High speed friction of thin surface course systems

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ABSTRACT

An in-depth study to investigate the effect of using smaller aggregates in thin surface course systems was started in 2004. A number of trial sites were set up on in-service roads and TRL monitored low- and high-speed skid resistance, as well as texture depth, to compare the performance of three different aggregate sizes. The programme provided a sound foundation for revision of specification requirements and made recommendations for development of a high speed friction criterion. Subsequent research for the Highways Agency, in consultation with industry stakeholders, has showed that a type approval trial for high speed friction may be suitable for use in place of a requirement for texture depth. A performance specification such as this has the potential to drive product innovation and sustainability by targeted improvement of surfacing durability.

The paper will summarise results from site testing and present the proposed high speed friction criterion.

1. INTRODUCTION

The friction between a vehicle's tyres and the road surface falls with increasing speed and the texture depth of the road surface affects the extent of that fall (Sabey, 1966). Texture depth has also been shown to be linked to accident risk (Roe, Webster, & West, 1991) and, in particular, the combination of low skid resistance and low texture depth has been associated with a higher accident rate (Parry & Viner, 2005). Since it is not practical to measure high speed friction on a routine basis, texture depth has been used as a proxy for it, leading to the requirement for the texture depth of surfacing materials used on high-speed roads.

However, work carried out by TRL as part of a collaborative programme of research, sponsored by the Highways Agency (HA), Mineral Products Association (MPA), and Refined Bitumen Association (RBA), showed that proprietary thin surface course systems with relatively small coarse aggregate provided good high speed friction despite having lower texture than would normally be accepted (Roe & Dunford, 2012).

Clearly, texture depth alone is inappropriate as a surrogate for high-speed performance in these cases. To make best use of their properties, while excluding small-aggregate and low-textured materials that may not perform acceptably, a strategy is needed to enable new small-aggregate materials to be assessed and certified for use on high-speed roads. It has been proposed that this should be achieved by incorporating a specific requirement for such materials based upon the outcomes of a Type Approval Installation Trial (TAIT), in which high-speed friction performance will be assessed.

This paper summarises the findings of the collaborative research programme and describes further work that sought to develop and evaluate a suitable methodology for the assessment of high speed friction (Brittain & Viner, awaiting publication).

2. HIGH SPEED FRICTION AND SMALL AGGREGATES

All high speed friction testing carried out during the collaborative research programme, and for the further study, used the Highways Agency's Pavement Friction Tester (PFT), shown in Figure 1. The PFT is a locked-wheel friction tester capable of measuring the friction generated between a pavement surface and a standard ASTM test tyre at speeds up to 120 km/h. During a test, the towing vehicle maintains a constant test speed while the trailer mounted test wheel is forced to lock for a short interval before being released. Whilst testing, the load and drag forces on the test wheel are measured every 0.01 seconds throughout the braking cycle.

Two values are derived from the force measurements: peak friction and locked-wheel friction. Peak friction is the highest value obtained before the wheel locks and locked-wheel friction is the average friction recorded over a 2 second period once the test wheel has locked and is sliding over the surface. The two values represent, respectively, the maximum braking/cornering potential on surfaces for vehicles that do not skid and the friction experienced by vehicles that do skid.

Figure 1 HA Pavement Friction Tester

The expected relationship between friction and speed is demonstrated by the graph shown in Figure 2: as test speed increases, friction decreases. Each point on the graph represents an individual skid, and points representing repeat tests are grouped about each of four target speeds. The trend curve is calculated using a least-squares regression. In theory, the trend for decreasing friction with increasing speed is expected to be steeper on surfaces with low texture depth.

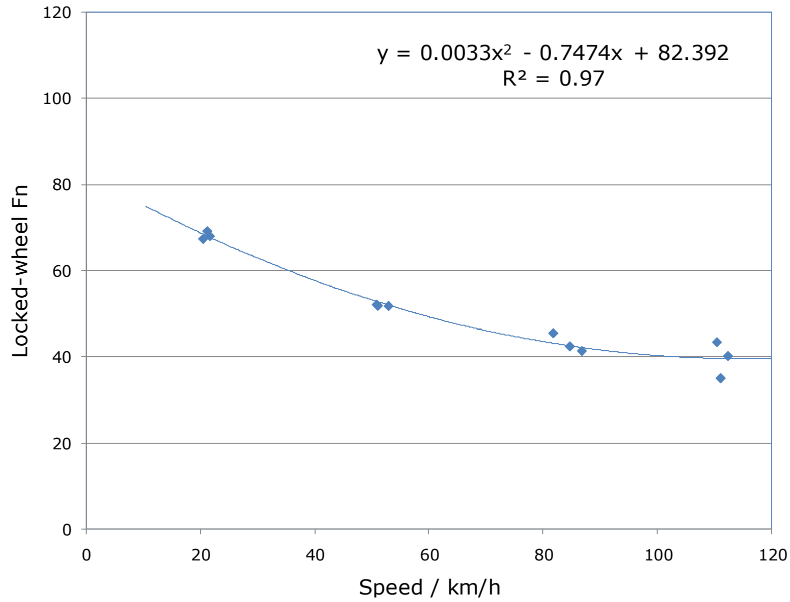

Figure 2 Example of a friction/speed curve

This theory was supported by the study reported in TRL367 (Roe, Parry and Viner, 1998), in which measurements of high speed friction were made using the PFT on over 100 sites deliberately chosen to provide examples of a wide range of surfacing types and textures. The work showed that at texture depths (measured as SMTD) above about 0.8 mm, increased texture depth did not improve high-speed performance but, below this level there was a marked tendency for high-speed friction to decrease as texture decreased.

