# SIMULATIVE POLISHING IN THE LABORATORY; COMPARISON WITH TRAFFIC AND USE TO INVESTIGATE AGGREGATE BLENDING

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## ABSTRACT

Two experiments with the Wehner-Schulze machine, which is designed to apply a controlled amount of polishing to and measure the friction of road surfacing products, are described and their results summarised.

In the first experiment the polishing action of the machine is compared to the polishing action of traffic using UK roads. It is shown that there is a strong correlation between friction measured after polishing by traffic in a non-event location and friction measured after polishing in the machine. It is shown that polishing in the machine is more severe than that applied by free-rolling traffic on straight roads.

In the second experiment, the machine is used to show that it may be possible to predict the long-term friction performance of asphalt prepared with a blend of coarse aggregates using a mass ratio formula.

## 1. INTRODUCTION

The work described in this paper was carried out under a project commissioned by the UK Highways Agency. The work sought firstly to evaluate the ability of a new laboratory procedure to simulate the polishing action of traffic and its suitability for use in the specification of road surfacing aggregates and secondly to demonstrate its potential for use in research to investigate skid and polish resistant properties of aggregates and asphalts.

The procedure in question uses the Wehner-Schulze (W-S) machine, purchased in 2005 by the Highways Agency. The W-S machine is a commercially available laboratory device designed to apply a controlled amount of polishing to samples of road surfacings or their constituent parts. The machine has an integrated friction measurement device and its purpose is to estimate the specimen's likely in-service skid resistance performance. The machine's purchase, installation at TRL and subsequent commissioning are described in published project report PPR144 [1].

The methodology used to compare polishing in the W-S machine with polishing by traffic is presented, followed by a comparison of the visual appearance of specimens and an analysis of friction measurements made after polishing and their implications in terms of the machine's simulative capability. The remainder of the paper presents an experiment in which the W-S machine was used as a research tool to investigate the effect of combining coarse aggregates with different polish resistance properties.

The experiments summarised here are described in more detail in project reports prepared for the Highways Agency [2] [3].

## 2. BACKGROUND

Aggregates used in the surface course on UK roads are required to meet a pre-defined specification in terms of their resistance to polishing under the action of traffic. The current method of testing this polishing resistance is via the 'Polished Stone Value' (PSV) test, in which the skid resistance of small samples of aggregate is tested after they have been subjected to controlled polishing in the laboratory. The first experiment described in this paper attempted to compare the polishing action of the Wehner-Schulze machine with the polishing action of traffic on in-service highways. It was hoped that the results could be used to determine both the machine's ability to compliment the PSV test for materials specification and its value as a research tool, as in its use in the second experiment.

The second experiment was carried out to investigate the potential for improving the sustainability of surface course construction. Stocks of the most polish resistance aggregates (PSV > 65), which are specified for use in demanding situations such as bends and approaches to roundabouts and traffic lights, are limited [4]. Furthermore, haulage of these aggregates from their source quarries results in significant cost and energy consumption for surfacing schemes on many parts of the network. Aggregates that have polish resistance high enough to allow their use as coarse aggregate in the surface course, but too low for use in high-demand situations, (PSV 50-65) are somewhat more readily available [5]. The most practical use of this more abundant resource, if the specification does not immediately allow it, might be in combination with a high-PSV aggregate, either by mixing different proportions of coarse aggregate, or by varying the source of fines. The polish resistance of aggregate blends is also likely to be of significance when considering the use of reclaimed aggregate in surface courses.

The Wehner-Schulze (W-S) test equipment, shown in Figure 1, was developed during the 1960s in Germany, at the Technical University of Berlin (TUB), as an alternative laboratory test procedure for assessing the polishing of aggregates in road surfacings. At that time, it was considered that the polished stone value (PSV) test was not satisfactory because it gave relatively small numerical differences between different aggregates used in Germany and had poor reproducibility.

Figure 1 – The Wehner-Schulze machine

The W-S procedure, similarly to the PSV test, is designed to simulate accelerated polishing on road surfacing materials and test the friction provided by the specimen before and after that polishing. The W-S procedure uses large, flat specimens (usually 225 mm diameter) that can be obtained from actual road surfaces, asphalt test specimens manufactured in the laboratory or laboratory-manufactured test plates using aggregate alone. The test is carried out using a purpose-designed machine that is available commercially. The UK machine was the twelfth machine to be manufactured.

Polishing is achieved in the Wehner-Schulze machine by lowering three conical rubber rollers so that they are independently forced into contact with the test surface. The polishing head is made to rotate at a speed of 500 rpm while a suspension of silicon dioxide in water is pumped onto the surface to act as a polishing medium. During the polishing operation, each roller is independently forced onto the test surface at a contact pressure of approximately 0.4 $Nmm^{-2}$, equivalent to 4 bar (58 psi), typical of the tyre pressures of a commercial vehicle. The mounting bearings are engineered to provide some friction so that, although the rollers are free to rotate, there is some drag, giving a slight slip of 0.5 to 1.0 %. Grooves 2 mm wide, 2 mm deep and 20 mm apart are cut in the roller rubber, running from the apex to the base of the rollers, to simulate tyre treads.

Friction is calculated from measurements of torque imparted to the surface when a test head, comprising three separate rubber sliders and rotating at a pre-defined speed, is dropped onto the surface and allowed to slide to a halt under its own mass. In the standard test, the measuring head is accelerated until it is rotating at 3000 rpm, which is equivalent to a tangential speed for the rubber sliders of 100 km/h. Just before the head has reached the target speed, water is sprayed on to the test surface to attain a theoretical water film thickness of 0.5 mm and the assembly is dropped onto the surface from a height of about 10 mm, imparting a pressure of 0.2 $Nmm^{-2}$, equivalent to 2 bar (29 psi) in tyre pressure. The friction test value reported, $\mu_{PWS60}$, is the friction calculated when the friction head has slowed to an equivalent tangential speed of 60 km/h.

