a large number of specimens to be made for accelerated polishing machine. The intention was to make as many as samples possible from a limited supply. Totally, 81 samples were made.

The first stage was using polishing machine operating on fresh aggregates with Corn Emery. To complete this stage, the APM was stopped at predefined stages and the specimens were taken out for measurements. Then, the specimens were replaced in the machine and the polishing process was pursued. This process was repeated for every one hour. The second stage was using polishing machine operating with Emery Flour. To complete this stage, the APM was stopped at predefined stages and the specimens were taken out for measurements. To examine the different stages of polishing of aggregate, researchers usually interrupt the 6-hours test and measure PN to examine that how much PN goes down in each individual aggregate [9]. Polishing is much a function of the aggregate characteristics, which is accelerated by the presence of abrasive material. Obviously, the finer the particles constitute this material, the smoother the resulting wear surface will be, and the wear is slower as well. Consequently, slower wear means more polishing, hence lower skid resistance. The rate of reduction in PN value will be assessed and compared with the performance of control stone aggregate.

3. Material and Methods

To conduct the standard test, samples of aggregate are fixed into moulds using resin, together with a control sample of known PSV (Control Stones). Each is then subjected to polishing in the accelerated polishing machine, in a prescribed order. This is measured as part of a standard test known as the Accelerated Polishing Machine test. As already noted, this test consists of two 3-hours polishing stages using different polishing agents.

As is shown in Fig. 1, the polishing actions were simulated in laboratory by means of Accelerated Polishing Machine. The polishing action is achieved by interrupting test to observe the rate of reduction in pendulum test values and the performances of fine and coarse materials.

The Polished Stone Value of aggregate gives a measure of resistance to the polishing action of vehicle tires under the conditions similar to those occurring on the surface of a road. The action of road vehicle tires on road surfaces results in polishing of the top, exposed aggregate surface, and its state of polish is one of the main factors affecting the resistance to skidding. Resistance to this polishing action is determined principally by the inherent qualities of the aggregate itself. The PSV test is carried out in two stages - accelerated polishing of test specimens followed by measurement of their state of polish by a friction test.

To examine different stages of polishing of aggregate, researchers usually interrupt the 6-hours test and measure PN to examine that how much PN goes down in each individual aggregate.

In this research, attempts have been made to relate aggregates' performance to probable wear rates by a regime of tests, which simulate the wear of each individual aggregates in 3h and 1h intervals to observe the rate of reduction in pendulum test values. It should be noted that the final value of interrupted test should not be directly compared with the PSV obtained on the polishing of specimen of the original experimented series; since, the interrupted test procedure is different from that of polished stone value (PSV) according to the BS 812 part 114.

Fig.1. Accelerated polishing machine

Interrupted test could be divided into:

a. Standard test, which is interrupted only once in three hours i.e. changing from Corn emery and emery Flour;
b. Interrupted test, every one hour to observe the rate of reduction of the pendulum value with time for durability, this test is being run for six hours (3h of Corn emery and 3h emery Flour) as well.

4. Results and discussion

In Table 1, 27 different types of aggregates examined in this study are listed. In this Table all aggregate samples and their petrological name could be seen. In the first step, the samples were polished using Corn Emery. PN is calculated at the intervals of one hour for each sample. Values in the Table are an average of three replicates of each type of aggregate. The third, fourth and fifth columns are the PN after one, two, and three hours, respectively. The sixth column shows the PN difference between baseline and after three hours of polishing using fine abrasive. Considering that in initial state no force is applied on the sample and aggregates are not snapped together, the initial PN does not represent the actual number. Therefore, the initial number is assumed after one hour polishing, similar to the state that traffic is allowed to pass through on road. As can be seen, the drop in PN after 3-hours polishing is negligible. Generally, equal to 5.5% of the total drop occurs in the first 3 hours.

In Table 2, PNs with one-hour intervals are inserted, where Emery Flour is used as an abrasive. The third column (column A) contains PN after three hours, where Corn Emery is used. In Column B, after the fourth hour or after one hour polishing with fine abrasive, PN is observed. Likewise, in columns C and D, PN is shown after the fifth and sixth hour. The next three columns show the difference between PNs in one consecutive hour. It could be seen that the highest rate of drop is the fourth hour or in other words the first hour of polishing process with fine abrasive, in such a way that nearly 80 percent of drop occurs in this hour. The last column in Tables 1 and 2 indicates the amount of PN in the standard PSV test.

