THE PAFV TEST AND ROAD FRICTION

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Abstract

In Australia, the measurement of aggregate polishing values can be obtained from either using a horizontal testing wheel / flat mould system as developed and applied to polished aggregate friction value (PAFV), or a vertical testing wheel / curved mould system as developed for polished stone value (PSV) and applied to Australian PAFV. What caused this to happen, and does it really matter?

Meanwhile, there is continuing debate overseas regarding the limitations of the PSV test. It has been postulated that PSV is only a ranking method dependent on the stressing conditions imposed during the test, and that PSV provides some indication of on-road skid resistance performance of an aggregate but surfacing type and aggregate source may be a more important indicator. Is it time for a new test?

This paper summarises the results of a literature review into these issues.

Keywords: polished stone value, polished aggregate friction value, skid resistance, aggregate

1 Skid resistance

Current skid resistance monitoring programs and investigatory limits used in Australia are based on systems developed in the U.K. where the climate, traffic intensity, network configuration and resourcing is very different. These do not necessarily suit Australian conditions and have high cost implications in terms of monitoring and maintaining surfaces if at inappropriately high skid resistance levels. This paper summarises the result a literature review into a selection of these issues.

2 PAFV or PSV?

When beginning to understand Australian skid policy and practice to some depth, the background of polished aggregate friction value (PAFV) and polished stone value (PSV) testing needs to be clarified. Confusion can arise in Australia from the historical issue of using either a horizontal testing wheel / flat mould system as developed and applied to PAFV, or a vertical testing wheel / curved mould system as developed for PSV and applied to Australian PAFV.

An aggregate's resistance to polishing is measured by performing a pendulum friction test on laboratory-polished pieces of aggregate. (Interestingly, the measurement scale used on the pendulum is different to many scales used for in-service skid resistance tests.)

The Australian Standards relevant to polishing of aggregates are:
• AS 1141.40-1999: Methods for sampling and testing aggregates – Polished aggregate friction value – Vertical road-wheel machine

• AS 1141.41-1999: Methods for sampling and testing aggregates – Polished aggregate friction value – Horizontal bed machine

• AS 1141.42-1999: Methods for sampling and testing aggregates – Pendulum friction test.

The first two standards describe two alternative methods for accelerated polishing of aggregates in the laboratory, using coarse and then fine abrasive materials to wear away (polish) the aggregate’s microtexture. These two methods are briefly outlined in 3 and 4 below. Following polishing by either method, the third standard is used to determine the friction value of the resulting polished aggregate using a pendulum friction test. Depending on the test method used, this value is then reported as the PAFV or PSV of the aggregate.

3 Development of the vertical-wheel polisher and PSV test

This British introduction is found in Hosking (1992):

After the 1939-1945 war the large increase in motor vehicles and higher traffic speeds gave additional impetus to the need to study the relation between road materials and the skid-resistance of roads. In 1952 an accelerated wear machine was constructed by the Road Research Laboratory to study the 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, and that the machine showed promise as a method of studying the polishing action of traffic.

This British accelerated wear machine tested aggregates set in mortar around the rim of a vertical wheel, and against the tread of a pneumatic tyre. By 1957 it had become the basis for testing aggregate resistance to polishing. After wearing, the extent of polish 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 sideways-force coefficient (SFC) at 30 mph of surfacings when wet. This led to the development and adoption in 1958 of the polished stone coefficient (PSC).

Not long afterwards these polished stone coefficients were multiplied by 100, to avoid confusion with SFC, with the results of the test then being expressed as polish stone values (PSV). This amended accelerated polishing test was then published by the British Standards Institute as BS 812:1960.

In 1965 changes to the test procedure (replacing the pneumatic tyre with a solid tyre) led to a general reduction in PSV of approximately 10%.

By the early 1970s, BS 812 (PSV) testing had been adopted by a significant portion of the Australian industry, with the test now spread through the world (Mastrad Limited 2009), and retained in subsequent revisions of British Standards BS 812 through to the current day.
Figure 1: PSV polishing machine

Figure 2: PSV vertical wheel

4 Development of the horizontal-bed polisher

A record of the early days of Australian laboratory polishing of aggregate experiments in NSW can be found in West and Ross (1962). The problem of skid resistance became ‘noticeable’ in Sydney by about 1956, as ‘traffic densities had increased considerably’. At the time, no standard apparatus or test method was available to test road surfaces and materials for skid resistance properties. The Department of Main...
Roads, NSW, therefore commenced an investigation into methods of measuring slipperiness and selecting appropriate materials for remedial treatments. Part of the investigation was to develop equipment to a) determine the coefficient of friction, and b) to simulate the polishing action of traffic.