New specimens may require cleaning to remove excess bitumen from the surface prior to testing. For this purpose, a custom-designed grit blasting cabinet is used. The cabinet has several automatic settings which control the duration and evenness of the blasting over the specimen surface. As well as for initial sample cleaning, the grit blasting can be used to ‘roughen’ the specimen surface as a specific test stage to simulate the action of winter weather.

## 3. COMPARING POLISHING IN THE LABORATORY WITH POLISHING BY TRAFFIC

### 3.1 Methodology

210 slabs of asphalt were prepared in the laboratory, using one basic asphalt design with fourteen different combinations of coarse and fine aggregates. Some of the specimens were just polished in the Wehner-Schulze machine, the majority were embedded in road sites to be retrieved after trafficking and some were left outside on the TRL site so as to be subjected only to the effects of weather.

#### *3.1.1 Description of specimens*

The asphalt slabs were prepared using a standard stone mastic asphalt design. Table 1 lists the fourteen combinations of coarse and fine aggregates used; for anonymity, aggregate sources are referred to by letter, and the PSV for each is the nominal value allocated by the supplier, where that information was available. All slabs were cored to give a disc of asphalt to fit the Wehner-Schulze machine (225 mm diameter).

Table 1 - Coarse and fine aggregate combinations used in asphalt slabs

| ID | Coarse aggregate | Coarse aggregate type | Nominal PSV of coarse aggregate | Fine aggregate |
|---|---|---|---|---|
| 1 | A | Felsite | 59 | L |
| 2 | B | Porphry | 60 | B |
| 3 | B | Porphry | 60 | L |
| 4 | C | Gritstone | 65 | C |
| 5 | D | Granite | 57 | L |
| 6 | E | Basalt | 55 | L |
| 7 | F | Gravel | - | L |
| 8 | G | Dolerite | 65 | L |
| 9 | H | Gritstone | 68 | L |
| 10 | C | Gritstone | 65 | L |
| 11 | J | Dolerite | 62 | L |
| 12 | K | Granite | 52 | L |
| 13 | L | Granite | 53 | L |
| 14 | M | Limestone | 36 | L |

For each of the fourteen aggregate combinations, fifteen asphalt discs were produced:

- 2 were subjected to polishing in the W-S machine
- 12 were embedded in sets of four into three trial sites, to be subjected to polishing by traffic
- 1 was subjected to the actions of weather.

For the remainder of this paper the fourteen aggregate combinations will be referred to as the ‘mix’ followed by the appropriate ID (as listed in Table 1). Each individual asphalt disc will be referred to as a ‘specimen’.

### *3.1.2 Polishing in the laboratory*

For each mix, two control specimens were subjected to polishing in the Wehner-Schulze machine. One was polished using the standard regime, recommended by the manufacturer, developed at the Technical University of Berlin (TUB). The other control was polished according to a regime developed by researchers in France to examine the evolution of friction throughout the polishing process. Details of the other polishing regime, and results from its use are included in the project report [2] but they will not be used in this paper.

The “TUB method” of polishing is as follows:

- Test friction
- Polish for one hour (90,000 roller passes)
- Test friction
- Gritblast
- Test friction
- Polish for one hour (90,000 roller passes)
- Test friction
- Test friction ‘to the limit’ (repeat friction tests until subsequent values differ by less than 0.005).

Table 2 shows the coefficient of friction, $\mu_{PWS60}$, measured at each stage of the TUB polishing method, on a control specimen of mix 1.

Table 2 – Friction measurements made on control specimen of mix 1

| Polishing stage | Number of roller passes | $\mu_{PWS60}$ |
|---|---|---|
| Initial friction | 0 | 0.431 |
| After one hour of polishing | 90,000 | 0.393 |
| After gritblasting | 90,000 | 0.679 |
| After further hour of polishing | 180,000 | **0.414** |
| After testing ‘to the limit’ | 180,000 | 0.382 |

The initial friction measurement is probably associated with the properties of the excess bitumen and fine material present on the surface of the asphalt specimen. Initial friction measurements were generally higher than the final measurement made after 180,000 polishing passes. It is the coefficient of friction measured immediately after the second hour of polishing (highlighted with bold text in Table 2) that is used for comparison purposes.

### *3.1.3 Trial sites and specimen embedment*

In order to investigate a range of levels of trafficking, the asphalt discs were embedded into three different sites. The three sites were well known, having been used as trial sites during a parallel programme of research, and are part of the Highways Agency’s trunk road network. The three sites carry 4500, 1200 and 200 commercial vehicles per day (CVD), according to Highways Agency records and they will be referred to as sites A, B and C respectively.

At each of the three sites 56 asphalt discs, comprising four specimens from each mix, were embedded during August 2007. The photographs in Figure 3.2 show some of the discs immediately before and after embedment into site C.

Figure 2 - Asphalt discs in site C about to be installed (left) and shortly after installation (right)

### 3.1.4 Specimen retrieval and testing

The intention of the experiment was to retrieve one specimen of each mix at six month intervals, during winter and summer periods. However, primarily due to constraints with gaining access to the live road network at the appropriate times, the specimens were removed on a more ad-hoc basis. Table 3 shows the timing of retrieval and the number of specimens retrieved on each occasion; the length of the trafficking period is shown in brackets. It was not possible to gain access to sites B and C for the second visit and one set of fourteen discs remains embedded in those sites.

Table 3 - Number of asphalt discs retrieved from sites during each visit

| Site | April 08 (8 months) | October 08 (14 months) | April 09 (20 months) | August 10 (36 months) |
|---|---|---|---|---|
| A | 14 | 14 | 14 | 11† |
| B | 14 | 0 | 13* | 13* |
| C | 14 | 0 | 14 | 14 |

*one specimen damaged on retrieval
†three specimens damaged by unrelated road works

After extraction, friction was tested on the surface of every specimen, and photographs of most of the surfaces were taken for later inspection.