Trial sites were set up for the collaborative programme comprising sections of various proprietary thin surface course systems. At each site, the sections used coarse aggregate from the same source but in different sizes: 0/6 mm, 0/10 mm and 0/14 mm. Measurements of friction and sensor measured texture depth (SMTD) were made on the trial sites over the course of the research programme. Values for locked-wheel friction at 20 km/h and 100 km/h (representing low- and high-speed friction respectively) from the various trial sections have been plotted over comparable data used in TRL367. Separate graphs for the 0/6 mm, 0/10 mm and 0/14 mm sizes are shown in Figure 3.

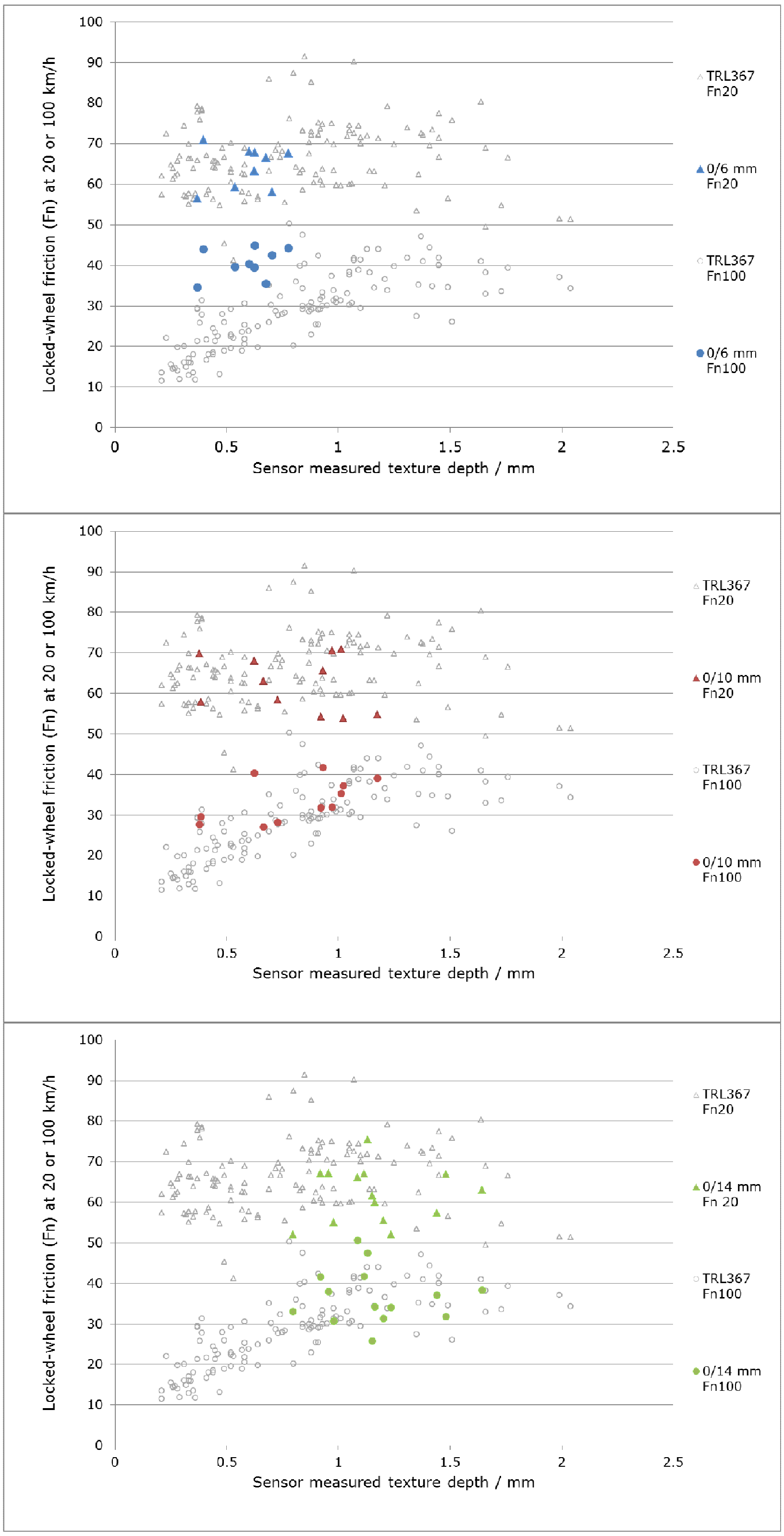

Figure 3 High- and low-speed friction against texture depth (SMTD): comparison of trial site data with historic data from TRL367

The 0/10 mm and 0/14 mm materials broadly follow the pattern of the historic data but the 0/6 mm materials do not. High speed friction (Fn100) on 0/6 mm materials is markedly higher than would be expected of surfacings with similar levels of SMTD and on a par with higher-textured materials. There is no obvious explanation for this uncharacteristic behaviour and various mechanisms and possibilities were explored in the laboratory within the scope of the collaborative research (Roe & Dunford, 2012).