Due to difficulties in procuring from overseas a Road Research Laboratory (British) pendulum tester, the Department built their own pendulum device patterned on the Sigler pendulum apparatus of California, and much later this was correlated with a Road Research Laboratory pendulum tester.

To polish aggregates in a laboratory, a specimen of road surface was initially applied to a revolving car wheel. This method was then adapted to include a rotating table to hold the road specimens, and two 8½ in. diameter semi-pneumatic rubber wheels to traffic the specimens. A correlation exercise was held whereby similar specimens were placed in a heavily trafficked (10,000 vpd) lane of the Sydney Harbour Bridge approach, giving acceptable results.

By 1962, this device was being used by DMR NSW as the standard method for artificially polishing aggregates, and was known as Test T233 (RTA 2001).

Yeaman (1976) later calibrated the DMR ‘West and Ross machine’, and Test T233, against the Accelerated Polishing Machine of the British Standard 812 and reported no differences in the polishing results between the two mechanisms.

This horizontal bed equipment developed for the DMR by West and Ross was also found to be useful in artificially polishing asphaltic concrete (AC), and the DMR used samples from the 150 mm diameter Modified Hubbard Field Test as polishing test specimens (Yeaman 1976).

Source: AS 1141.41 – 1984 (superseded)

Figure 3: Horizontal bed machine
Development of the Australian PAFV test

While the DMR NSW was continuing with this work, most other Australian states chose to adopt the British BS 812 vertical wheel polishing machine, as developed for PSV.

Although the British PSV machines were used, the accompanying British reference stone, grit and tyres were expensive to procure in Australia, and alternative Australian reference stone, grit and tyres that most closely reproduced the results of their British counterparts, were chosen.

Even so, it appears that by the mid 1970s there was still no specific Australian Standard for laboratory polishing of aggregate. Eventually a Standards Committee was charged with the task of drafting such a standard - but by then most states had adopted BS 812 (PSV) machines, and NSW was committed to the flat bed DMR test T233 machine.

As Australian Standards are consensus documents, the resulting AS 1141 - 1984 Methods for sampling and testing aggregates, contained both AS 1141.40 Laboratory testing of aggregate using the vertical road-wheel machine, and AS 1141.41 Laboratory polishing of aggregate using the horizontal bed machine.

It should be noted that the polishing regimes in AS 1141.40 and AS 1141.41 were specifically designed to give results that were comparable between the two methods.

However, there are differences between the PAFV test and PSV test, including the coarse abrasive, water and abrasive feed rates, polishing time, reference aggregate and rubber for friction testing. Therefore PSV and PAFV results may not be directly comparable.

A 1995 internal study by an Australian jurisdiction suggested the following relationship may exist between PAFV and PSV:
PSV = 1.28 * PAFV – 12.3

however this relationship was based on a very limited sample size.

![Graph showing possible relationship between PSV and PAFV](image)

Source: Private correspondence

**Figure 5:** Possible relationship between PSV and PAFV

More recently, another Australian jurisdiction commenced a comparison exercise between vertical wheel and horizontal bed PAFV - not PSV- testing and could not find a direct comparison, to the point where they are reluctant to change methods for fear that their historical database could become less meaningful (Private email, 2009).

In summary for Australia, only VicRoads imports and uses the British reference aggregate and grit in lieu of the Australian, and produces true PSV results. The rest of Australia produces PAFV, some with horizontal bed testing and some with vertical wheel testing, although the results from all three methods were originally intended to be roughly comparable.

6 PAFV/PSV relationship with on-site friction

How does a laboratory test that polishes hand made test samples, compare with the real life skid resistance situation of a road surface under traffic and climate?

Szatkowski and Hosking (1972) set out to determine the relationship between the SCRM's sideways friction coefficient (SFC), traffic and PSV using a regression analysis technique. A survey of SFC measurements was carried out for the years 1969 and 1970 and suitable sites were selected for inclusion in the study. These sites were either sprayed seals or hot rolled asphalt. Each SFC used in the analysis was an average of the mean summer values recorded on three consecutive years. Altogether 159 different sections were included.