## 3.2 Results

The result of polishing on an asphalt specimen, either by using a machine in the laboratory or by the action of passing traffic, can be observed in two ways. Firstly, the visual appearances of asphalt specimens were compared – if the machine is simulative of the action of traffic polishing, the specimen surfaces (from the same mix) should be similar. Secondly, a correlation between the friction measurements made after each type of polishing was sought – the friction measured after polishing in the machine should be similar (perhaps with some correction) to the friction measured after polishing by traffic.

### *3.2.1 Appearance of asphalt specimens*

The photographs in Figure 3 show the same specimen, one of the duplicates of mix 8 installed in site A, in August 2007 and in August 2008. After 12 months of service the specimen appearance is significantly altered, largely due to the ageing of the bitumen which gradually lightens in colour. On close inspection, some of the individual aggregate surfaces are revealed but there is still bitumen and fine aggregate present on the surface.

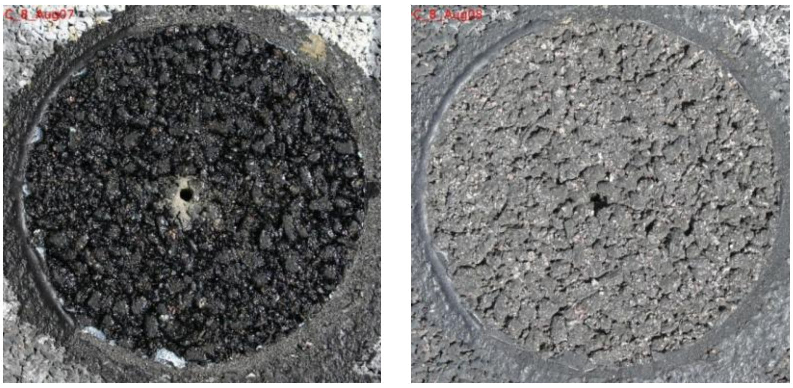

Figure 3 - Photographs of the same specimen, embedded in site A, taken immediately after embedment (left) and after 12 months of traffic

The presence of a residual film of bitumen and particles of the fine aggregate used is easier to see by comparing the surfaces of specimens of mix 14, prepared using limestone coarse aggregate, as in Figure 4. These photographs were taken after the specimens were extracted in August 2010, three years after installation, and it is immediately apparent that the amount of limestone coarse aggregate showing through is proportional to the volume of traffic at the site. For example, there is more limestone visible on the specimen from the more heavily trafficked site A (4500 CVD), shown in the left-hand photograph, than on the specimen from the least heavily trafficked site C (200 CVD), shown in the right-hand photograph.

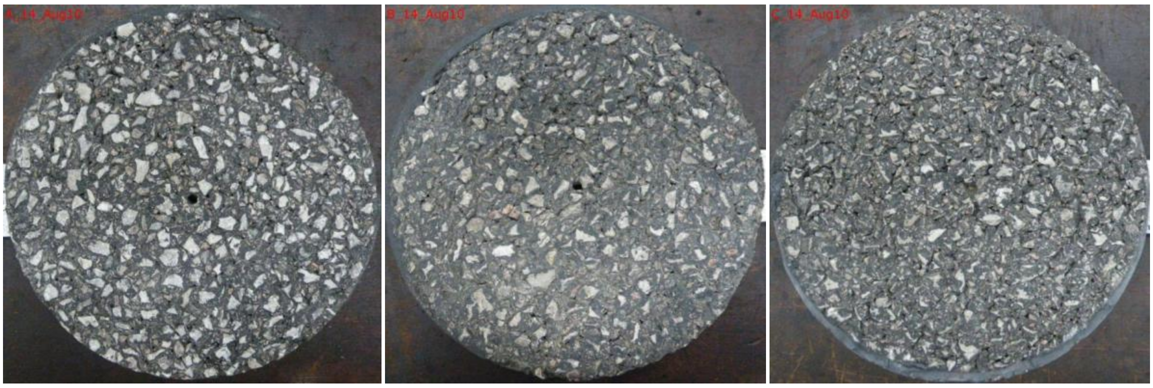

Figure 4 - Photographs of mix 14 specimens retrieved in August 2010 from (left to right) sites A, B, C

The dominant feature of the specimen photographs so far has been the presence or amount of bitumen and fines remaining on the surface. This is also true when comparing the different polishing mechanisms (machine or traffic).

For example, Figure 5 shows the surface of a specimen of mix 14 after testing in the W-S machine using the TUB method. Figure 6 shows specimens of mix 14 after extraction from sites A, B and C in April 2009, after 24 months of trafficking. The bitumen, including some from the sides and edges of the aggregate particles that might not be affected by vehicle tyres, has been removed by the gritblasting stage of the TUB method and the coarse aggregate has been polished smooth; the surface looks similar to the specimens polished by relatively heavy traffic at sites A and B.