The laboratory studies demonstrated that current techniques for assessing texture depth do not satisfactorily characterise the high speed performance of surfacings made with smaller aggregates. It was therefore recommended that future skid policy should include provision for direct in-service monitoring of high speed friction, and that a methodology for Type Approval Installation Trials (TAITs) should be developed. It should be noted that, although it was envisaged that this methodology would be introduced for thin surface courses using small coarse aggregates, the approach has the potential to be extended to other types of surfacing.

3. ASSESSMENT OF HIGH SPEED FRICTION: TEST METHOD

The objective of the work summarised in the following paragraphs, described in more detail by Brittain and Viner (awaiting publication), was to develop and evaluate a suitable methodology for the assessment of high speed friction. Again, the HA's Pavement Friction Tester has been used throughout because it is the only immediately available device suitable for measuring high-speed friction directly. The test conditions to be used, such as the test tyre type, slip ratio, and test speed were determined, as well as the assessment criteria to be set (discussed in the next chapter). The proposed methodology was circulated, in a consultation document, to industry representatives, and their feedback was incorporated.

3.1 MEASUREMENT

The proposed test method is the determination of longitudinal peak friction and locked-wheel friction. The test method is based on ASTM E1337 (ASTM, 1990) and ASTM E274 (ASTM, 2011) with the following notes and modifications:

- Measurements will be made at 90 km/h rather than the 40 mph (64k m/h) required by the ASTM Standards. This is necessary to properly reflect the high-speed performance that is the subject of the test.
- Measurements will be made using a standard smooth tyre ASTM E524 (ASTM, 2008), 1 mm water depth and 500 kg test wheel load.

It is proposed to define a single performance level:

- Level 1: suitable for high-speed applications (50-70mph).

Certification at Level 1 will be awarded if the measured high-speed friction exceeds the defined thresholds.

3.2 TEST SITE REQUIREMENTS

As for noise testing, it is proposed that at least two test sections will be tested and that these must be at least 100 m apart.

It is not proposed to specify a traffic requirement because suppliers may wish to offer different products for different traffic levels. In this case it will be necessary for clients to verify whether a product has been tested at a traffic level that is appropriate for their specific application.

The requirement for high-speed friction testing will present some additional constraints on the choice of test site for the trial, namely:

- Minimum length of test site: 150 m.
- Minimum acceleration length before the test length and minimum deceleration length after the test length: 500 m and 300 m, respectively.
- Derestricted single or dual carriageway.
- "Non-event" category A, B or C as defined in the HD28 of the Design Manual for Roads and Bridges (2004).

- Essentially straight, >1000m radius of curvature. This is the same requirement as for noise testing on high-speed roads.

3.3 INFLUENCE OF THE AGGREGATE SOURCE

The source of coarse aggregate, by way of the shape and PSV of the stone, is known to influence the low-speed friction characteristics of the surfacing product and probably also contributes significantly to the high-speed friction. However, the aggregate source is not generally defined by suppliers in product literature or on existing Highway Authorities Product Approval Scheme (HAPAS) certificates.

This presents a potential risk if suppliers use one source of aggregate for the TAIT and subsequently supply that product with different aggregate sources, appropriate to different traffic levels. It is anticipated that suppliers may choose to use a high-PSV aggregate (relative to the traffic) for the trial because this will improve their chances of achieving good performance in the high-speed friction tests. There is consequently a risk that the performance achieved in the trial may not be achieved subsequently if the product is supplied with an aggregate with lower PSV.

Two possible options are:

1. To state on the certificate the aggregate source, PSV and traffic level under which the TAIT has been carried out so that clients can assess whether the material is likely to be suitable for their application.

2. To limit the validity of the friction performance level to the specific aggregate source used in the trial. This implies that a low-textured product for high-speed applications would be associated with a specific source of aggregate.

The second option has additional merit because it caters for variation in aggregate shape associated with different aggregate sources, and the effect this may have on the high-speed friction characteristics. This approach would therefore provide a greater degree of confidence for clients, but has the disadvantage of imposing a substantially higher burden of testing for suppliers offering products with a number of different aggregate sources. This disadvantage could be expected to lead to higher costs and longer lead times for bringing good products to market.

