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HA/QPA/RBA Collaborative Programme 2004/07: Surface requirements for asphalt roads

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TRL Limited

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HA/QPA/RBA COLLABORATIVE PROGRAMME 2004/07: SURFACE REQUIREMENTS FOR ASPHALT ROADS

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Client:	**Highways Agency** **Quarry Products Association** **Refined Bitumen Association**

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Executive summary

The UK central government and road construction industry, through the Highways Agency (HA), the Quarry Products Association (QPA), the Refined Bitumen Association (RBA) or their predecessors, have been commissioning a rolling programme of collaborative research through TRL for many years. This work, has always focussed on the practical needs of both the Agency and the Industry in providing and maintaining the UK road infrastructure.

The latest phase of the research, the 2004 – 2007 Collaborative Programme, has had as its focus "The performance and durability of asphalt roads". The project has been co-ordinated by a Steering Group, comprising representatives from the sponsor organisations and the research contractor (TRL). The Group decided on a three-year programme to be carried out in four stages that would: define the scope of the research; develop the research methodology; carry out the bulk of the research (over about 21 months and, finally, disseminate the research findings through a seminar for the Sponsor organisations and written reports, of which this report is one.

Three main topics of particular concern to the project sponsors at this time were identified, all of which related to important practical issues regarding the sustainable use of aggregates and asphalt for modern roads in modern condition. This report deals with the first of these: Topic 1 – Surface requirements for asphalt roads. The main emphasis being on the initial specification requirements for surface courses using modern materials.

The main focus of the research has therefore been the skid resistance performance of modern asphalt surfacings and hence how they should be specified, particularly in relation to the polishing resistance of the aggregates used and the texture depth that needs to be provided to give adequate safety performance.

The Steering Group also identified two other areas of interest that they would like to be reviewed within the Topic 1 task: requirements for road lighting and the spray-reduction capabilities of different types of thin surfacing. The work done on the spray sub-task is included in this report; the review of lighting requirements, which was carried out as part of the process of finalising the scope of the project but not taken further, has been summarised in an Appendix.

The research programme established for Topic 1 had four main components:

- **A database study:** this was intended to make use of existing data to compare the performance of modern thin surfacings in-service with the current requirements for the PSV of the coarse aggregate related to traffic levels. The concept was to draw together information from routine skid resistance monitoring with data regarding the make-up of the surfacings.
- **Establishing trial sites:** lengths of thin surfacings using the same aggregate in different coarse aggregate sizes have been laid on in-service roads. Their skid resistance performance is being compared under the same traffic and environmental conditions. The original intention was to use data from these sites primarily to validate any predictive models that might have emerged from the database study but in the event they have become a major focus of the work. This has included measurements of low-speed skid resistance, together with wet locked-wheel friction over a range of speeds to assess the relative influences of aggregate size and texture depth.

  An expected effect of low texture depth is greater reduction in wet friction at high speeds; it will be important therefore to establish whether smaller aggregate sizes show this effect and whether it might be offset by any increased skid resistance provided by the use of smaller aggregate.
- **Laboratory studies:** it was recognised that it would not be possible to study a full range of aggregates in different sizes on the road and therefore a procedure was needed that might make it possible to study factors such as aggregate sizes over a wider range of PSVs in the laboratory.

  At about the time that the scope of this programme being considered, the Wehner-Schulze test, a procedure from Germany new to the UK was being assessed at TRL for Highways Agency. It was decided to include a small programme of tests with the equipment in the Topic 1 programme.

- **Spray:** a small component of the overall programme, this work was intended to assess whether it might be possible to make an objective comparison of the amount of spray generated by traffic on different types of thin surfacings.

Despite the quantity of thin surfacing materials that have been used on UK trunk roads in recent years, records were inadequate to enable enough relevant information to be brought together for the database study and so this part of the work was unsuccessful. This inherent difficulty was compounded by the fact that only a relatively limited range of aggregates had been used on the network and this limited the scope of any potential analysis.

An attempt was made to compare the data that were available with information from past research on traditional surfacings. This showed a slight tendency for thin surfacings to give greater equilibrium skid resistance at low speeds than older HRA surfaces using chippings from the same nominal sources but the differences were not statistically significant and no rigorous conclusions could be drawn.

In the event, five trial sites were established, covering a range of traffic conditions and aggregate PSV. A sixth site which combined relatively low PSV with very heavy traffic was established, but this entered service too late to be monitored in this phase. At the time of writing, the sites are at different stages of the process of wearing away the bitumen from the surface to expose the aggregate and for the aggregate to polish to its equilibrium skid resistance level. For this reason it is not possible to draw general conclusions.

Construction of new asphalt surfaces allowed their early-life skid resistance to be assessed on some of the sites. This showed similar behaviours to that observed in or inferred from earlier research. All sites are currently showing a trend for 0/6 mm mixtures to provide higher skid resistance than 0/14 mm materials both at low and high speeds, even with relatively low texture depth on the 0/6 mm surfaces. However, it remains to be seen whether these differences will still exist or will be of practical significance once the surfaces have polished to their equilibrium levels.

Samples of the aggregates that had been used in the trial sites were used for the laboratory programme, supported by tests on cores taken from one of the trial sites. Tests on specimens using aggregate only suggest that in the laboratory smaller aggregates give greater friction after polishing, although the differences seen to date have been small. Tests have also been made on cores taken from the trial and early indications are that the laboratory friction test gives broadly comparable results to those from the test vehicles.

It remains to be seen how the friction developed through the standardised polishing procedure compares with the equilibrium skid resistance achieved on the road under varying traffic conditions, but the work suggests that this technique could be a useful standardised method for further study of a wider range of aggregates, both as aggregates alone and in asphalt mixtures.

Trials of a mobile photographic method for measuring spray were made. The technique provided a feasible way of measuring spray in traffic under moderate rainfall conditions when the surface texture is not flooded with water. However, it failed when the rainfall was heavier and the surface texture appeared flooded.

The system was used on a circuit comprising mostly motorways that included both HRA and thin surfacings. No significant differences in spray generation by the target vehicle were detected between the different surfaces, either in moderate or heavy rainfall conditions.

Topic 1 set challenging objectives and it was recognised at the outset that conclusions might not be reached within the three-year timescale for the project. Although significant progress has been made, the nature of the work means that this is necessarily an interim report. Therefore it is premature to attempt to draw conclusions at this stage. Nevertheless, some interesting points are emerging which should become clearer as the next phase of the Programme proceeds.

1 Introduction

For many years, the UK central government and road construction industry, through the Highways Agency (HA), the Quarry Products Association (QPA), the Refined Bitumen Association (RBA) or their predecessors, have commissioned a rolling programme of collaborative research through TRL, focussed on the practical needs of both the Agency and the Industry in providing and maintaining the UK road infrastructure.

The latest phase of the research, the 2004 – 2007 Collaborative Programme, has had as its focus "The performance and durability of asphalt roads". The project has been co-ordinated by a Steering Group of representatives from the sponsor organisations and the research contractor (TRL). The Group decided that work for the three-year programme would be carried out in defined stages:

- Stage 1, over the first six months, to identify and define the scope of the research.
- Stage 2, which was to cover a three-month period, would be used to develop the research methodology.
- Stage 3, over about 21 months, would be used to carry out the bulk of the research.
- The final Stage 4, over the last six months of the programme, would be used to produce outputs and disseminate the research findings through a seminar for invited members of the Sponsor organisations and written reports, of which this report is one.

It was recognised that, as the programme progressed and the scope became more clearly defined, some of these stages would operate in parallel with one another.

The scoping process identified three main topics of particular concern to the project sponsors at this time:

- Topic 1 – Surface requirements for asphalt roads.
- Topic 2 – Durability of asphalt construction.
- Topic 3 – Laying asphalt on concrete.

These all relate to important practical issues in relation to the sustainable use of aggregates and asphalt for modern roads in modern conditions:

- The initial specification requirements for surface courses using modern materials.
- Improving the service lives of asphalt roads by reviewing and encouraging best practice in the way in which they are generally constructed and maintained.
- Assessing what best practice should be in relation to the specific situation of laying asphalt over concrete surfaces and bridge decks.

This is a comprehensive report describing the work carried out for Topic 1 - Surface requirements for asphalt roads. This had as its main focus the skid resistance performance of modern asphalt surfacings and hence how they should be specified, particularly in relation to the polishing resistance of the aggregates used and the texture depth that needs to be provided to give adequate safety performance.