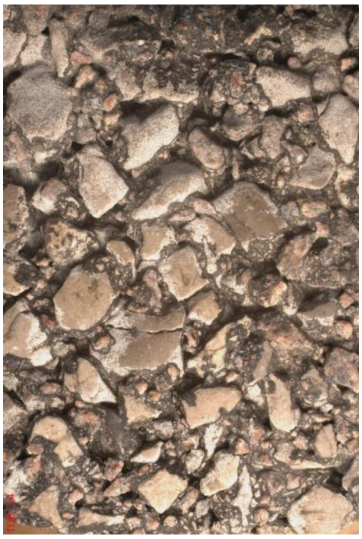

Figure 5 - Photograph of mix 14 specimen polished in the W-S machine

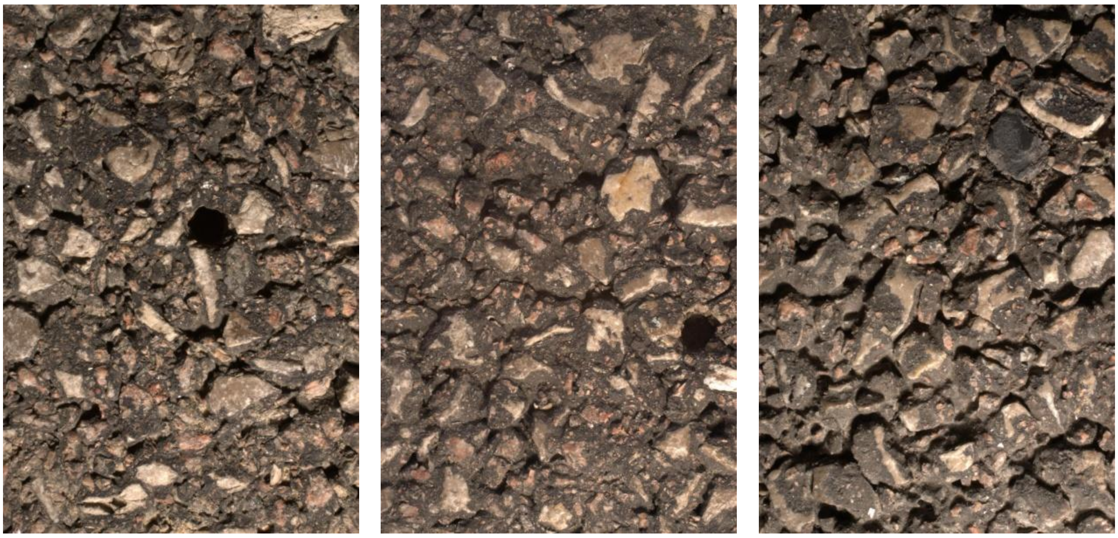

Figure 6 - Photographs of mix 14 specimens after polishing by traffic in site A (left), site B (middle) and site C (right)

### *3.2.2 Friction measurements*

The graph in Figure 7 shows the average friction measured across all specimens retrieved from the three sites on all four occasions. The error bars indicate the range of friction measurements on individual specimens. It is clear that, by August 2010, the average level of friction on specimens retrieved from the site with the lowest traffic (site C) is higher than on specimens retrieved from the sites carrying more traffic. The ranges of measurements made on individual specimens overlap and so a brief statistical analysis was carried out – summarised in the following text. The results should be considered in the context of expected physical phenomena of equilibrium skid resistance and seasonal variation.

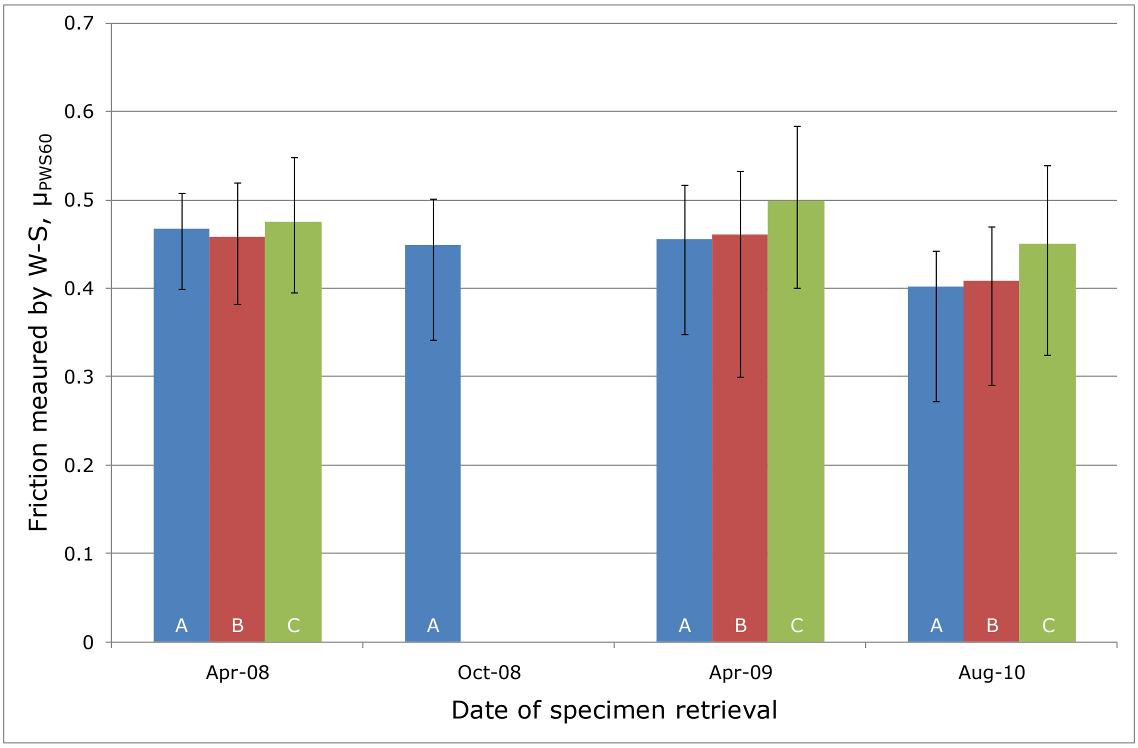


Figure 7 - Average friction on all specimens removed from embedment sites

A statistical test (Student's t-test with paired samples and assumed two-tail distribution) confirms that:

- The equilibrium level of skid resistance on the site carrying less traffic (site C) is higher than on sites carrying more traffic (A and B) but it took longer than eight months to reach that condition (discs were embedded in August 2007)
  - The average friction measured on all specimens retrieved from site A in April 2008 is not significantly different from that measured on specimens retrieved from site C at the same time (probability value 0.16)
  - The average friction measured on specimens retrieved from site A in April 2009 and August 2010 are significantly different from those measured on specimens retrieved from site C at the same times (probability values 0.002 and 0.003 respectively)

- Skid resistance across all sites is higher in the winter than it is in summer
  - The average friction measured on all specimens in April 2008 is not significantly different from that measured on all specimens in April 2009 (probability value 0.38)
  - The average friction measured on all specimens is significantly lower in August 2010 that it is in April 2008 and April 2009 (probability value 0.00 in both cases).