3.4 SEASONAL VARIATION AND NUMBER OF TESTS

Confidence in measurements of high speed friction will depend on the inherent variability of surface properties and the repeatability of the test itself. For practicality, the test method, and criteria for measured values, should take into account potential variability so that a limited number of measurements can be considered representative of the surface under inspection.
Friction measurements are influenced by seasonal factors but it is believed that requiring multiple measurements throughout the year would be too onerous. Seasonal variation in friction should therefore be incorporated into the friction criteria using the following reasoning. For annual surveys of low speed skid resistance, in accordance with HD28, variation is accounted for by applying correction factors (Design Manual for Roads and Bridges, 2004). These are multiplication factors and typically vary between 0.9 and 1.1 (i.e. the effect of seasonal variation on low speed skid resistance is approximately

±10%). Experience has shown that changes in repeat surveys for PFT measurements appear to mirror the changes in low speed skid resistance measurements at the same site. This means that friction measurements made by the PFT could reasonably be expected to vary during the survey season by approximately ±10%. Therefore, to account for the effect of seasonal variation it is proposed that the test criteria developed by this work are raised by 10%.

The repeatability of the PFT was investigated by testing on the TRL research track. Although primarily interested in the result at 90 km/h, tests were conducted at 4 speeds for completeness (30 km/h, 50 km/h, 70 km/h and 90 km/h) and valid PFT tests were obtained at each speed on a range of different surfaces. The results were used to derive a level of confidence that the value obtained from an assessment is representative of the test surface. It was found that the width of the 95% confidence interval decreases rapidly when more repeat tests are carried out but decreases more slowly once at least 9 tests had been made. It is therefore recommended that 9 tests are carried out, and the surface should be accepted as passing the criteria if the mean result exceeds the threshold by at least the value of the confidence interval. This means that if a surface achieves the desired performance based on the mean of 9 measurements, there is only a 1 in 20 chance that a second assessment would find that it had failed to pass.

To ensure that testing has conformed to expected behaviour, a threshold for the standard deviation of those 9 tests should also be applied. Based on the measurements made on the track, standard deviation between 9 tests should not exceed 2.67 for locked-wheel friction and should not exceed 4.17 for peak friction.

4. ASSESSMENT OF HIGH SPEED FRICTION: CRITERIA

The basis for the development of high-speed friction criteria is that the performance delivered by low-textured materials passing the assessment should be broadly consistent with the performance of existing materials that meet current texture depth requirements. Initial criteria were therefore developed based on the measurements already used for comparison, reported in TRL367 (Roe, Parry, & Viner, 1998). The criteria were then assessed by applying them to measurements made on the trial sites set up for the collaborative research programme (Roe & Dunford, 2012). Finally, the praticality of the test method and the applicability of the criteria were verified by carrying out limited field trials.

4.1 SETTING INITIAL CRITERIA

The proposed test method requires a test speed of 90 km/h (56 mph), chosen because it is close to the speed of heavy goods vehicles on dual carriageways whilst being sufficiently high to represent high-speed friction. The measurements made during the earlier study (TRL367), using the fitted friction/speed trend, were reanalysed to obtain the expected friction at 90 km/h for both locked-wheel and peak friction tests.

The graphs in Figure 4 and Figure 5, show locked-wheel and peak friction measured at 90 km/h on a variety of surfaces. Also marked on each graph is a broken vertical line indicating 0.8 mm SMTD, considered to be acceptable texture depth for in-service roads, and a broken horizontal line indicating the proposed friction criterion in each case. It can be seen that the majority of the data below 0.8 mm texture depth are below the proposed friction requirements whilst the majority of the existing data above the 0.8 mm of texture are above the proposed friction requirement.

The friction criteria (locked-wheel and peak friction) were determined by calculating the 10th percentile of the friction values for sites with texture depth above 0.8 mm. This implies that the majority of surfaces that exceed the in-service texture requirement of 0.8 mm will also exceed the friction criteria, whilst ensuring that the criteria itself is not unduly affected by previous outlying measurement. Using this approach generates a requirement, for 90 km/h tests, for locked wheel friction to exceed 31.5 and peak friction to exceed 64.3.