The Steering Group also identified two other areas of interest that they would like to be reviewed within Topic 1: requirements for road lighting and the spray-reduction capabilities of different types of thin surfacing. The work done on the spray sub-task is reported here, in Section 7. The review of lighting requirements was carried out very early in the programme as part of the process of finalising the main scope of the project. As it formed only a small part overall and no work was identified for taking forward in the main programme, the subject is not discussed in the main body of this report. However, for completeness, the findings of the review have been summarised and included in the report as Appendix A.

2 The context and scope of the research for Topic 1

2.1 General background

Proprietary thin surfacing systems have been successfully used on UK trunk roads for over 10 years; currently around fifty of these have Highway Authorities Product Approval Scheme (HAPAS) certificates for use for a range of traffic levels. These systems can provide a quiet and durable surface course while maintaining good friction and spray properties when the road is wet. However, a significant disadvantage of these materials from cost and sustainability viewpoint is that they use polish-resistant aggregate throughout the surface course rather than as a thin layer of chippings spread on the surface.

Thin surfacing systems also have specific characteristics in terms of their surface texture, lighting characteristics and longitudinal profile. Their surface texture – often described as “negative texture” – interacts with vehicle tyres in a different way to traditional materials, such as hot rolled asphalt (HRA) and surface dressing, and results in relatively low tyre noise. A different interaction mechanism may also lead to different polishing action and, hence, different in-service skid resistance.

In bringing the new surfacing systems into wider use in the UK, the process of approving them has focussed on ensuring that the material characteristics meet some of the existing specifications, rather than optimising the specifications for the new materials. There are potential benefits to be gained by refining the specifications of these materials in order to deliver better properties for road operators and users and also to allow greater flexibility in the choice of surfacings materials in appropriate contexts.

A greater understanding of how the properties of thin surfacing systems affect their performance is required in order to propose an optimised specification. If it could be shown that aggregates used in thin surfacing systems generally provide higher skid resistance than they do in traditional materials (on which current specifications are based) there might be scope for reducing PSV (polished stone value) or texture depth in some situations.

Also, it is known from historic research on surface dressings that smaller chipping sizes can give slightly higher skid resistance at low speeds. However, the use of smaller aggregate sizes is associated with lower texture depth, thus potentially negating any advantage at low speeds by reduced high-speed skid resistance. However, if the combination of smaller aggregate size and the form of the texture in a thin surfacing gave a sufficient improvement in skid resistance to overcome the adverse effects of lower texture depth, there could be increased scope for using materials of this type in appropriate locations.

Optimising specifications to take account of these effects, if they can be shown, could ease current supply problems with high PSV aggregates in two ways. Permitting the use of lower-PSV aggregates in a wider range of circumstances will reduce pressure on the limited range of high-PSV sources. The wider use of finer-sized thin surfacing products, albeit with lower texture, would permit the use of the smaller fractions (such as 6 mm material) that are a by-product of current production and at present are stockpiled. A further benefit of making wider use of smaller sizes could be increased opportunities for recycling existing surfacings: high-PSV aggregate from the body of old surfacings that might be reduced in size during the planing and re-mixing processes could be re-used.

Thus, the Steering Group decided that the main emphases of the research for Topic 1 would be:

- to assess thin surfacing skid resistance performance, with a view to the possible revision of the present requirements for PSV and texture depth where thin surfacing systems are to be used and
- to consider the potential for making greater use of smaller aggregate sizes.

Another feature of many thin surfacings is the way in which water drains from or through them. As the use of thin surfacings has become more widespread, it has been observed anecdotally that they can reduce vehicle-induced spray (in comparison with older materials) and that some types may be more effective than others. It was therefore decided that a small proportion of the programme should be dedicated to a sub-task assessing this subject.

2.2 Scope

In the light of the general background described above, it was decided that, essentially, the research programme in relation to skid resistance needed to address the following questions and potential outcomes:

- Do modern surfaces with negative texture give better low-speed skid resistance than traditional materials for the same PSV?
    - *Can PSV be relaxed for negative-texture materials?*
    - *Can current texture depth requirements be relaxed for these materials?*
- Do smaller aggregates used in thin surfacings give relatively higher skid resistance than sizes currently used?
    - *Is there scope for a trade-off between PSV and aggregate size?*
- Smaller aggregate usually means lower texture depth:
    - *Could texture depth be reduced and maintain adequate high-speed skid resistance through the surface lifetime?*
    - *If not, in what circumstances might such materials be used?*

The research programme that was devised had three component tasks to address these issues. A fourth, separate, task was to address the issue of spray. The specific context and scope of each of these tasks is described in Sections 2.2.1 to 2.2.4 below. The methodology applied and the results obtained are discussed in detail later, in Sections 3 to 7.

2.2.1 Database study

This component of the work was included to address the first main question – *Do modern negative-texture surfaces give better low-speed skid resistance than traditional materials for the same PSV?*

Currently, aggregates for use in new asphalt surfacings are required to have a minimum PSV that takes account of:

- The level of skid resistance required for the site at which the surfacing is to be laid.
- The general daily level of heavy traffic expected to use the road during lifetime of the surfacing.

Suitable minimum levels for PSV are set out in tables in HD36 in the Design Manual for Roads and Bridges (DMRB). However, the standard recognises that different aggregates may perform differently in different locations and so there is some flexibility in the choice, particularly where the performance of a particular aggregate is known locally.

The concept was introduced in the mid-1970s but ever increasing traffic and the introduction of skid resistance standards for in-service trunk roads meant that the old models were no longer adequate so the requirements were updated following further research in the 1990s and reported in TRL322 (Roe and Hartshorne, 1998). This work took advantage of the fact that, with the introduction of skidding standards, the skid resistance of the network was being monitored with SCRIM (Sideway-force coefficient routine investigation machine) and a wider range of actual performance data would have been recorded and was potentially available for analysis.

A further study known as the SKIDPREDICT project was sponsored collaboratively by HA, CSS (County Surveyors Society) and QPA and carried out by TRL and the University of Ulster (Roe and Woodward, 2004). The project examined a wider range of factors than had been possible in the work for TRL322 and considered variations to the PSV test technique in an attempt to improve the predictive models. In the event, this work was not able to improve on the requirements already in HD36 at the time. The most recent revision to HD36, published in 2006 took account of changes to the skid resistance standards introduced in 2004, but the essential requirements for PSV were largely unaltered.

However, all the previous studies, and hence the requirements in HD36, were based upon the in-service performance of aggregates in traditional surfacings, predominantly HRA and, to a lesser extent, surface dressings. There were a few thin surfacing sites available to the SKIDPREDICT project but the materials were not in widespread use at that time.

At the time that work for this Collaborative Programme work began, thin surfacing materials had been in routine use on trunk roads for about five years. So, there should have been a proportion of the network that was both surfaced with a thin surfacing, had been trafficked for long enough to have reached its equilibrium skid resistance level and was being routinely monitored for skid resistance.

Therefore, it was decided to compile a database of information that could be used to assess the skid resistance in-service specifically for aggregates in thin surfacings. The performance of the aggregates in the database might then be compared with those studied in the earlier projects, possibly developing alternative performance models in relation to PSV and traffic.

It was envisaged that most information relating the aggregates would need to be obtained either from maintaining agents or surfacing contractors, while in-service skid resistance data would be drawn from the Highways Agency Pavement Management System (HAPMS). Some provision was made to make measurements with SCRIM on selected sites where this would add usefully to the data, for example on sites identified that were on roads not routinely monitored.

2.2.2 Validation trial sites

Although the database study could potentially provide information on the performance of materials in-service, it was recognised that it would not provide any information about small aggregates sizes because at that time, apart from one or two recently-laid short trial lengths, none were in regular use. Further, if the database study were to lead to new models for predicting skid resistance for thin surfacings, it would be important to be able to validate these.

It was therefore decided to develop a number of validation trials on which thin surfacings of known characteristics would be laid and the skid resistance monitored. By including aggregates of different sizes from the same source, it would be possible to make a direct study of the effect of aggregate size under the same traffic conditions. Any such sites would also provide a back-up in the event that the database study did not yield sufficient useful data.