Multiple regression yielded the equation

\[ SFC = 0.024 – 0.663 \times 10^{-4} q + 1 \times 10^{-2} PSV \]
Where q is the traffic flow in commercial vehicles per lane per day and PSV is the PSV test result for the aggregate. This relationship is shown graphically in Figure 6 for a PSV range of 45 to 65 units.

![Figure 6: Skid resistance achievable on sprayed seals and hot rolled asphalt with aggregate of given PSV under different traffic condition](image)

Traffic levels increased following the original TRL work and subsequently there was concern that the expected performance was not being achieved in practice. A further investigation was therefore carried out by Roe and Hartshorne (1998).

This second study found that the previous model did not adequately reflect in-service performance for skidding resistance under 1998 conditions. There was clear evidence that the same aggregate on the same road could give different performance with a change in traffic behaviour such as braking approaching a slip road. It appeared, therefore, that site category could be important in determining skid resistance.

Their findings, for site category: Band 1 (Traffic light controlled intersections, pedestrian/school crossings, railway level crossings, and roundabout approaches), and site category: Band 3 (Intersections), are shown in Figure 7. SCRIM values are in terms of the Mean Summer SCRIM Coefficient at 50 km/h (MSSC).
Figure 7: Predicted MSSC for different PSV levels and two IL bands

In Australia, MSSC units are not used since SCRIM readings are not corrected for seasonal effect or to correspond with measurements made in the U.K. between the years 1963 and 1972 as is done in the U.K. and New Zealand (Oliver and Halligan 2006).

The debate regarding the limitations of the Polished Stone Value (PSV) test still continues in the UK. It has more recently been postulated that that PSV provides some indication of on-road skid resistance performance of an aggregate, but surfacing type and aggregate source may be a more important indicator.

Woodward, Woodside & Jellie (2005) in Northern Ireland continued with earlier research that indicated the standard PSV test is a ranking tool for a given set of laboratory conditions, but the aggregate skid resistance is dependent on other test conditions related to in-service conditions. They identified in-service conditions as a complex interaction between factors such as: differences in rock-type; change in properties such as strength, soundness and skid resistance during engineering life; variation in the contribution of properties such as strength depending on mix type, variation in traffic induced stressing on properties such as load transfer or polish resistance; adhesion to bitumen; and the presence of moisture at the aggregate / bitumen interface. They consider that these in-service conditions may be better judged by testing aggregate properties such as strength, abrasion and durability.

The concluded that ‘this is particularly important for countries that either currently do not have higher PSV aggregate sources, who are looking for higher PSV sources, or who are interested in using or specifying higher PSV aggregates’.

In addition, the standard PSV test is carried out on 10 mm aggregate. However, this is not the main aggregate size in most asphalt mixes. They then undertook work which showed a general increase in skid resistance with reducing particle size.

In 2006 in the UK, Dunford undertook an experiment to compare the polishing performance of different aggregates with similar PSVs. The starting premise was that aggregates with similar PSVs may polish in different ways in the road, and that by knowing this, road trials are sometimes used to predict performance with greater certainty. Dunford investigated the use of the Wehner Schulze machine as a surrogate for road trials. One interesting outcome was that one sample with a high polished resistance was easily crushed, and under repeated friction testing results continued to decrease considerably. It was concluded that versatility of the Wehner Schulze machine gave it a key advantage over alternative testing methods (Dunford 2008).

In New Zealand, Wilson (2006) demonstrated that a higher published PSV aggregate did not necessarily lead to a higher initial skid resistance value as measured in the field by a Griptest, nor did it necessarily reflect the level of ‘field’ polishing (Wilson and Black 2008). Wilson asserted that these results corroborate the NZ research of Cenek et. al. (2004) that showed poor relationship between an aggregate’s PSV, and the in-field skid resistance as measured by SCRIM.

Wilson and Black (2008) then worked on developing a new accelerated polishing method, and concluded that the PSV test can not reliably be used as a predictor of the initial skid resistance of an aggregate, nor of the level of any equilibrium skid resistance after polishing.
Clarke, Mortimer and Robinson (2008) point out that from their New Zealand work the PSV test is a measure of relative polishing potential between one aggregate and another, but it is not necessarily a good predictor of in-service performance.