Table.1. PN of each aggregates interrupted standard test every one hour using Corn Emery

Aggregate No	Type of aggregate	Mean PN readings of 3 samples of each aggregates interrupted standard test every one hour using *Corn Emery*			Total reduction in 3 hour test PN readings	Standard PSV
		After 1h	After 2h	After 3h		
1	Dolerite	70	70	68	2	50
2	Spilite basalt	68	68	67	1	51
3	Trachyandesite	70	70	70	0	53
4	Dolerite	69	69	69	0	60
5	Altered dolerite	69	69	68	1	52
6	Trachyandesite	55	55	55	0	53
7	Dolerite	70	70	70	0	53
8	Altered dolerite(CON)	72	72	71	1	52
9	Granodiorite	79	79	79	0	56
10	Porphyritic microgranite	75	75	74	1	53
11	Coarse granite	68	68	66	2	52
12	Coarse granite	64	65	64	1	52
13	Coarse granite	70	70	70	0	50
14	Ganodiorite	62	62	62	0	56
15	Porphyritic microgranite	70	70	69	1	53
16	Recrystallized sandstone	62	60	60	2	43
17	Calcareous sandstone	71	70	69	2	44
18	Meta argillite-greywacke	71	71	71	0	61
19	Greywacke	70	70	69	1	53
20	Recrystallized greywacke	75	75	75	0	53
21	Limestone	55	54	54	0	61
22	Marble	60	60	60	0	35
23	Granophyre	70	70	70	0	55
24	Altered meta-gabbro	70	70	70	0	54
25	Hydrothermally altered diorite	73	73	70	3	61
26	Leuco diorite	70	65	65	5	49
27	Altered diorite	58	58	58	0	49
Total unit drop in 3 hour test readings					23	
Total % drop in 3 hour test					5.50%	

Table.2. PN of each aggregates interrupted standard test every one hour using Emery Flour

Aggregate No	Type of aggregate	Mean PN readings of 3 samples of each aggregates interrupted standard test every one hour using *Emery Flour*				drop in 3 hour test PN readings			Total unit drop in 3 hour test readings	Standard PSV
		A	B	C	D	A-B	B-C	C-D	E	
1	Dolerite	68	52	49	49	16	3	0	23	50
2	Spilite basalt	67	53	50	49	14	2	1	18	51
3	Trachyandesite	70	62	61	61	8	1	0	9	53
4	Dolerite	69	65	64	64	4	1	0	5	60
5	Altered dolerite (CON)	68	49	47	47	19	2	0	22	52
6	Trachyandesite	55	48	48	47	7	0	1	8	53
7	Dolerite	70	60	59	58	10	1	1	12	53
8	Altered dolerite	71	48	47	45	23	2	0	27	52
9	Granodiorite	79	59	59	59	20	0	0	20	56
10	Porphyritic microgranite	74	62	62	62	13	0	0	12	53
11	Coarse granite	66	51	51	50	15	0	1	18	52
12	Coarse granite	64	51	45	45	13	5	0	19	52
13	Coarse granite	70	63	62	62	7	1	0	8	50
14	Granodiorite	62	50	45	45	12	5	0	17	56
15	Porphyritic microgranite	69	60	55	55	9	5	0	15	53
16	Recrystallized sandstone	60	44	43	42	16	1	1	20	43
17	Calcareous sandstone	69	62	60	59	7	2	1	12	44
18	Meta argillite-greywacke	71	60	59	56	11	1	3	15	61
19	greywacke	69	62	62	61	6	0	1	8	53
20	Recrystallized greywacke	75	60	59	58	15	1	1	17	53
21	Limestone	54	32	30	30	22	2	0	24	61
22	Marble	60	42	40	40	18	2	0	20	35
23	Granophyre	70	55	55	54	15	0	1	16	55
24	Altered meta-gabbro	70	60	60	60	10	0	0	10	54
25	Hydrothermally altered diorite	73	70	58	58	12	0	0	15	61
26	Leuco diorite	70	65	64	55	1	9	3	18	49
27	Altered diorite	58	58	50	48	8	2	0	10	49
Total unit drop in 3 hour test readings						324	56	15	418	
Total drop in 3 hour test (%)						79.50	11.50	3.60	100%	

In Fig. 2 the contribution of each of the intervals in the drop in PN could be seen. It follows that the greatest contribution is related to the first hour of polishing with fine abrasives and the first three hours with coarse abrasive (5.5%). The last two hours polishing with fine abrasive (11.5% and 3.5%) have a little contribution in the loss of the PN.