Ideally, a number of different sites with different traffic conditions would be chosen and these would be laid with a number of different thin surfacings with different aggregates, each with a range of coarse-aggregate sizes. This would enable efficiencies of operation, particularly when carrying out skid resistance measurements, but it would be very complex and expensive to arrange in the relatively short timescale available. Therefore, while recognising the importance of the trials, a simpler approach was needed that would provide useful data within the budgetary scope of the project.

It was therefore decided that the work could most economically and straightforwardly be taken forward by means of individual companies offering sites to the project, rather than attempting to set up a controlled experiment with a wide range of materials in just one or two locations. The principle would be that on a site for which an existing contract that involved resurfacing was going ahead, the surfacing contractor would “drop in” one or two sections of materials using different sizes of coarse aggregate from the same source as that which was being used on the main contract. This could be arranged through QPA member companies at no additional cost to the main contract or to the project in regard to the surfacing operations.

In this way, each site would allow direct comparisons of different sizes of the same aggregate to be made under identical traffic conditions. Although there would be logistical issues for monitoring and limitations to the number of materials that could be tested, it was considered that this provided the best opportunity to establish the trial sites.

Once in place, each site would be monitored at intervals as the skid resistance developed. The measurements would include tests with SCRIM to assess low-speed skid resistance. The Pavement Friction Tester (PFT), illustrated in Figure 2.1, which could measure locked-wheel friction at a range of speeds, would be used to assess the influence of texture and different aggregate sizes on high-speed friction.

The opportunity would also be taken to make measurements of early-life skid resistance on the new asphalt surfacings at some sites (where this was practical to arrange) for comparison with other ongoing work on that specific topic.

Figure 2.1 The Pavement Friction Tester

The vehicle is driven at a selected test speed. The test wheel on the left side of the trailer is fitted with a special smooth tyre. The brake on the test wheel is applied so that the wheel locks: it is held for 1 second and then released. The frictional forces are measured every 1/100th s. throughout the brake cycle. For wet tests, water is fed at a controlled rate from the nozzle in front of the test wheel.

2.2.3 Laboratory tests

Although the main focus of the research was to be on the Database and Trial Site components of the programme, it was recognised at the outset that it was likely that these studies would not be able to cover as wide a range of aggregate types or sizes as might be desirable.

Provision was therefore made for a small-scale programme of laboratory studies that would be taken up at a later stage of the programme, as progress with the other components was understood.

It was decided that the programme should concentrate on making comparisons in the laboratory of the skid resistance performance of samples of asphalt and samples of aggregate following accelerated polishing. For this purpose the Wehner-Schulze test would be used. This test procedure (described briefly in Appendix B) was new to the UK at the start of the Collaborative Programme and equipment was at that stage undergoing evaluation at TRL (Woodbridge et al, 2006).

It was agreed that initially the programme would comprise a series of tests on examples of specimens made with aggregate alone in four sizes (20, 14, 10 and 6 mm) using the same aggregates as those on the validation trial sites. At a later stage, cores would be taken from those sites to allow direct comparisons with the asphalt, both as-laid and after traffic.

2.2.4 Spray assessment

Road surface texture is observed to influence the generation of spray from vehicles in wet conditions. When it rains on a traditional positively-textured surfacing, all the water collects on the surface and is dispersed by the tyres through channels between the aggregate particles on the surface and the tyre tread, generating spray. In contrast, porous materials (when new) allow the water to pass through the material to drain away at the interface with the underlying layer: with less water at the surface, spray is reduced.

Different types of modern asphalt surfaces fall between these two extremes. The negative texture provides voids into which the water can drain and interconnected voids within the surface allow water to move within the material. Thus, pressure created by passing tyres forces the water to move away from the interface and spray may be reduced. However, the materials are not usually fully permeable and in steady rain can become saturated, in which case water flows over the surface and spray can be generated. Permeable surfaces, as they age and become clogged, may suffer from the same effect.

The purpose of this small sub-task was to assess the development of spray on thin surfacing materials. The following potential activities were identified and they would be reviewed and progressed in stages taking into account the available resources.

(i) *Initial review*: before commencing any practical work, a review of published work in the topic area would be carried out. This would focus both on test methods for measuring spray and procedures for assessing its effects that may have been used both in the UK and overseas.

(ii) *Test methods*: alternative approaches to measuring spray highlighted by the review would be considered, and in the light of this, possibly develop a simple system that could be used to make direct measurements of spray to assess different materials, for example, on the validation trial sites.

(iii) *Develop a subjective "spray index"*: at present the spray-reducing or generating properties of different surface types are largely anecdotal. This activity would look at the possibility of developing a simple "spray index" that could be used to rank materials in the absence of, or in conjunction with, an objective test measurement.

3 The Database Study

3.1 The general approach taken to setting up the database

As explained in 2.2.1, the primary purpose of the database study component of the project was to collate together information from thin surfacings that had been in-service on the network for some time. In principle, the database would:

- Provide direct information on in-service low-speed skid resistance performance (derived from routine SCRIM measurements) of thin surfacings using different aggregates.
- Enable an investigation of equilibrium skid resistance in relation to factors such as PSV, traffic level, aggregate size and, possibly, the influence of local conditions.

3.1.1 Data requirements

The major requirement was to be able to identify where on the network thin surfacings had been laid, and to collect together relevant information in relation to those areas. Once a location had been identified, certain key data would be required, including:

- Details of the site location (defined with sufficient precision to allow other sources to be interrogated to find data such as skid resistance, gradient or curvature).
- Details of the surfacings used, particularly the coarse aggregate source, its PSV and size, together with similar information relating to the fine aggregate if possible and general binder type.

In most cases the data for skid resistance would already be available either via HAPMS or through TRL records (a number of sites had been part of other monitoring programmes that had been carried out since the introduction of thin surfacings into the UK). It was recognised that there might be some sites where direct measurement would be needed but, in the event, this was not necessary. Similarly, for most sites, traffic data should have been available from HAPMS or other HA databases.

Also, for the purposes of assessing equilibrium skid resistance, the sites in general needed to have been in-service for at least 2-3 years with at least one skid resistance survey having been made on the route after that period of time and this would further narrow the field. The requirement to be able to draw on HAPMS for equilibrium skid resistance data within the project timetable meant that sites currently in-service would generally have had to be laid prior to 2004, exceptionally 2005.

3.1.2 Gathering data

Although it was self-evident that thin surfacings were being increasingly widely used on the network, it was not so obvious how such details as aggregate source and PSV were to be obtained. In principle such information should be recorded with the contract documents but with diverse circumstances ranging from short summary treatments of 100-200 m through to major resurfacing contracts finding the appropriate sources of information would be difficult.

It was decided that the best approach to gathering the data would be to develop a standard electronic form (using Microsoft Excel®) that could be used by those approached for information to record what they knew of a particular site. TRL would use this form to upload data into a database programme (using Microsoft Access®). For ease of completion, the form was provided with drop-down menus for the answers to the more general questions.

However, it became apparent at an early stage that HA managing agents were unlikely to have sufficient relevant data available, either because it had not been recorded (other than as a general indication of the PSV requirement for the works) or because the information had been lost as a result of a number of reorganisations that had taken place since the surfacing works had been completed.

In discussion with the project Steering Group it was decided that the approach most likely to be productive would be to ask QPA members for information on the location of sites since they were the most likely to know exactly what had been laid in any particular place. A request for assistance, together with a copy of the electronic form was therefore sent to QPA members.

In addition to this potential data source, TRL's records of thin surfacing sites that had been included in skid resistance monitoring programmes for other research were also trawled for suitable locations to include in the database.

3.2 Data obtained

Through this process, data were eventually obtained from information provided by a number of QPA member organisations. Over 100 sites were identified from TRL trial site records. However, for a significant number of sites the information was either incomplete or insufficient to be able to obtain other supporting data. For example, some were not sufficiently well-enough defined to be able to identify the location within the HAPMS database or were on traffic lanes not normally surveyed for skid resistance. On others, there were indications within HAPMS that the site had subsequently been resurfaced and so relevant skid resistance data were not available.

The nature of the sites varied from short experimental sections of 100 m or so in length to longer main line resurfacing treatments where several kilometres had been resurfaced with the same material and were subject to the same traffic conditions. Therefore, in order to prevent sites like the latter dominating the analysis, the data were grouped into a number of "unique" sites for which the surfacing material, traffic and road geometry (i.e. gradient and curvature) were the same throughout, using the average skid resistance and texture depth for the whole of the unique site to represent its performance. For this purpose, a site could be a minimum of 20 m long.