Also in New Zealand, Cenek, Davies, & Henderson (2008) reported that skid resistance issues tend to drive road surface maintenance, and this has increased annual maintenance expenditure by approximately five times. One reason put forward for this over-expenditure is that countries over-reliance on aggregate Polished Stone Value (PSV) in meeting New Zealand’s skid resistance investigation and treatment selection specifications. The authors claim that studies have shown that ‘different aggregates with the same PSV provide a range of skid resistance levels in practice’. The authors then undertook their own study to determine whether aggregate source (being the name of the quarry) was a better measure of in-service skid resistance rather than PSV. This would then hopefully group mineralogical properties, stone hardness and stone shape, and even crusher type.

By using statistical modelling of site measured equilibrium SCRIM coefficient values, they found that the categorical variable of ‘aggregate source’ was highly statistically significant, and in fact a better indicator of in-service skid resistance performance than the quantitative variable of ‘PSV’.

In the UK, Anderson (2008) maintains it is possible to get higher skid resistance with lower PSV. He argues that PSV does not necessarily assist in any resistance to polishing of the overall mix, and mix properties other than PSV are very important in establishing and maintaining good skid resistance.

In summary, there is a substantial body of work, that suggests that PSV as the stand-out aggregate test for skid resistance is falling short under the closer scrutiny of the current road operating climate.

7 The Wehner Schulze Test

The specifications that support the UK skidding standards are essentially based on the hot rolled asphalt (HRA) with pre-coated chippings, and surface dressing materials that were traditionally used on that network. Hot rolled asphalt is not in use in Australia, and is of little relevance here.

However, in recent years different types of asphalt mixtures – the so-called “thin surfacings” – have become more widely used, and in the UK are the first choice for new surfacings on trunk roads where their reduced tyre/road noise and speed of laying bring advantages. It has been found that it is less easy to make these materials comply with current specifications, particularly in relation to texture depth.

Particularly, their shape and form of texture could mean that these materials develop better skid resistance for a given level of polishing resistance. This then raises the possibility of greater flexibility of aggregate choice in some situations.

Allen, et. al. (2008) report that the PSV test was originally developed in the 1940s and became a UK specification requirement in 1976, whereas the Wehner Schulze test method was developed during the 1960s by Wehner and Schulze at the technical university of Berlin and now has wide acceptance in Germany.

As indicated earlier, the greatest attraction of the Wehner Schulze method was originally that it tests samples that are of the actual surfacing, not individual aggregate...
pieces, and these can be either laboratory produced or field cored. The sample
diameter is also the same as that of the Circular Texture Meter.

Source: ARRB

**Figure 8:** Various Wehner Schulze test samples

Source: Dunford (2008)

**Figure 9:** Wehner Schulze machine layout

The samples to be tested are polished with rotating polishing rollers on the left hand side workstation, and then friction is measured with rotating pads on the right hand side workstation.

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Ledee, Delalande and Dupont (2005) examined the Wehner Schulze test from the French point of view. One advantage they is that the friction measurement after polishing remains independent of the British pendulum, and is performed by sliding pads that rub the surface and are connected to a force sensor. This system enables greater accuracy than the traditional PSV test, and in addition wearing course samples cored from pavements can also be tested.

Still in France, Do et al. (2007) of the Laboratoire Central des Ponts et Chaussées (LCPC) comment that despite the PSV test popularity, it cannot be adapted to asphalt mixes because of the bent shape of specimens. They investigated the Wehner Schulze method using the French LCPC procedure, and concluded that not only could the results be correlated with PSV, but results were far more accurate and could include samples taken from the field.

In England, Roe & Caudwell (2008) accept that the polished stone value test has its limitations and alternatives that might provide an even better ability to predict performance and help select the most appropriate aggregates continue to be considered. They identified the Wehner-Schulze test, which is now becoming more widely considered outside Germany with the availability of commercially-produced test equipment, as a possible alternative.

The Highways Agency purchased this test equipment in 2006 for initial evaluation at TRL and is pursuing a program of research to establish whether the test could have a role in relation to materials specifications, in support of the skidding standards in the UK. In conjunction with this the TRL is also working with the UK asphalt industry through the Quarry Products Association, in using this equipment to assess new types of surfacing materials or aggregate sources.