It should be borne in mind that these measurements can only serve as a snapshot of skid resistance condition. However, the observations are consistent with measurements made at other sites and with the expected physical phenomena. It is likely that the levels of friction measured on specimens extracted from site C will never drop, in the future, to the levels of friction currently observed on the specimens extracted from sites A and B, even after the same cumulative amount of traffic has passed. This could be shown using the specimens that remain embedded in that site.

It is possible to demonstrate that the relationship between friction after machine polishing and friction after traffic polishing is dependent on the average daily traffic volume. A similar observation was made by Beaven and Tubey [6] when equivalent work was carried out using the PSV test. The graph in Figure 8 shows friction measured on specimens retrieved in August 2010 from sites A, B and C, against friction measured after testing in the W-S machine with the TUB method. The broken lines are lines of best fit, excluding the measurements made on mix 14 specimens which seem to be outlying points. Although the correlation is not very strong in either case, it is clear that specimens from sites A and B have been polished by traffic to a greater extent than those from site C. This is as expected given the average results presented in Figure 7.

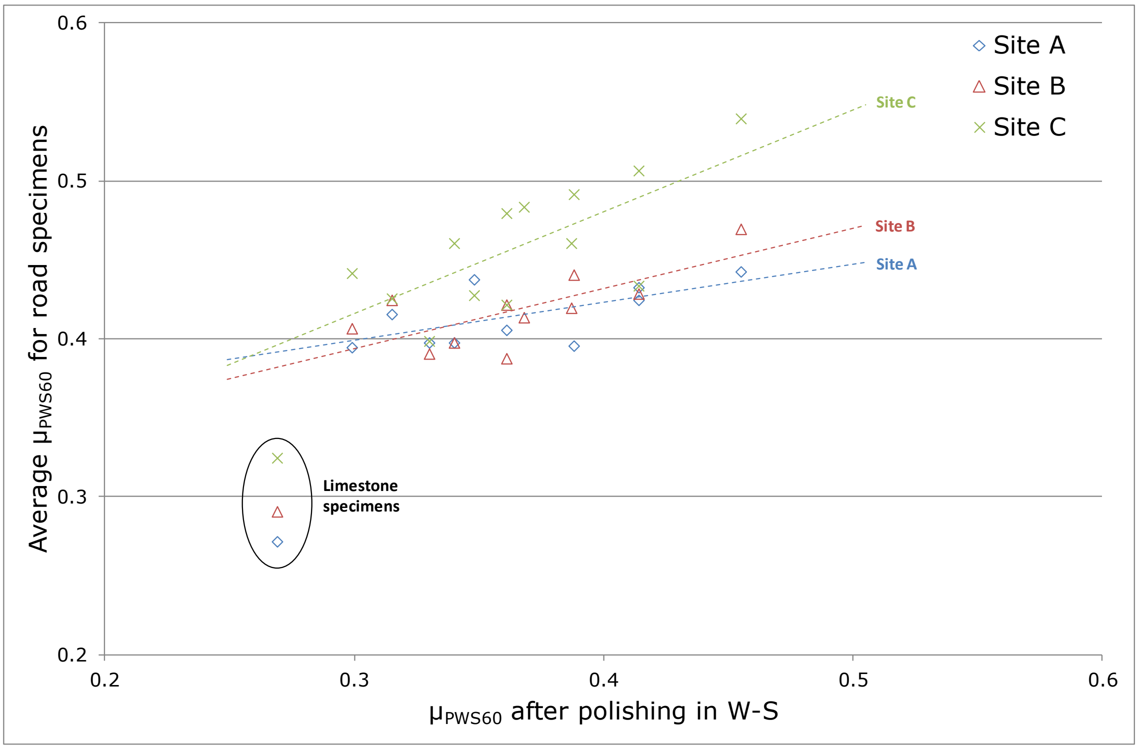


Figure 8 - Relationship between friction on extracted specimens and control specimens

The correlation between friction after polishing by road or W-S machine (TUB method) is improved by use of the average friction measured on all specimens of the same mix retrieved from all three sites, as shown in Figure 9. There is a wider distribution of friction measured on the specimens polished in the machine. This might improve its ability to differentiate between alternative surfacing solutions for non-stress locations.