Eventually, the information was narrowed down to 28 sections representing about 81 kilometres of road providing some 454 "unique" sites for further analysis. The coarse aggregate used in the surfacings on these sites came from just 14 quarries. Unsurprisingly, given that all sites were on trunk or principal roads and would probably have been laid taking a cautious approach to the requirements of the Design Manual for Roads and Bridges, HD36, a relatively narrow range of quoted PSVs was represented. Most sources were in the 65 to 68 range with two sources (one unknown, the other a BOS steel slag) quoted as 60 and three sources quoted as 70 or over. Aggregates with lower PSV were used in the finer-graded component of some of the asphalts.

In order to assess the range of data available and what further analysis might be possible, the surfacings were sub-divided by coarse aggregate size (which, given the period in which the surfacings were laid, was either 0/10 mm or 0/14 mm) and the sites were divided into five broad traffic categories: Low, Medium, Intermediate, Heavy and Very Heavy (as used in developing the trial site matrix described in Table 4.1 on page 10).

Table 3.1 summarises the results of this breakdown. In order to respect potential commercial sensitivities, specific aggregate sources are not identified but are assigned a code letter in this illustrative table. It can be seen that 60% of the total length of road represented was surfaced with aggregate from just two sources (2 and 5) and that these accounted for more than half of the "unique sites". Also, throughout the data, the heavier traffic levels predominate.

Table 3.1 Summary of sections of road available in database for analysis

Coarse aggregate characteristics					Traffic Level	Surface age in 2005	Overall Length	No. of unique sites
Source Number	**Type**	**Petrographic description**	**Reported PSV**	**Particle size (mm)**				
U1	unknown		60	10	Intermediate	6	2352	18
U2	unknown		65	10	Heavy	10	441	4
U3	unknown		65	14	Heavy	6	4011	10
1	Gritstone	Greywacke	65	14	Intermediate	4	2559	23
2	Gritstone	Precambrian Greywacke	65	10	Intermediate	11	673	13
					Heavy	3	10268	30
				14	Heavy	3	5376	31
					Heavy	4	10414	40
				14	Very Heavy	3	2895	17
					Very Heavy	4	11593	60
					Very Heavy	5	793	6
3	Gritstone	Devonian Sandstone	62	14	Medium	5	1579	8
4	Gritstone	Greywacke	65	14	Heavy	3	3084	9
5	Gritstone	Carboniferous sandstone (Pennant beds)	70	10	Heavy	5	3560	17
					Heavy	6	198	3
					Very Heavy	6	1637	8
5a	Gritstone	Carboniferous sandstone (Pennant beds)	68	14	Heavy	7	1100	7
6	Gritstone	Lithic Sub-Greywacke	72.5	14	Intermediate	7	791	12
7	Gritstone	Silurian limestone & greywacke	65	10	Heavy	7	441	4
8	Gritstone	Carboniferous sandstone (Pennant beds)	68	14	Heavy	8	990	6
9	Tuff	Ordovician Andesitic Tuff (Borrowdale volcanics)	68	14	Low	4	710	19
10	Tuff	Ordovician Andesitic Tuff (Borrowdale volcanics)	71	14	Intermediate	6	1677	11
11	Gritstone	Precambrian sandstone	65	10	Medium	4	150	2
					Intermediate	4	4958	25
12	Gritstone	Carboniferous sandstone (Pennant beds)	68	14	Intermediate	4	3551	31
					Intermediate	7	450	7
13	Slag	BOS Steel slag	60	10	Intermediate	5	4027	28
14	Gritstone	Greywacke	65	14	Very Heavy	3	457	5

4 The validation trial sites

4.1 The planned approach

As explained in Section 2.2.2, it was decided that the validation trial sites would be established on the principle that the surfacing contractor would “drop in” one or two sections of materials using different sizes of coarse aggregate from the same source as that which was being used on an existing planned surfacing contract. Thus, each site would allow direct comparison of combinations of different sizes of the same aggregate to be made under identical traffic conditions.

Any combination of 0/20, 0/14, 0/10 or 0/6 mm material would be considered, but it was envisaged that the most likely combinations would be 0/14 mm (typically the standard material) plus one other size (usually 0/10 or 0/6 mm) as a minimum on each site. On some sites, three materials (probably 0/14, 0/10 and 0/6 mm) might be possible.

4.1.1 A target matrix of PSV and traffic levels

It was recognised that it would only be possible to set up sites that would be acceptable to both the materials suppliers and to the clients’ engineers and that this might restrict the range of materials that could be laid or studied. Nevertheless, in order to provide some structure to the exercise and so that an appropriate range of combinations of key parameters would be included, a target matrix was planned. This would take account of different levels of PSV and different levels of traffic and enable appropriate comparisons to be made.

For this purpose, five PSV categories and five categories of traffic levels were defined as shown below in Table 4.1.

Table 4.1 PSV and Traffic Categories for trial site planning

PSV Categories		**Traffic Categories**	
Category	*PSV range*	*Category*	*Traffic level (CVD)*†
1	>65	Very Heavy	>4000 CVD,
2	61 – 65	Heavy	2000 - 4000
3	56 – 60	Intermediate	750 - 2000
4	50 – 55	Medium	250 -750
5	<50	Light	<250

† *Commercial vehicles per lane per day*

As the ultimate number of trial sites would be relatively small, there was limited value to be gained in studying aggregates with very high PSV or very low PSV. Rather, there would be greater scope to exploit any improved performance identified for aggregates in the other ranges: for example, for heavier traffic levels or where higher skid resistance was needed than is currently allowed for. It was decided therefore to target PSV categories 2, 3 and 4.

In an analogous way, it was decided to target traffic levels in the Heavy, Intermediate and Medium categories. However, it was recognised that, although we would not plan on this basis, by utilising both lanes of dual carriageway sites, it might be possible to include examples of the Light category in some locations.

In order to provide a practical range of sample conditions for study, the matrix would consider aggregate and traffic combinations that represented typical current use and more demanding situations that are currently used or permitted. Two sources from each of the three PSV categories would both be compared at two traffic levels. Using this approach would require twelve sites, which was considered a reasonable target. The target matrix decided upon thus covered six aggregate sources in three PSV categories and three broad levels of traffic, as set out in Table 4.2. Coloured shading is used in this table to distinguish between the different aggregate and traffic levels, for ease of comparison with the final matrix achieved (discussed in section 4.2).

Table 4.2: Validation trial target matrix

Site Number	PSV Category†	Coarse Aggregate	Traffic Level (in Lane 1)†
1	2	Source 1	heavy
2	2	Source 2	heavy
3	2	Source 1	intermediate
4	2	Source 2	intermediate
5	3	Source 3	heavy
6	3	Source 4	heavy
7	3	Source 3	intermediate
8	3	Source 4	intermediate
9	4	Source 5	intermediate
10	4	Source 6	intermediate
11	4	Source 5	medium
12	4	Source 6	medium

† *See Table 4.1 for definition of the categories*

However, it was recognised that this was a challenging target and that it was likely that fewer sites than this would be available and it might not be possible to cover the preferred range of PSV and traffic combinations.

4.1.2 Basic site requirements

The basic requirements for each test site proposed to QPA members were as follows:

- 2-lane, non-event dual carriageway.
- Generally straight and reasonably level (gentle curves >500 m would be acceptable).
- Minimum overall length 1500 m.
- Roundabout or other options to enable the test vehicles to turn round reasonably close to each end of the site.
- Minimum 500 m before first test section and after last test section (to allow for acceleration and deceleration of test vehicles for the higher-speed tests).
- Minimum test section length 150 m.
- Sites should be grouped in geographical regions if possible, to simplify monitoring and reduce the impact of seasonal effects on the results.

4.1.3 The process of establishing test sites

In early August 2005, QPA members were invited to consider whether they could provide sites for this exercise. The procedure that was followed in arranging the construction of each site usually included the following elements:

- Initial contact from the QPA member company to TRL with the offer of a site.
- Initial visit to the site and meeting with the contractor and a senior TRL team member to discuss what was required, what could be offered, and to assess the suitability of the proposed site for inclusion in the monitoring programme.
- Follow-up visits as necessary to meet with the Maintaining Agent and Police to discuss at a senior level the practical aspects of laying the trial sections in the context of the particular contract and the traffic management requirements of the monitoring programme.
- Detailed liaison between the contractor's site staff and the TRL monitoring team and between the TRL team and the police to co-ordinate the initial site measurement visits.
- Visit to site with TRL monitoring team leader to verify details of site layout, reference locations etc. to aid measurement programme planning.
- Liaison between TRL and the local water authority for provision of water supply/standpipes etc. for the measurement vehicles where necessary.
- Lay the experimental sections.
- Carry out first measurements.