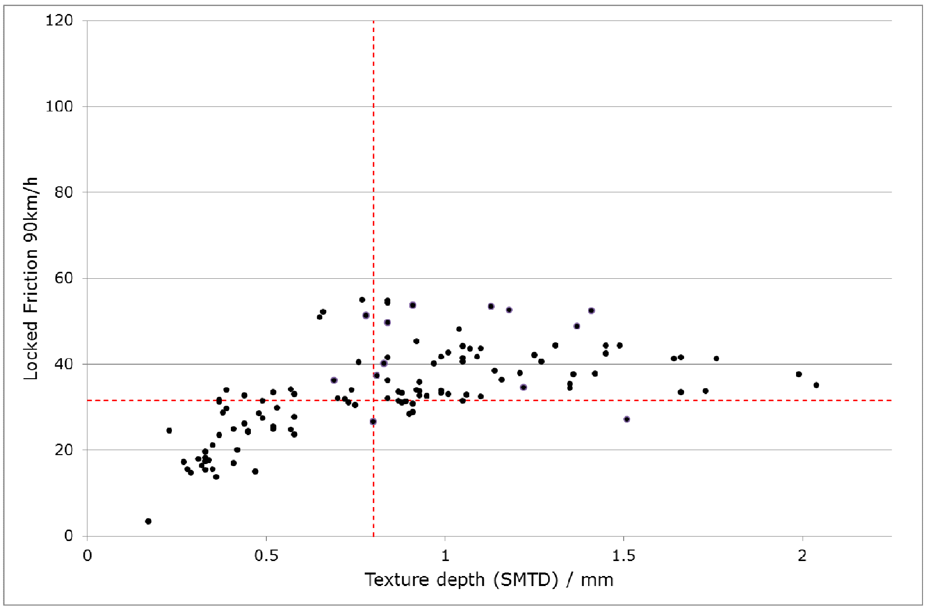

Figure 4 Locked wheel friction at 90 km/h, derived from TRL367

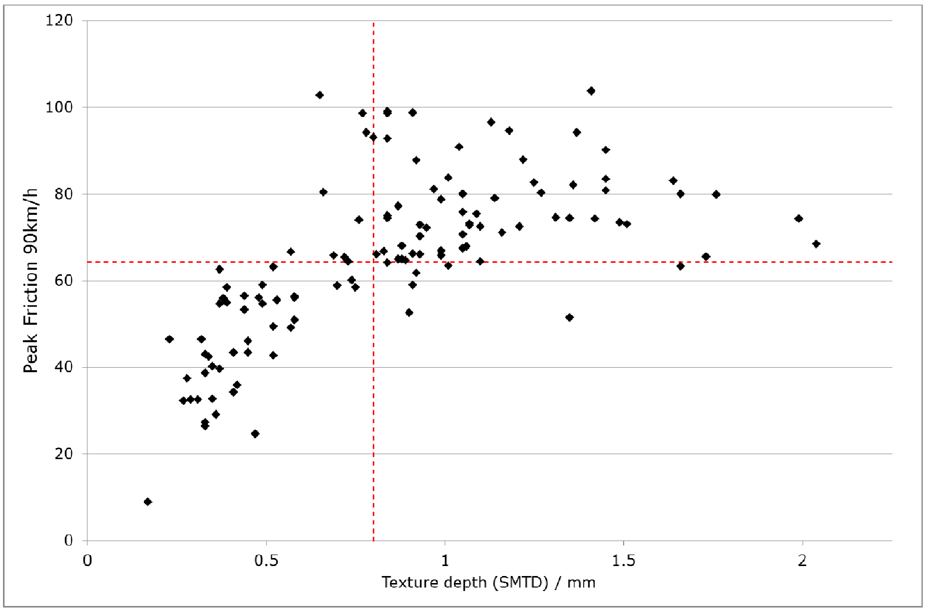

Figure 5 Peak friction at 90 km/h, derived from TRL 367

4.2 ASSESSING THE CRITERIA

To provide an initial assessment of the proposed high speed friction criteria, the results from the surfaces tested during the collaborative research programme (Roe & Dunford, 2012) were reassessed. The graphs in Figure 6 and Figure 7 show locked-wheel and peak friction respectively, again with texture and friction criteria marked with broken vertical and horizontal lines. On these graphs, the friction criteria have been increased to incorporate a margin of error for seasonal variation and the confidence interval resulting from repeatability of the test: i.e. locked-wheel friction should exceed 36.3 and peak friction should exceed 73.3.

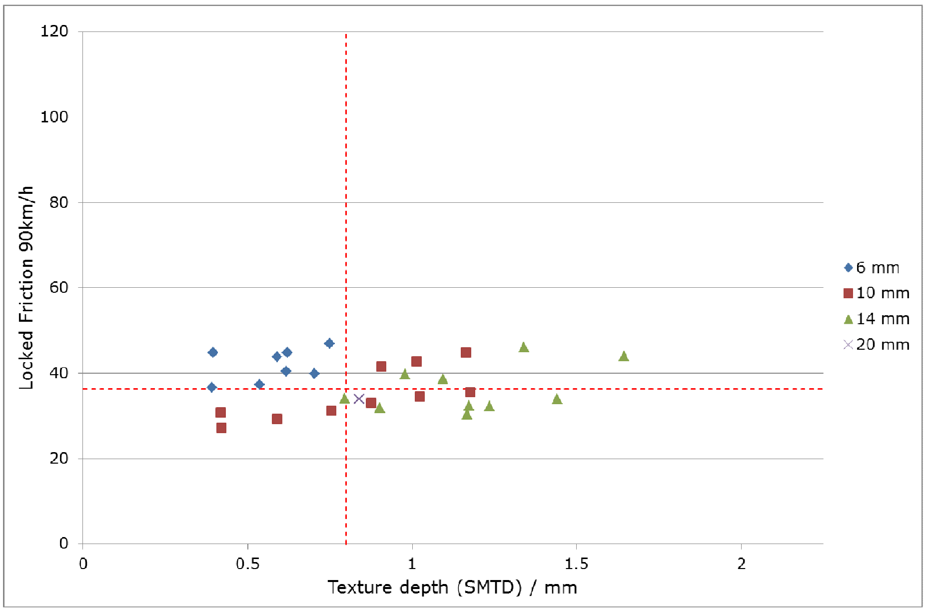

Figure 6 Locked wheel friction at 90 km/h, derived from collaborative programme measurements, assessed against locked-wheel friction criterion