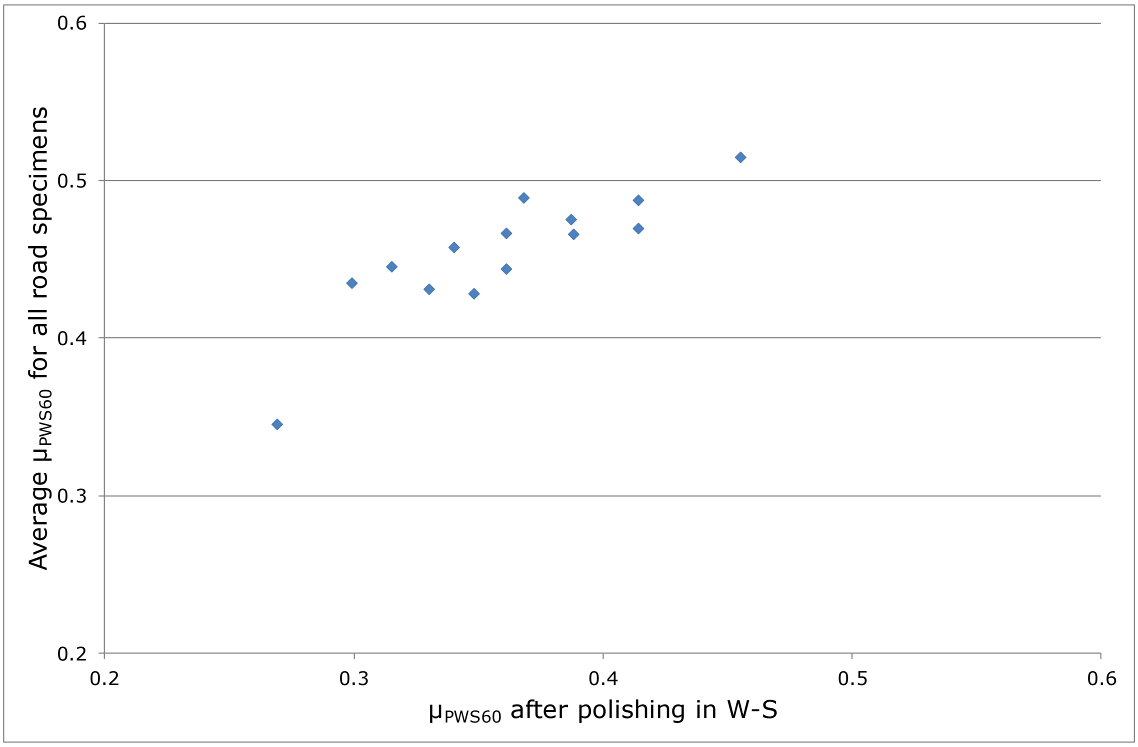


Figure 9 - Average friction on all retrieved specimens vs friction after TUB method

The graph in Figure 10 shows friction after W-S polishing (TUB method) and friction after average traffic polishing, ranked in order of increasing friction measured on the W-S control specimens. Broken lines of best fit (excluding the specimens from mix 14) are shown and it can be seen that, as would be expected given the correlation in Figure 9, a similar rank order is achieved for machine and traffic polishing. So, if one asphalt performs better than another after polishing in the W-S machine, it will probably also give better in-service performance. Assuming that the specimens from the same mix all started with similar friction, it appears that the reduction in friction caused by polishing is much greater in the W-S machine than it is on the road, especially for polish-susceptible materials.

The polishing state, or limit of polishing, achieved in the W-S machine is more severe than at non-event in-service locations even under heavy traffic, especially for those materials that are not resistant to polishing. This work could be developed further by considering locations where polishing by traffic is also harsher, such as at junction, roundabout and crossing approaches or on bends. This could be achieved either by use of the specimen insertion techniques used here or through a long term programme of testing asphalt samples collected during construction of new surfaces for later comparison against in-service performance.

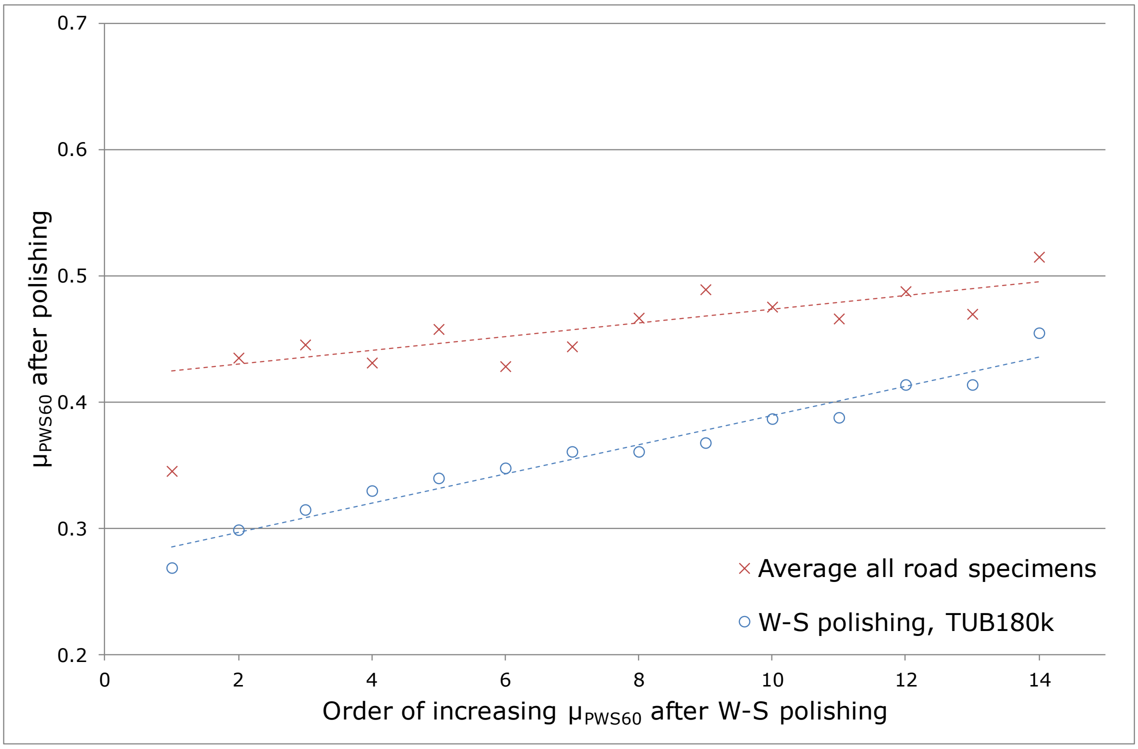


Figure 10 - Friction measurements on specimens polished by W-S, ranked in order of increasing value, and corresponding average friction on all road specimens

# 4. LABORATORY INVESTIGATION OF THE POLISHING PROPERTIES OF AGGREGATE BLENDS

## 4.1 Methodology

Asphalt specimens were made in the laboratory according to a standard specification. The Wehner-Schulze machine was used again to polish and measure friction on a set of specimens made by blending the coarse aggregate constituents.