On sites laid later in the programme, some of these stages could be merged or omitted as experience from previous sites could be brought to bear by the contractor at an early stage of the discussions.

4.2 The sites achieved

Response to the request for sites was slow initially but it was possible to find sites on two jobs scheduled to be completed in late November/early December 2005. Location 1, on the A5 at Gibbet Hill in Leicestershire, used an aggregate with a PSV at the lower end of Category 1, in three sizes: 0/14, 0/10 and 0/6 mm. In this case, a different aggregate was used for the trial sections compared with the main contract. That used a Category 1 aggregate in a 0/14 mm material, so an additional length of this material was also included for comparison. These materials were laid in both lanes, providing two sites with different traffic levels for comparison, referenced 1a and 1b for Lane 1 and Lane 2 respectively.

Location 2, on the A5 Tamworth by-pass in Staffordshire, used an aggregate in PSV Category 3 but only in the 0/14 mm and 0/10 mm sizes. Both lanes were treated, giving a further two sites referenced as 2a and 2b for lanes 1 and 2 respectively.

The same two companies were each able to provide a further sites in the summer of 2006. Location 3, on the A14 near Creeting St Mary in Suffolk, was effectively a replicate of Location 1 but under much heavier traffic. The trial surfaces were laid in Lane 1 only and denoted Site 3. Location 4, on the A43 north of Brackley used a Category 2 aggregate in 0/20, 0/14 and 0/10 mm sizes, together with a 0/6 mm material that used the same coarse aggregate as had been used on sites 1a, 1b and 3 but this time in different proprietary product. Both lanes were also treated at this location, providing a "light" traffic level for comparison, lanes 1 and 2 being denoted Site 2a and Site 2b respectively.

A third company was able to add Location 5, on lane 1 of the A14 near Thrapston in Northamptonshire in September 2006. Here, two different aggregates from Category 3 were used, each being laid in 0/14, 0/10 and 0/6 mm mixtures with the two aggregates being designated Site 5a and Site 5b.

By this time it was clear that Category 4 PSV aggregates (lower-PSV than had been used on the earlier sites) were the main gap in the emerging matrix. However, although several efforts were made to negotiate a suitable site, it took some time to find an acceptable location. Location 6, on the A14 near Stanford on the westbound approach to the A14/M1 junction was eventually completed in August 2007. The surfacings use an aggregate from Category 4, in 0/14, 0/10 and 0/6 mm sizes on both lanes, providing a relatively-light traffic site alongside a very heavy one, designated 6a (lane 1) and 6b (lane 2). Unfortunately, this location was completed too late to be included in the initial rounds of monitoring included in this report.

Table 4.3 shows how the sites that had been laid at the time of writing fit into the target matrix. As was expected, there was limited scope for controlling the range of aggregate and traffic level combinations, which is therefore not quite as envisaged, but nevertheless it can be seen that a good outcome has been achieved with, in effect, eleven sites across the six locations. For reasons of potential commercial sensitivity the individual aggregate sources are identified by a code letter rather than their individual quarry names.

Table 4.3 The site matrix achieved

Site			Coarse Aggregate		Traffic		Sizes used			
Number	**Location**	**Lane**	**PSV Category**	**Source (PSV)**	**Category**	**Approx. CVD†**	**0/20**	**0/14**	**0/10**	**0/6**
3	A14 Creeting St Mary	1	1	B (65-66)	very heavy	4050	✗	✓	✓	✓
4a	A43 Brackley	1	1	A (65)	intermediate	1650	✓	✓	✓	✗
			1	B (65-66)			✗	✗	✗	✓
			1	G (66)			✗	✓	✗	✗
1a	A5 Gibbet Hill	1	1	B (65-66)	intermediate	1200	✗	✓	✓	✓
			1*	H (68)			✗	✓	✗	✗
5a	A14 Thrapston	1	3	D (60)	heavy	3250	✗	✓	✓	✓
5b	A14 Thrapston	1	3	E (55)	heavy	3250	✗	✓	✓	✓
2a	A5 Tamworth	1	3	C (60)	intermediate	1200	✗	✓	✓	✗
6a	A14 Stanford	1	4	F (53)	very heavy	>4500	✗	✓	✓	✓
6b	A14 Stanford	2	4	F (53)	medium	>250	✗	✓	✓	✓
4b	A43 Brackley	2	2	A (65)	light	<250	✓	✓	✓	✗
			1	B (65-66)			✗	✗	✗	✓
1b	A5 Gibbet Hill	2	1	B (65-66)	light	<250	✗	✓	✓	✓
			1*	H (68)			✗	✓	✗	✗
2b	A5 Tamworth	2	3	C (60)	light	<250	✗	✓	✓	✗

†Commercial Vehicles per Day, estimated from traffic flow data recorded in HAPMS or other database available to TRL.
* Part of main contract included for comparison.

All locations except one have the three main aggregate sizes, and one has 0/20 mm in addition. Some of the aggregates have been laid on roads with higher traffic levels than anticipated in the target matrix but their performance in such a context is still of considerable interest. One aggregate was used on more sites than in the original concept but this nevertheless provides alternative interesting comparisons, because it can be studied under four different traffic levels, with scope for comparison of the same aggregate at the smallest size in two different proprietary materials[1].

Further details of the individual trial sites, including schematic diagrams of the layout of the sections on each site, are given in Appendix C.

4.3 Monitoring programme

4.3.1 Purpose of the measurements

The monitoring programme for the sites was focussed on understanding two main points:

- The general equilibrium level of skid resistance achieved by the surfaces with the different aggregate sizes, traffic levels etc.
- The relationships between skid resistance and speed on the different aggregate sizes with their associated different texture depths.

Secondary issues were to gain an indication of the way in which skid resistance developed in the intervening period between laying and reaching equilibrium and to assess the early-life skid resistance behaviour of the materials, particularly the smaller sizes.

Three types of measurement were therefore proposed:

- Standard measurements of low-speed skid resistance using SCRIM.
- Locked-wheel wet friction measurements using the Pavement Friction Tester at a range of test speeds.
- Locked-wheel dry friction measurements on some sites to assess additional early-life effects associated with a reduction in dry friction observed in previous research.
- Measurements of texture depth – as sensor-measured texture depth (SMTD) – using the laser sensor fitted to on the TRL SCRIM machine.

4.3.2 Timing of measurements

With these objectives in mind, it had been proposed initially to make "early-life" measurements on the new surfaces as soon as possible, either before (if practical) or shortly after opening to traffic. Further visits would then be made, primarily during the summer period, over the next two or three years in order to assess the changing skid resistance levels as the initial bitumen coating was worn or weathered away and the aggregate became exposed to polishing by traffic.

It was recognised that all the sites would need up to three years of summer traffic before the skid resistance could be considered to be at, or close to, the equilibrium level for the site and traffic level. This would mean that, with the delay in establishing the sites (the first being late in 2005), it was unlikely that the equilibrium level would be reached during the planned duration of the 2004/07 programme.

However, measurements would be made so that initial indications of the effects could be observed and consideration then given to continuing monitoring or adding additional sites to the programme. Table 4.4 lists the monitoring visits that have been made at the time of writing.

[1] It should be stressed, that the purpose of this part of the study is to assess effects on skid resistance of aggregate size and texture depth across a range of coarse aggregate PSV and traffic levels. It is not to make comparisons between different proprietary material types or aggregate sources.