Roe & Caudwell (2008) conclude that if this work shows that the new test has a role in the UK, then there will be the challenge of introducing it into routine use, whether for source approval or verification of material compliance. Potentially, this could involve the development of predictive models that can be used to prepare modified specifications, introduction of additional test facilities and quality management.

Because of growing opinion that the performance of aggregate in roads is not sufficiently characterised by the PSV test, the TRL undertook in situ trials on an aggregate that was a candidate for extensive use in a road network (Dunford 2008). Dunford concluded that the capability of the Wehner Schulze machine to test asphalt mixtures (both laboratory-prepared and paver-laid) as well as crushed, uncoated aggregate is a key advantage of the machine over alternative testing methods. Research into the capabilities of the machine is ongoing.

Allen et al. (2008), also undertook a comparative evaluation of the PSV and Wehner Schulze test methods for a range of UK asphalt mix and aggregate types. Their work concluded that by assessing the asphalt mix, the Wehner Schulze test is questioning traditional UK assumptions of what contributes towards optimising the skid resistance properties of asphalt surfacing materials.

8 Seasonal variation

The traditional PSV test, along with many other stone polishing tests, have a limitation in that they do not allow for the effects of roughening of the aggregate and restoration of microtexture, as observed in seasonal variation.
Research in New Zealand has identified this omission. Wilson (2006) undertook a literature review of the various options available for polishing, testing and analysing pavement surfacing friction properties in the laboratory. From a shortlist of 4 devices, he chose to adapt the National Centre for Asphalt Technology (NCAT) ‘slab polishing machine’ developed in the US to specifically wear samples at an appropriate diameter for the dynamic friction tester (DF Tester).

![Wilson’s accelerated polishing machine](image1)


**Figure 10:** Wilson’s accelerated polishing machine

To examine and simulate the ‘approximately seasonal’ variation of measured skid resistance required two stages of laboratory testing, being:

- Stage 1: Polishing the prepared surface samples to Equilibrium Skid Resistance (ESR) level; and
- Stage 2: Simulating the cyclical effects of variation of the summer and winter polishing, rejuvenation of surface samples through the effects of contaminants, rainfall and vehicle trafficking.

![Stages of accelerated polishing](image2)


**Figure 11:** Stages of accelerated polishing
Samples treated as above were then tested with the DF tester. Wilson reports that the results of this laboratory work demonstrated degrees of variation similar to those shown at field sites under normal heavy traffic. He summarised his main findings under the following categories:

Polishing to an Equilibrium Level:
- The accelerated wet polishing of aggregates (without any contaminant additions) can polish natural aggregates to an ‘equilibrium skid resistance level’ (ESR);
- The level of polish achieved at ESR does not specifically relate to the Polished Stone Value (PSV) results.

The Addition of Contaminants with Accelerated Polishing:
- Significant variations (both increases and decreases from ESR) in measured skid resistance can be simulated in the laboratory by the addition of various contaminants;
- The significant variation in measured skid resistance observed in the field is intrinsically related to the geological properties of the aggregates themselves and the contaminants that end up in the macrotexture of the surfacing.

Geological Properties of Aggregates (Grain Size and Hardness):
- Contaminants that are fine in size (less than 10μm) and that consist of hard minerals (e.g. emery powder) polish the aggregate surfaces, thereby reducing the measured skid resistance;
- The amount of decrease in measured skid resistance that is achieved on a specific aggregate depends upon the difference in hardness and the geological makeup of the contaminants and the aggregate surface being polished (the greater the difference, the greater the decrease in skid resistance)

Once again, the traditional PSV/PAFV test is found to be not as comprehensive as some would expect, and an alternative has been investigated.

9 Conclusion

The PSV test, from its beginnings in the 1950’s, has remained a relatively simple and uncomplicated test, whilst the skid resistance environment that we face now is evolving to become far more sophisticated.

The debate regarding the limitations of the Polished Stone Value (PSV) test still continues in the UK. It has been postulated that the PSV test is only a ranking method dependent on the stressing conditions imposed during the test. Limitations have also been raised in New Zealand and Ireland. On the other hand the Wehner Schultze method is dominant in Germany, may well be accepted by France, and is being considered in the UK.

Another possibility is that polishing tests should become sophisticated enough to include seasonal variation.

Australia needs to be aware of this debate and become more actively involved in it, particularly if aggregates of high PSV value become more difficult or expensive to source.
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