Four coarse aggregates were used, representing the range of PSV and mineralogical diversity available in the UK; they are shown Table 4, and they will be referred to by the (capitalised) letter code.

Table 4 - Aggregates used in asphalt study

| Aggregate | Rock type | Nominal PSV |
|---|---|---|
| A | Limestone | 39 |
| B | Granite | 53 |
| C | Siltstone | 65 |
| D | Greywacke | 68 |

Asphalt specimens were prepared using guidance for material specifications for Stone Mastic Asphalt (Annex D.3.2 of British Standard PD 6691:2007 [7] with D=10 mm). The target composition limits for aggregates passing various sieve sizes, according to the guidance for SMA materials, are shown in Table 5.

Table 5 - Target aggregate grading for SMA materials

| Sieve size (mm) | Passing sieve % by mass |
|---|---|
| 14 | 100 |
| 10 | 93-100 |
| 6.3 | 28-52 |
| 2 | 20-32 |
| 0.063 | 8-13 |
| Binder content | 6.2 |

Note that it is common to also record the percentage passing sieve sizes 0.25 mm and 0.5 mm, although no target limits are given for these sizes.

Stocks of each aggregate were procured, and these were stored in three nominal fractions: 4/10 mm, 2/6 mm and crushed rock fines (CRF). In addition, limestone filler was used in asphalt preparation throughout. The coarsest two fractions were blended proportionally and crushed rock fines from the aggregate B stockpile were used throughout.

The grading (as delivered) for each of the four aggregates was checked by sampling the three stockpiles for each aggregate and analysing by sieve (proportions passing 20, 14, 10, 6.3, 2, 0.5, 0.25, 0.063 mm sieves). The information was used to correct the amount of crushed rock fines and filler needed in order to achieve the desired asphalt design. For example, the 2/6 mm stockpile of aggregate C contained a slightly greater proportion of 0.5/2 mm size particles than the 2/6 mm stockpile of aggregate B - a blend of A and C would therefore require less crushed rock fines than a blend of aggregates A and B. A more accurate blend might have been achieved by further grading of the aggregate stockpiles, but this process would have been laborious given the small effect on the skid resistance expected.

Although additional information about binder demand was provided by the quarry owner for each of the aggregates, it was found that an element of trial and error experimentation was required before a satisfactory result was achieved – primarily by alteration of the amount of filler used. To do this, small batches were prepared using a table-top mixer. When the asphalt design had been finalised, enough asphalt was mixed (according to EN 12697-35:2004 [8]) to fill one or two 300 mm square moulds to 50 mm depth. Table 6 shows the percentage proportions, by mass, of the constituent parts of a 50/50 % blend of aggregates A and C.

Table 6 - Example of asphalt made with 50/50 blend of aggregate A and aggregate C

| Fraction | Aggregate | Percentage by mass | Mass required per mould (g) |
|---|---|---|---|
| 4/10 mm | A | 35 | 3,740.0 |
| | C | 35 | 3,740.0 |
| 2/6 mm | A | 2.5 | 267.1 |
| | C | 2.5 | 267.1 |
| CRF | B | 13.5 | 1,442.6 |
| Filler | Limestone | 11.5 | 1,228.9 |
| Total aggregate | | 100 | 10,685.8 |
| Binder | | 4.9 | 550.6 |

The asphalt was compacted (according to EN 12697-33:2003 [9]), using a Cooper steel roller compactor, and cores were cut from the asphalt slabs to provide a 225 mm diameter disc of asphalt that could be tested in the Wehner-Schulze machine. The asphalt discs were gritblasted to remove excess bitumen and then subjected to 1 hour of polishing in the Wehner-Schulze machine before the friction on each surface was measured.

## 4.2 Results

The first set of single coarse aggregate specimens was made in duplicate so that future comparisons could be made against an average value rather than relying on the accuracy of a single test. Measurements of friction on these specimens, after polishing, are shown in Figure 11 (columns in the background) along with the average friction for the pair of specimens.