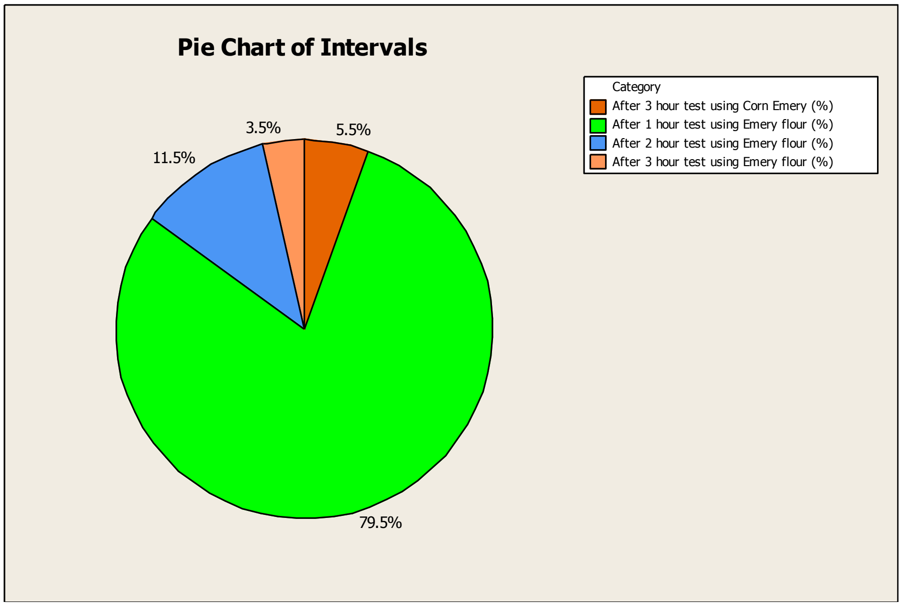

Fig.2. The contribution of each one of intervals in the drop in PN

According to the obtained results, only one hour polishing could be used instead of 6-hours of polishing, using a fine abrasive to polish the stone samples and the obtained PN could be proposed as the final PN with acceptable accuracy.

In table 3, the average PN resulted from three samples of aggregates after one hour polishing with fine abrasive is listed in the third column. The proposed PSV values using Equation 1 are shown in the fourth column.

In the laboratory tests outlined in EN 1097-8 (Determination of the polish stone value), the PSV of an aggregate is obtained by correcting the value obtained empirically using the following equation [2]:

$$PSV = S + 52.5 - C \quad (1)$$

where: S- the average value of the skid resistance of aggregate specimens, measured on the pendulum scale; C= the average value of the skid resistance of specimens of control aggregate, measured on the pendulum scale.

In the fifth and sixth columns, the standard PSV obtained from PSV test and PN of control stone are listed respectively.

To measure the validity, the results of the proposed PSV have been compared with standard PSV in Fig. 3.

Using the values of PSV in Table 3, polynomial regression model equation can be derived as Eq. (2):

$$PSV_{Standard} = 36.5 - 1.717PSV_{obtained} + 0.0653PSV_{obtained}^2 - 0.000524PSV_{obtained}^3 \quad (2)$$

In the last column of the Table 3, the proposed PSV is shown which is calculated from proposed equation.