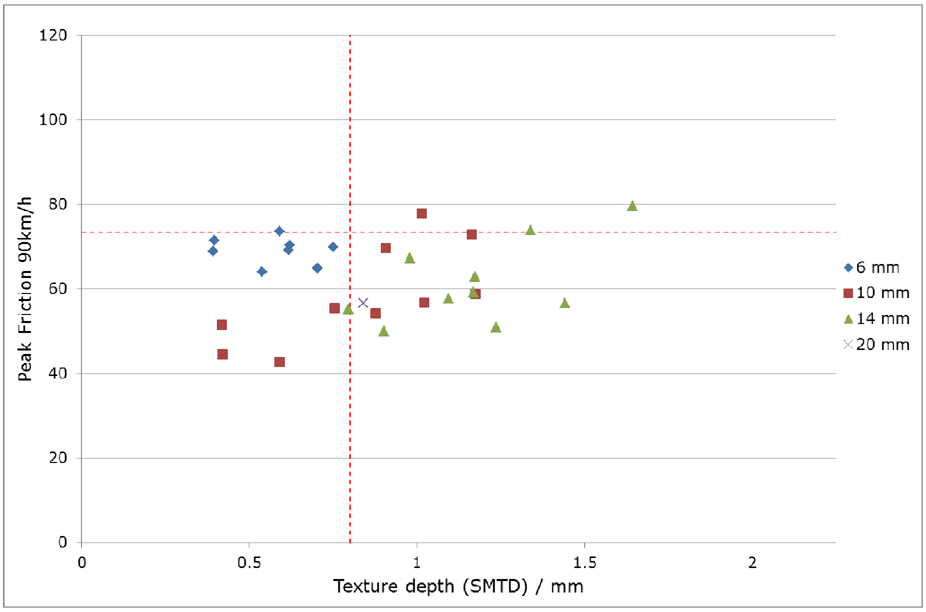

Figure 7 Peak friction at 90 km/h, derived from collaborative programme measurements, assessed against peak friction criterion

Sections with 6 mm coarse aggregate fall above the locked-wheel friction threshold and sections with larger coarse aggregate that have texture depth (SMTD) greater than 0.8 mm generally fall at or above the locked-wheel friction threshold. However, peak friction values are below the allocated threshold on most trial sections even for sections using larger aggregates with texture greater than 0.8 mm.

The criteria represent the 10th percentile performance of surfaces meeting the existing standard so performance against the locked-wheel friction threshold is as expected, with a proportion of sections falling below the threshold, which has been increased to take into account seasonal variation and repeatability. This is not the case for the peak friction threshold and examination of the collaborative research programme measurements alone suggests that peak friction criterion may be too high, making it an unrealistic target.

Further investigation into the peak friction criterion, and the apparent discontinuity between acceptable values for measurements reported in TRL367 and measurements made during the collaborative research programme, was carried out. The surface type was considered and so was the possibility that the machine may have changed in the time between the two sets of measurements (almost 20 years). It was found that the relationship between locked-wheel and peak friction was not strongly dependent on surface type. A slight decrease in the ratio of peak to locked-wheel friction measured by the PFT was found, which may have contributed to the change in measurements, but it was not enough to fully explain the difference.

The data derived from collaborative research programme measurements used trend lines based over a range of speeds, rather than multiple tests at 90 km/h and it was therefore not possible to assess the proposed standard deviation criteria.

4.3 VERIFYING THE TEST METHOD AND CRITERIA

A field trial was conducted to supplement the historic data, and to assess the practicality of performing the proposed testing. The field trial sites included surfaces with a range of texture depths, from a mixture of local authority dual carriageways and Highways Agency motorways.

The testing carried out during the field trial identified no additional practical issues which would inhibit the implementation of the test method. It is reiterated that test sections should be located on straight sections (or close to straight) and a suitable approach should be allowed to obtain the correct test speed. It is also noted that efficiency in the test procedure can be obtained by locating the test section between junctions, rather than over junctions, which helps to reduce the time taken between test passes and thus reduce the overall test time.

The results from measurements made on the field trial sites are shown in Figure 8 and Figure 9, for locked-wheel and peak friction respectively. Sites with low texture do not meet the criteria for either locked-wheel or peak friction. These sites were surfaced with an unknown, negatively textured material with a low texture depth and it is therefore not unexpected that they fall below the test criteria. However, it is also clear that the majority of the sites failed the peak friction criterion, including those with higher texture depth, as previously observed for measurements made during the collaborative research programme.

The additional requirement for a limit on the standard deviation of repeat tests was reviewed. It was found that 4 of the 37 test positions failed the allocated threshold for locked-wheel friction and 9 failed the threshold for peak friction. In practice, this would result in a requirement for further testing, until outlying points can be excluded and there is confidence that the measurements made properly represent the performance of the surface.