Table 4.4 List of monitoring visits

Site	Date laying main sections completed	**Date of measurement visit and age of surfacing** *approximate age in brackets in days (d), weeks (w) or months (m)*					
		Winter 05		*Summer 06*	*Autumn 06*	*Summer 07*	*Autumn/ winter 07*
1 a/b	27/11/05	30/11/05 (3 d)	06/12/05 (10 d)	23/06/06 (7 m)	05/10/06 (11 m)	30/08/07 (21 m)	25/10/07 (23 m)
2 a/b	4/12/05		07/12/05 (3 d)	22/06/06 (7 m)	04/10/06 (11 m)	29/08/07 (21 m)	24/10/07 (23 m)
3	02/6/ 06			02/06/06 (0 d) 03/06/06 (1 d)	20/10/06 (4 m)	22/08/07 (14 m)	17/10/07 (16 m)
4 a/b	24/6/06				14/11/06 (4 m)	05/09/07 (14 m)	28/11/07 (17 m)
5 a/b	21-23/9/06				15/11/06 (7 w)	06/09/07 (11 m)	29/11/07 (14 m)
6 a/b	30/8/07	monitoring expected to start Summer 08					

4.3.3 Basic measurements made at each visit

The following basic pattern of measurements was made at each visit, although there were small variations on this pattern depending upon the circumstances and local conditions at the time. On sites where the trial surfaces were replicated in both lanes, a similar test pattern was usually followed in both lanes.

SCRIM:

- A single pass measuring both texture depth and sideway-force coefficient (SFC) at a test speed of 50 km/h plus a single pass measuring SFC at 80 km/h. The lower test speed is the standard reference speed for such measurements in the UK and the higher speed is the standard target test speed for routine surveys on high-speed dual carriageways and motorways.

PFT:

- DRY locked-wheel friction tests.
  - A single pass through the site at 50 km/h, with one skid per section.
- WET locked-wheel friction tests (1 mm theoretical water depth).
  - Measurements at test speeds of 20, 50, 80 and 110 km/h. A minimum of three skids per surfacing section at each speed. For high-speed tests, a single skid per section was made with repeat passes as necessary. On sites with longer sections or at lower test speeds, replicate measurements were made within the section to avoid making repeat passes.

Generally, the measurements were made during daylight hours with a police escort vehicle controlling the traffic behind the test vehicles for the duration of a test, allowing the traffic to flow normally once a pass had been completed and the vehicles were returning to the start for another run.

5 The laboratory test programme

5.1 Samples made from aggregate alone

This series of tests was carried out to assess the effect of particle size on friction after polishing without the additional influences of incorporating the aggregate into an asphalt mixture. Test specimens for the Wehner-Schulze machine were prepared using a mosaic of aggregate particles embedded in epoxy resin, using a technique analogous to that of the PSV test to prepare the 225 mm diameter specimens. These were subjected to accelerated polishing and friction testing in the Wehner-Schulze machine which is described briefly in Appendix B and more fully in PPR144 (Woodbridge, et al, 2006).

The samples tested within this programme were made using the same aggregates as those used on the validation trial sites and, where possible, using four particle sizes (20, 14, 10 and 6 mm). Table 5.1 shows which aggregates were used and in which sizes; duplicate specimens were made in each case.

Table 5.1 Aggregates tested

Source	PSV category (nominal PSV)	Sieved Sizes (mm)
B	2 (65)	5/6, 6/10, 10/14, 14/20
B*	2 (65)	5/6, 6/10, 10/14, 14/20
C	3 (60)	6/10, 10/14
D	3 (56)	5/6, 6/10, 10/14
E	3 (56)	5/6, 6/10, 10/14
F	4 (51)	5/6, 6/10, 10/14, 14/20
G	2 (62)	10/14

* A second sample from the same quarry was used

5.1.1 Wehner-Schulze test specimen manufacture

To prepare the test specimens, aggregate particles are arranged on wooden base plates, bounded by a metal ring so that their flattest sides are facing downwards and they lay neatly side-by-side. This approach is used so that the specimen surface will be as even and flat as possible, which is important for the later polishing and friction testing process. Fine sand is poured over the aggregate to approximately 1/3 of the average depth of the particles; this is to prevent the resin mixture from seeping through to the specimen surface.

An epoxy resin mixture, of the same type used to make specimens for the PSV test, is poured over the aggregate and sand so that the level of the mixture is just beneath the top of the metal ring. A second wooden base plate is sprayed with mould release spray and gently pressed on top of the specimen; this is in order to get a smooth and flat bottom surface. A weight is placed on top of the mould in order to prevent the specimen from warping during as the resin cures. After approximately 12 hours, the specimen is dry and can be tested in the Wehner-Schulze machine.

Figure 5.1 shows the aggregate being arranged in the mould and a completed mosaic after sand has been poured prior to filling with resin. Figure 5.2 shows examples of some of the specimens produced.

Figure 5.1 ***Left:*** **aggregate particles being arranged in a mould**
Right: **a completed mosaic with sand**

Figure 5.2 Completed aggregate mosaic specimens using 14 mm aggregate particles

5.1.2 Test programme

The specimens were subjected to a reduced version of the standard test as described by the manufacturer and by the Technical University of Berlin: fuller details can be found in PPR144. The reduced test procedure, omits an initial grit-blasting phase. This is normally included in order to remove the coating of bitumen on the surface to be tested that is present when the test specimens have been made from asphalt mixtures. In this case, with no bitumen present, the grit-blasting stage was not necessary. The procedure used had the following stages:

- Initial friction test.
- Polish for 90,000 roller passes (One hour duration).
- Friction test.
- Friction test to limit. (This involves repeated testing until the measured value differs by no more than 0.005 from the previous one.)

Typically, friction test results are given in terms of a value of coefficient of friction, μ, for the surface being tested, at a given test speed and for given experimental conditions.

Texture depth was measured on each sample using a circular texture meter (CTM), modified to scan the friction testing path. The CTM is manufactured by Nippo Sangyo Co., Ltd. It uses a laser displacement sensor to measure to profile of the surface on which it is placed. The CTM reports the mean profile depth (MPD) and the root mean square (RMS) texture.

5.2 Cores taken from the trial sites

In addition to the tests of different aggregate sizes in resin mosaic samples, the Wehner-Schulze machine was also used to test the friction on cores taken from the first of the validation trial sites (Sites 1a and 1b) which used aggregate from source B. Cores were taken in August 2007 from each of the sections (0/6, 0/10 and 0/14 mm): at least one pair of cores was taken from Site 1a (lane 1) in the nearside wheelpath, Site 1b (lane 2) in the offside wheelpath and from an untrafficked area representative of both sites. Friction tests were made on all of the cores, and accelerated polishing was carried out on one of each pair from the trafficked areas of Sites 1a and 1b.

For specimens on which accelerated polishing was to be performed, the full Wehner-Schulze procedure was employed because there was still some residual bitumen on the core surfaces. The procedure therefore comprised:

- Friction test. (assess initial condition)
- Polish for 90,000 passes.
- Friction test. (after standard polishing with residual bitumen present)
- Gritblast. (remove remaining bitumen and restore an “unpolished” surface)
- Friction test. (assess the new initial condition)
- Polish for 90,000 passes.
- Friction test.
- Friction test to limit.

In this case, the friction measured before polishing on the machine reflected the condition of the surface after trafficking up to the date at which the core was taken from the road. This measurement, therefore, can eventually be compared with appropriate skid resistance measurements from the trial site measurement programme as well as with the effect of standard polishing (after grit-blasting).

The results of the friction tests from this programme are presented in Section 6.3.

6 Results to date

In this chapter of the report, some of the results emerging from the various parts of the study are presented. It is stressed that this is an interim report in that the work is continuing into the next Collaborative Programme, particularly in relation to the ongoing evaluation of the trial sites which, at the time of writing, have yet to reach their equilibrium skid resistance level. The results reported here should therefore be seen in that context.

6.1 Summary of analyses and findings from the Database study

The limited number of aggregate sources in the database, and the predominance of heavier traffic levels, taken together with the breakdown into aggregate size, meant that there was limited scope to develop a meaningful analysis of the data in relation to assessing the effect of PSV or aggregate size on skid resistance. An attempt was made to assess the influence of factors such as gradient and curvature but there were insufficient data to draw meaningful conclusions.

One of the objectives of the whole project, however, was to make an assessment of whether thin surfacings generally might be expected to provide higher skid resistance than their hot rolled asphalt (HRA) precursors using the same aggregates. The database information was used to attempt to assess this by making a comparison with results from the databases prepared in previous research on which current PSV requirements are based. For this, the skid resistance recorded for aggregates represented in both databases was compared.

Ten aggregate sources were identified for which skid resistance data were available for both thin surfacings and HRA. However, only six of these had data for comparable traffic levels and reported PSV.