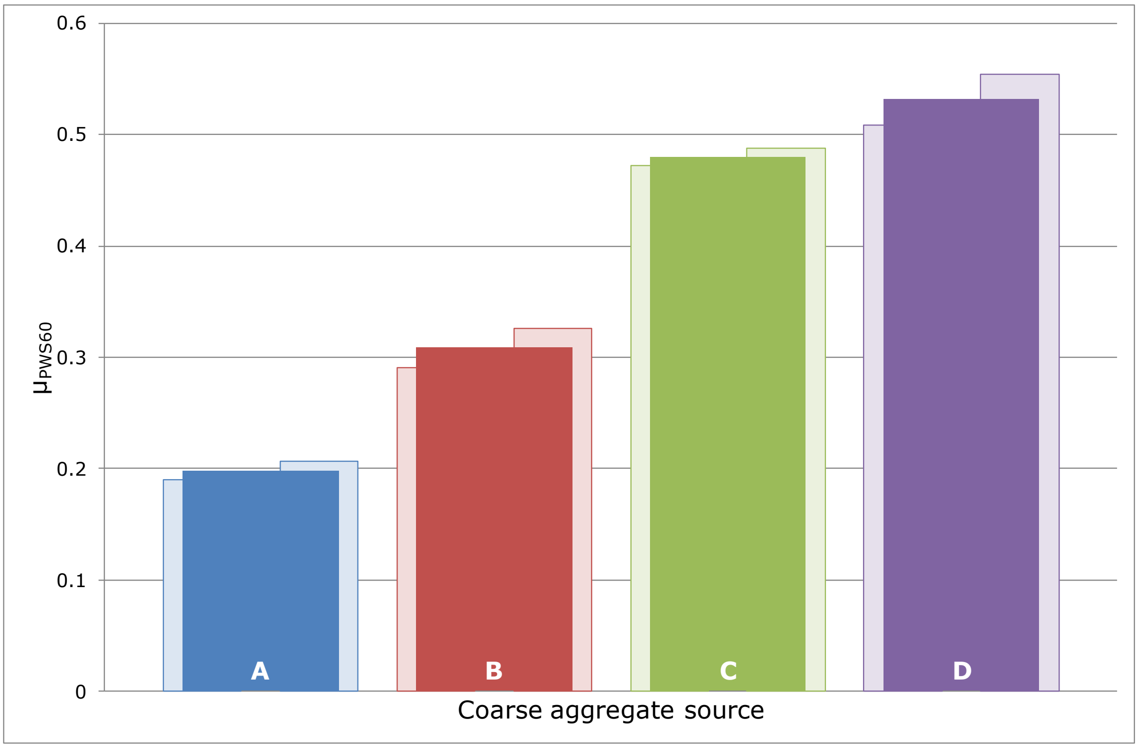


Figure 11 - Friction measurements on 100% asphalt specimens

The graph in Figure 12 shows friction measurements made on the blended asphalt specimens against the friction calculated for the same specimens, using the mass ratio formula shown. The broken line drawn on the graph is a line of unity. The error bars give an indication of the repeatability of the test – 0.05 for this type of specimen [2] – but a detailed analysis of the errors involved has not been performed.

It should be noted that these results will not necessarily follow for other asphalt types, such as hot rolled asphalt and or surface dressings, because it may be more difficult to achieve a homogeneous surface when blending the coarse aggregates.

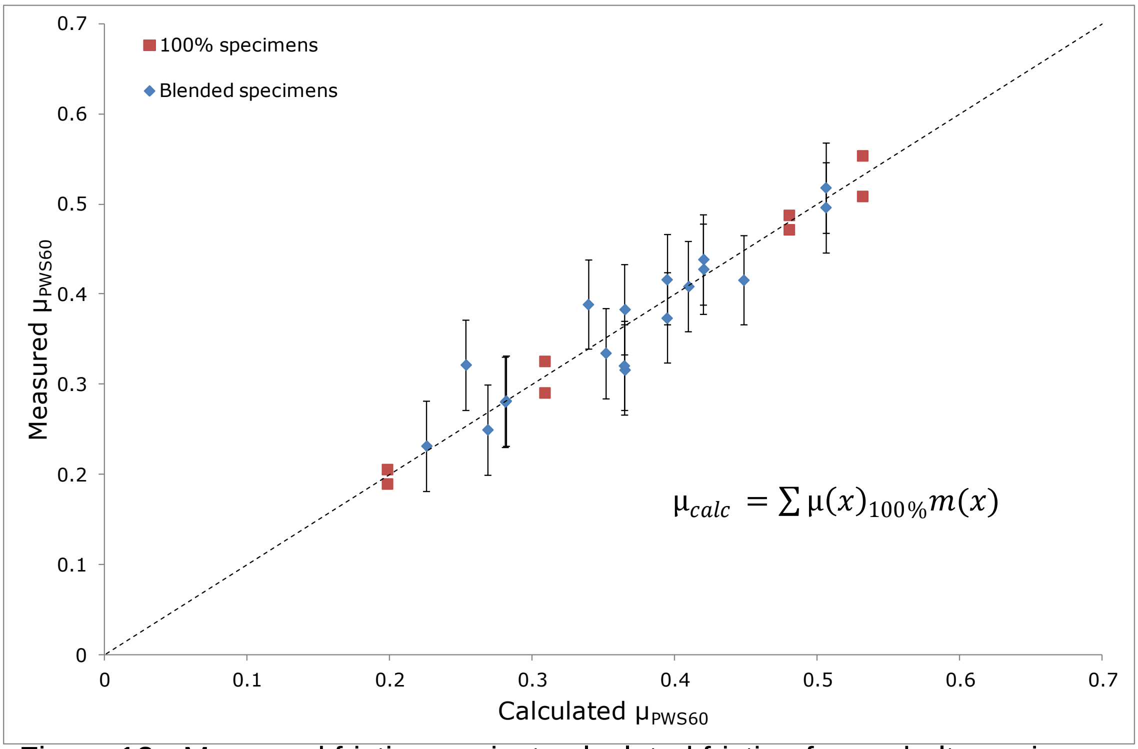

Figure 12 - Measured friction against calculated friction for asphalt specimens

## 5. CONCLUSIONS

This study has shown that friction measurements made after polishing by traffic correlate well with friction measurements made after polishing by the Wehner-Schulze machine. Polishing applied by the machine does not directly mimic polishing by traffic at non-event locations: rather, it is more severe and results in lower friction. It has not been possible to compare polishing in the machine with polishing caused by more severe traffic loading, as on roundabout or junction approaches.

The Wehner-Schulze machine has considerable potential for use as a tool in quick and practical investigations of the properties of asphalt and asphalt constituents. An experiment summarised in this paper demonstrates that the skid resistance provided when two aggregates are combined, when they are the coarsest constituent of a standard stone mastic asphalt (SMA) mix, can be predicted using the skid resistance of the individual aggregates and a mass ratio formula. It is suggested that blending of this kind might enable better use of local resources when designing a new surface course to current specifications.

The Wehner-Schulze machine will become increasingly valuable as natural resources dwindle and demand for sustainable, innovative, road surface construction intensifies.

## 6. ACKNOWLEDGMENTS

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