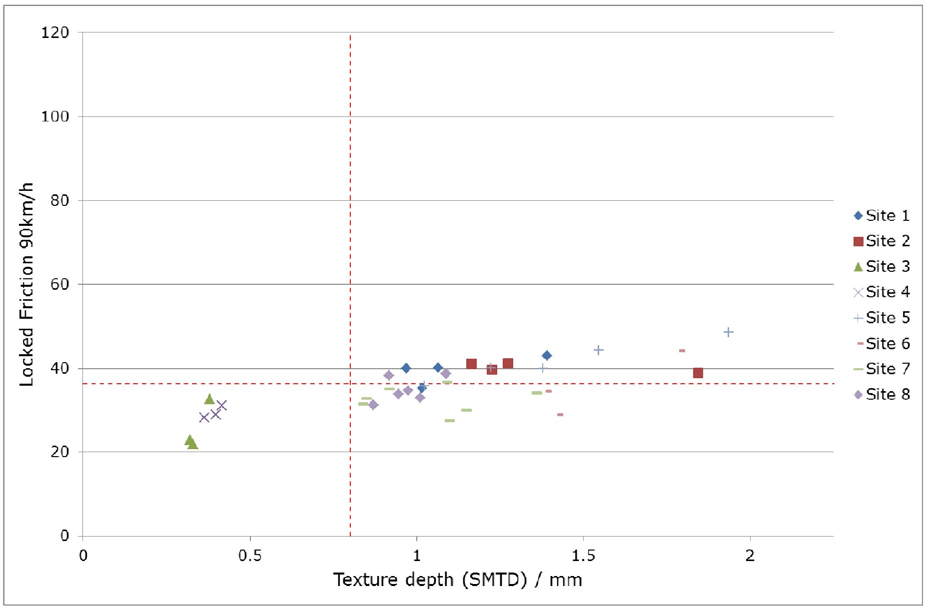

Figure 8 Locked-wheel friction at 90 km/h from the field trial, assessed against locked-wheel friction criterion

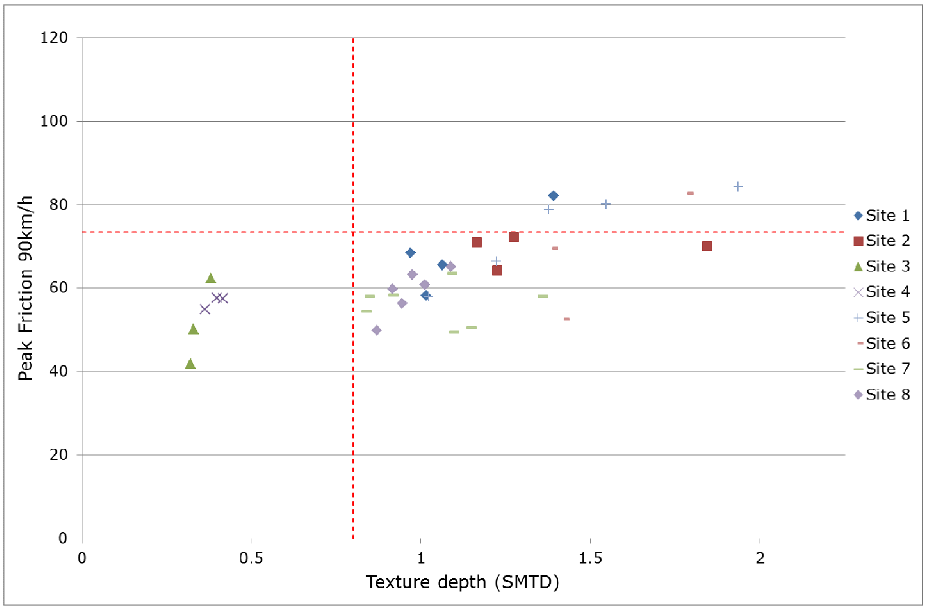

Figure 9 Peak friction at 90 km/h from the field trial, assessed against peak friction criterion

5. DISCUSSION AND CONCLUSIONS

A methodology for the assessment of high speed friction using the Highways Agency's Pavement Friction Tester has been developed and assessed. Neither industry consultation nor a field trial identified practical barriers to the proposed test methodology. Criteria based on the locked-wheel and peak friction values obtained using the Pavement Friction Tester (PFT) operating at 90 km/h have been proposed. The criteria were set to represent a consistent level of performance compared with existing surface materials having a texture depth above 0.8 mm SMTD, taking into consideration seasonal variation and measurement repeatability.

In general, it was found that the criterion for locked-wheel friction, measured at 90 km/h, appears to be correctly placed: surfaces failing the proposed locked-wheel friction assessment should be investigated further. The peak friction criterion, derived in the same way, appears to be unnecessarily stringent.

In the absence of further data it is proposed that high speed friction tests are examined against the locked-wheel friction criterion, with a comparison against the peak friction criterion made for information purposes only, until the threshold can be revised.