Table 6.1 summarises this analysis, showing the difference between the Characteristic SCRIM Coefficient (CSC) recorded on the thin surfacings and the Mean Summer SCRIM Coefficient (MSSC) recorded for the HRA surfacings. (The different parameters reflect the change in the methods used to assess equilibrium skid resistance between the two studies but they are broadly comparable.) It can be seen from the right-hand column of Table 6.1 that, with one exception, there was a general trend for the TS to give higher equilibrium skid resistance than the HRA (the CSC of the TS is slightly higher than the MSSC of the HRA). However, none of the differences was statistically significant so no robust conclusions may be drawn from this.

Table 6.1 Difference in skid resistance for aggregates used in HRA and Thin Surfacing

Source Number†	Average PSV reported as used in thin surfacings	Traffic band	Difference in skid resistance (CSC minus MSSC)‡
2	65	Intermediate	-0.04
		Very Heavy	0.09
5	70	Heavy	0.10
		Very Heavy	0.02
9	68	Low	0.06
11	65	Medium	0.03
		Intermediate	0.05
12	68	Intermediate	0.07
14	65	Very Heavy	0.10

† *Source number as in Table 3.1*

‡ *None of the differences recorded here was statistically significant*

6.2 Measurements from the trial sites

In this section various values of skid resistance and road/tyre friction are reported to illustrate some of the results emerging from the trial sites. The measurements of skid resistance with SCRIM shown here are for the standard conditions of a test speed of 50 km/h and a wet road surface. Results are shown as SCRIM Coefficients, to two decimal places, following the normal convention.

To distinguish the measurements made in this study from other types of friction measurement, such as those used by police collision investigators, all measurements made by the PFT are referred to in this report simply as "friction" and are equivalent to the data recorded by the machine. This is the coefficient of friction measured with a standard smooth tyre in locked conditions at a controlled speed, multiplied by 100. The text context and captions indicate whether the measurements refer to wet or dry tests.

6.2.1 Low-speed skid resistance (SCRIM)

The normal method for assessing low-speed skid resistance on UK roads is to measure them with SCRIM. For comparison with skid resistance standards this is done in a defined way at defined times of year but for this project the measurements have been made at different times as the surfacings age.

Figure 6.1 illustrates the way in which skid resistance has varied over time on Site 1a, the location that has been open to traffic longest (since late November 2005) and has the most available data for comparison. The graph shows the average SCRIM Coefficient at a 50 km/h test speed measured at the different visits for the three trial sections. Measurements on a section from the main resurfacing contract on this site (using 0/14 mm aggregate and slightly higher PSV) have also been included for comparison.

Figure 6.2 is a similar graph illustrating the measurements on Site 1b (Lane 2 at the same location), although in this case it was not possible to make measurements in this lane during first visit.

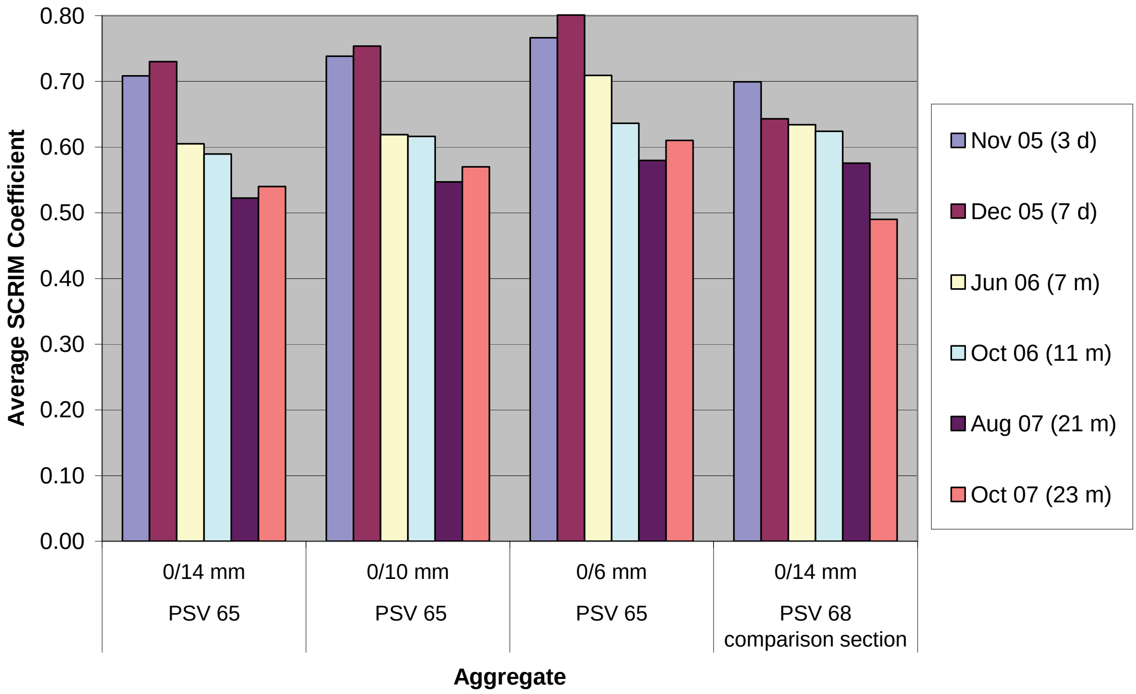

Figure 6.1 Variation in low-speed skid resistance (SCRIM Coefficient at 50 km/h) over time: Site 1a (A5 Gibbet Hill, Lane 1), Nov. 2005 to Oct. 2007

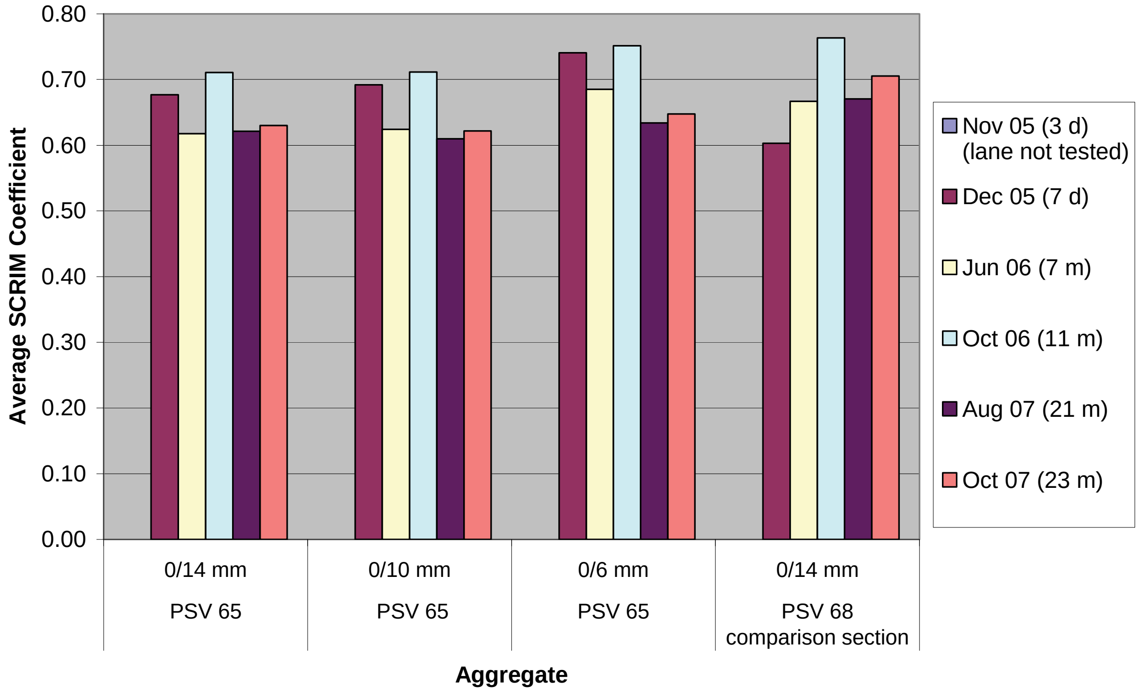

Figure 6.2 Variation in low-speed skid resistance (SCRIM Coefficient at 50 km/h) over time: Site 1b (A5 Gibbet Hill, Lane 2), Dec. 2005 to Oct. 2007

At the time of writing it is too soon in the lives of the surfacings to assess their expected long-term in-service skid resistance performance. However, there are a number of points that can be made in relation to the patterns of behaviour that can be observed in the graphs:

(i) The initial low-speed skid resistance on Site 1a (the dark blue bars) was very high, typical of SCRIM measurements on very new asphalt surfaces.