Table.3. Proposed PSV and standard PSV

Aggregate No	Type of aggregate	Mean PN readings of 3 samples of each aggregates first hour using Emery Flour used as final PN	PSV obtained from Eq.1	Standard PSV	PN of control stone	Proposed PSV
1	Dolerite	52	53.5	50	51	51.3
2	Spilite basalt	55	56.5	51	51	53.4
3	Trachyandesite	60	60.5	53	52	55.6
4	Dolerite	62	62.5	60	52	56.3
5	Altered dolerite	49	52	51	50	49.7
6	Trachyandesite	48	49.5	49	51	48.0
7	Dolerite	60	61.5	53	51	56.0
8	Altered dolerite (CON)	48	49.5	50	51	48.0
9	granodiorite	59	59.5	56	52	55.1
10	Porphyritic microgranite	52	52.5	53	52	50.5
11	Coarse granite	51	53.5	52	50	51.3
12	Coarse granite	51	52.5	52	51	50.5
13	Coarse granite	55	56.5	53	51	53.4
14	Granodiorite	50	51.5	48	51	49.7
15	Porphyritic microgranite	60	62.5	54	50	56.3
16	Recrystallized sandstone	44	45.5	44	51	44.2
17	Calcareous sandstone	60	62.5	56	50	56.3
18	Meta argillite-greywacke	60	62.5	61	50	56.3
19	greywacke	62	63.5	61	51	56.6
20	Recrystallized greywacke	60	62.5	53	50	56.3
21	Limestone	32	34.5	34	50	33.5
22	Marble	42	44.5	40	50	43.2
23	Granophyre	55	56.5	55	51	53.4
24	Altered meta-gabbro	60	61.5	55	51	56.0
25	Hydrothermally altered diorite	60	60.5	61	52	55.6
26	Leuco diorite	60	61.5	50	51	56.0
27	Altered diorite	50	50.5	49	52	48.8

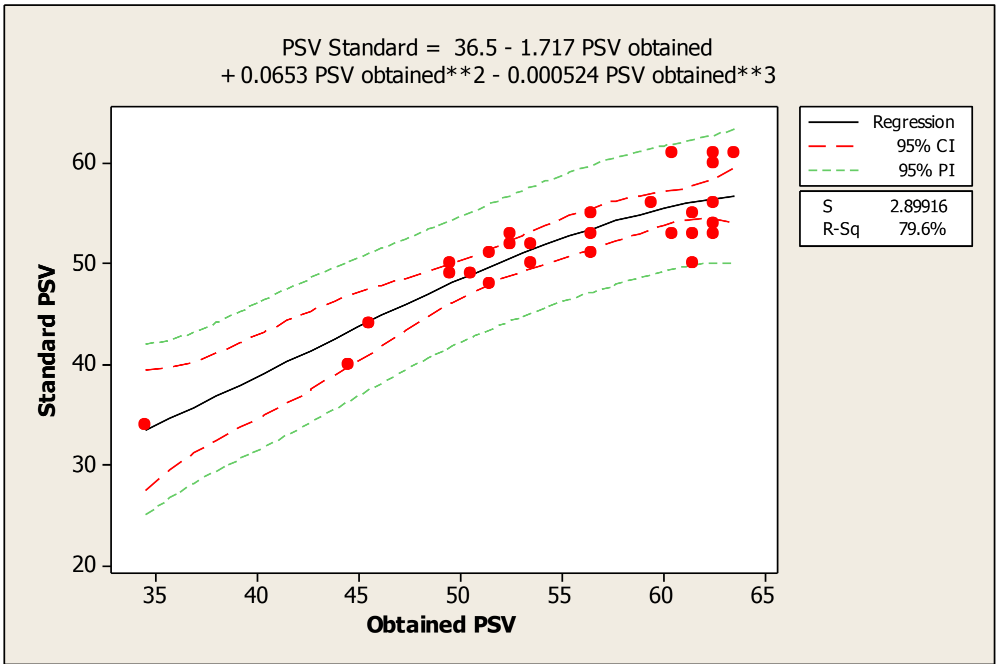

Fig.3. The correlation between standard and interrupted PSV test

5. Conclusions

As observed, the main purpose of this study was to evaluate the effect of mineral abrasives size on road surface stones polishing. The main results of this study are as follows:

- In general, the presence of finer materials wears surfaces faster than coarser ones.
- The rate of microtexture waning in time is a good factor to measure the PSV of aggregates in the presence of different sizes of mineral abrasives.
- The maximum amount of drop in PN is related to the first hour of polishing with fine abrasive and in the first three hours using coarse abrasive, and little change occurs in PN.
- According to the obtained results, one hour polishing with a fine abrasive could be used instead of the 6-hours polishing to polish the stone samples and the obtained PN could be proposed as the final PN with acceptable accuracy.

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