<u>Locked wheel friction criteria</u>:	Mean (locked wheel friction) > 36.3 Standard deviation (locked wheel friction) < 2.67
<u>Peak friction criteria</u>:	Mean (peak friction) > 73.3 Standard deviation (peak friction) < 4.17

The high speed friction test methodology was developed in response to a need to verify the performance of thin surface course systems using small coarse aggregate, which would normally be considered unacceptable for use on high speed roads because of low texture depth. However, it should be noted that the methodology is, in principle suitable for assessment of any other new surfacing material and for specific site investigation.

Full details of the development of the high speed friction assessment methodology and criteria can be found in PPRxxx (Brittain & Viner, awaiting publication).

6. REFERENCES

HD 28 (DMRB 7.3.1) Skid Resistance. (2004, August). *Design Manual for Roads and Bridges*. The Stationery Office.

ASTM. (1990). *E1337-90 Standard test method for determining longitudinal peak braking coefficient of paved surfaces using standard reference tire.* West Conshohocken, PA USA: ASTM International.

ASTM. (2008). *E524-08. Standard specification for standard smooth tire for pavement skid resistance tests.* West Conshohocken, PA, USA: ASTM International.

ASTM. (2011). *E274-11. Standard test method for skid resistance of paved surfaces using a full scale tire.* West Conshohocken, PA, USA: ASTM International.

Brittain, S., & Viner, H. (awaiting publication). *PPRxxx. Development of a high speed friction performance criterion for asphalt materials.* Crowthorne: TRL.

Parry, A., & Viner, H. (2005). *Accidents and the skidding resistance standard for strategic roads in England TRL622.* Wokingham, Berkshire: TRL Limited.

Roe, P. G., & Dunford, A. (2012). *PPR564. The skid resistance behaviour of thin surface course systems. HA/MPA/RBA collaborative programme 2008-11: topic 1 final report.* Crowthorne: TRL.

Roe, P. G., Parry, A. R., & Viner, H. E. (1998). *TRL 367. High and low speed skidding resistance: the influence of texture depth.* Crowthorne: TRL Limited.

Roe, P., Webster, D., & West, G. (1991). *The relationship between road surface texture depth and accidents. TRRL Research report 296.* Crowthorne, Berkshire: Department of Transport. Transport and Road Research Laboratory.

Sabey, B. (1966). *Road surface texture and the change in skidding resistance with speed. Ministry of Transport RRL Report No. 20.* Crowthorne, Berkshire: Road Research Laboratory.

Author Biographies

Alan Dunford

Alan manages a portfolio of projects related to measurement research and advice. The projects are generally focussed on material properties, skid resistance and monitoring of other pavement surface characteristics as well as aspects of road user safety such as splash/spray generation and asphalt durability. Alan leads a team of staff, coordinates activities in over 20 projects and provides technical input and guidance. Alan leads research into new devices such as the Wehner-Schulze polishing machine and novel techniques such as the contactless measurement of microtexture; the latter formed the basis for his part-time study for a PhD at the School of Civil Engineering at the University of Nottingham.

Helen Viner

An experienced scientist and manager, Helen joined TRL in 1997 after two years of post-doctoral academic research. In January 2013, she was appointed as Chief Scientist and Research Director for Infrastructure Division, a role that includes developing collaborative research partnerships, preparing proposals for research funding, oversight of technical quality, and communicating our activities internally and externally. She is also the UK Research Coordinator within FEHRL (the Federation of European Highway Research Laboratories). Prior to this role, Helen led Infrastructure Division's Safety and Consultancy Group, with 11 technical specialists and a portfolio of projects for Government, private sector and overseas clients. Helen has worked extensively on the surface characteristics of road pavements, being responsible for innovative research and developing associated advice and standards. Her expertise includes tyre-road interaction (friction, splash/spray, rolling resistance and noise), accident trends, condition monitoring and management performance indicators.

Martin Greene

Martin has over 20 years' experience at TRL working, for a range of customers. His work is currently focussed on the development of skid resistance strategies for several national highway authorities and he has lead work on the development of guidance for the submission and prioritisation of highway maintenance works. He has organised and presented at training workshops on both these topics and has presented the findings of his research work at international conferences. More recently he has undertaken work for Highways Agency MACs to develop pavement maintenance options for schemes seeking renewals funding. Martin is a highly experienced Project Manager and in recent years has managed much of TRL's skid resistance and maintenance prioritisation related work with contracts in excess of £500k. He has also managed several EC funded collaborative projects.

Stuart Brittain

Stuart joined TRL in October 2005. Since that time he has worked on many projects in the pavement assessment field. He is currently the project manager for the ASPECT 4 project which covers the accreditation and QA of devices used on the Highway Agency (HA) trunk road network. Recently this work involved the review and update of the accreditation criteria and QA specification. He is also the project manager of the team supporting and developing the skid policy (HD28) for the HA. As part of this work Stuart calculates the seasonal correction factors for the SCRIM survey data collected on an annual basis (LECFs) and was deeply involved in the recent update to the skid policy standard (due to be published this year). Stuart is also involved in the calculation of the NPC value for the condition of the HA Network, which is reported monthly to HA. Stuart has also carried out work for other teams within the organisation to provide assistance with data processing and VBA programming.