(ii) There was a small increase in skid resistance on Site 1a between the first measurement (at three days old) and the second (when the surface was ten days old). This is probably reflecting changes that were occurring on the bitumen-rich surface in that early period of trafficking.

(iii) In the lightly-trafficked Site 1b, the skid resistance at the second visit after ten days was still high but rather lower than on the equivalent sections of the adjacent Site 1a. This suggests that the changes that occur during the early period of trafficking are influenced to some extent by traffic level. A similar effect was observed with the PFT measuring at low speeds.

(iv) In both lanes at this location there was a marked decrease in skid resistance between the early visits in November/December 2005 and six months later, in June 2006. This reflects a combination of seasonal variation (which normally results in lower skid resistance in summer) and the early stages of wearing away the bitumen and polishing of the aggregate as it becomes exposed.

(v) Early in the following autumn (October 2006) the skid resistance had increased noticeably on Site 1b compared with the mid-summer measurement. However, it had decreased on Site 1a: by a small amount on the 0/14 and 0/10 mm sections and more noticeably on the 0/6 mm section. Again, this probably reflects a combination of the wearing/weathering of the bitumen film to expose the aggregate microtexture and the progressive polishing of the microtexture by traffic. The different behaviour on the two sites is probably due to the different traffic levels, with less polishing occurring in Lane 2.

The relatively greater decrease on the 0/6 mm section on Site 1b compared with the larger aggregate sizes may be due to the fact that, on this section, polymer-modified bitumen was used. This typically takes longer to begin wear off under traffic and the difference observed here may therefore be due to a greater proportion of the summer polishing having occurred between June and October as more of the aggregate became exposed.

(vi) Skid resistance decreased again between October 2006 and the following summer (August 2007), again reflecting a combination of seasonal variation and further exposure of the aggregate and its polishing towards an equilibrium level. As might be expected, the skid resistance was higher on the less-heavily trafficked Site 1b.

(vii) Between August and late October 2007 there was an increase in skid resistance, almost certainly due to seasonal variation.

(viii) Throughout the trafficking period, the low-speed skid resistance was greater on the 0/6 mm sections than on the two larger sizes.

(ix) Other than in the first few months of service, the main-contract comparison sections (PSV 68) had slightly higher skid resistance than the 0/14 mm trial section (PSV 65) throughout the test period on both sites.

Having looked in detail at the two sites at the oldest location, it is of interest to give a general comparison of how low-speed skid resistance is developing on the remaining sites. Figure 6.3, therefore, compares the most recent SCRIM test results from all nine sites over the five locations. The sites are ordered from left to right in order of age and the colours of the bars in the graph indicate the aggregate used.

In reviewing these data, it should be stressed that: the measurements were made in early autumn, so the winter seasonal increase would have been under way to different extents in the different locations and on the different sections. Also, the different sites were at different stages in the process of polishing towards equilibrium. This is clearly apparent on the sites where similar materials were laid in both lanes (Sites 1a/b, 2a/b and 4a/b). In those cases, lane 2 (which is generally more lightly trafficked) typically had higher SC values than lane 1. It should also be noted that on Sites 4a/b the aggregate used for the 0/6 mm sections was different to that used for the other sizes, although of the same PSV. For all these reasons it is inappropriate to analyse the data in great detail. Nevertheless, there is a clear indication on all the sites that slow-speed skid resistance increases with decreasing coarse aggregate size.

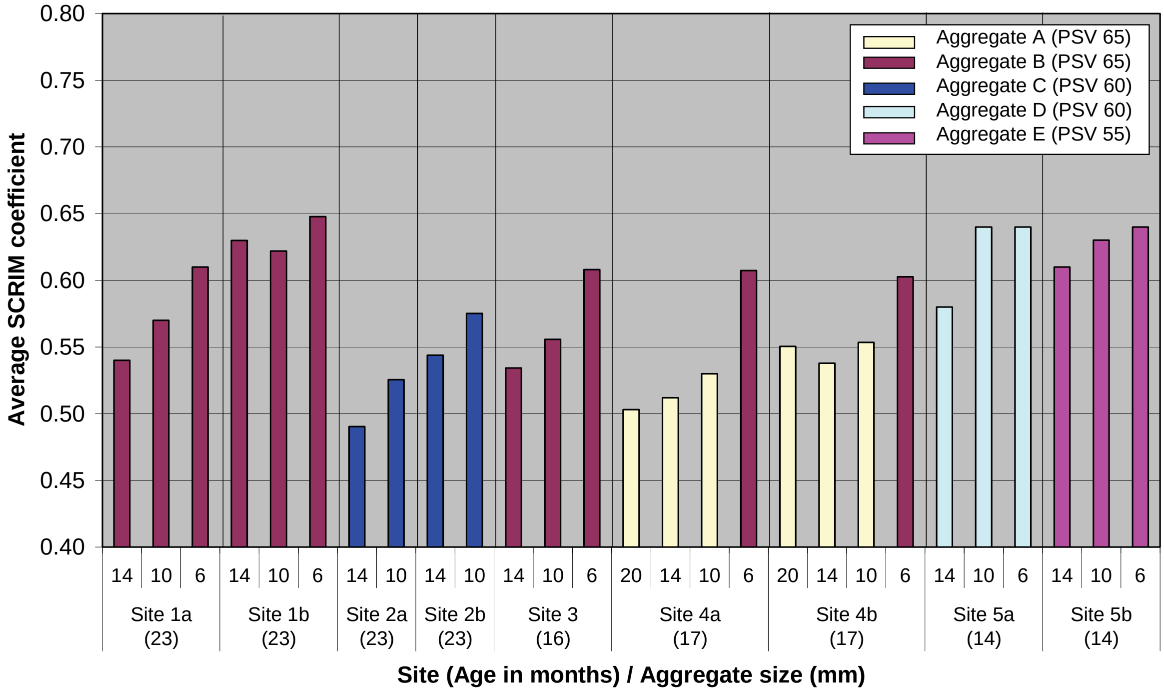

Figure 6.3 Average SCRIM coefficients (at 50 km/h) taken from the most recent visits to the trial sites (Oct/Nov 2007)

6.2.2 Texture depth

Texture depth is an important factor in the development of skid resistance, particularly at high speeds, so assessing its influence is an important aspect of this project. On most asphalt surfaces it is expected that the texture will reduce over time, often relatively early in the life of the surfacing. On an HRA surfacing, the loss of texture results from a combination of gradual embedment and wear of the aggregate chippings. However, this is offset by weathering of the surrounding asphalt mortar and generally the texture (provided it met the requirements initially) remains acceptable through out its service life.

However, with thin surfacing technology it is more difficult to achieve the initial texture depth normally required of traditional asphalt surfacings without a loss of durability. Also, in some circumstances, the mastic component of some thin-surfacing materials can flush to the surface with a resulting loss of texture. While it is possible to achieve reasonable texture depth levels on new thin surfacings that remain acceptable over time, with smaller-size coarse aggregate this becomes inherently more difficult. This was a particular concern in relation to the 0/6 mm material.

A laser-based measurement technique, which gives values known as sensor measured texture depth (SMTD), is the method normally used for in-service measurements on the HA network. This technique is used because it can be measured at traffic speeds and saves the cost and traffic disruption associated with closures to make patch test measurements. For comparative purposes, during this project, therefore, the texture depth of the trial sections is being monitored using the laser sensor on SCRIM, which allows texture to be recorded at the same time as the skid resistance.

However, optical methods do not work reliably on new asphalt and therefore it was not possible to measure SMTD on the surfaces as they were laid. The traditional patch method is used for contractual compliance purposes, and data from measurements made on the new surfaces were provided by the contractors. For the pairs of sites at locations where similar materials were laid in both lanes, only one value was provided and that has been assumed to be representative of both parts of the road.

Figure 6.4 illustrates the texture depth on the newly-laid trial sections (data were not available for all sections). To illustrate how texture has developed under traffic, Figure 6.5 shows the most recent (Autumn 2007) texture measurements from each site, by which time they were between 14 months and two years old. In these graphs, the sites have been arranged from left to right in the approximate order of decreasing traffic level and within each site the bars are arranged from left to right in order of decreasing particle size, which is also demarcated by colour. In reviewing these graphs it should be borne in mind that the two measurement techniques give different values (SMTD is usually lower).

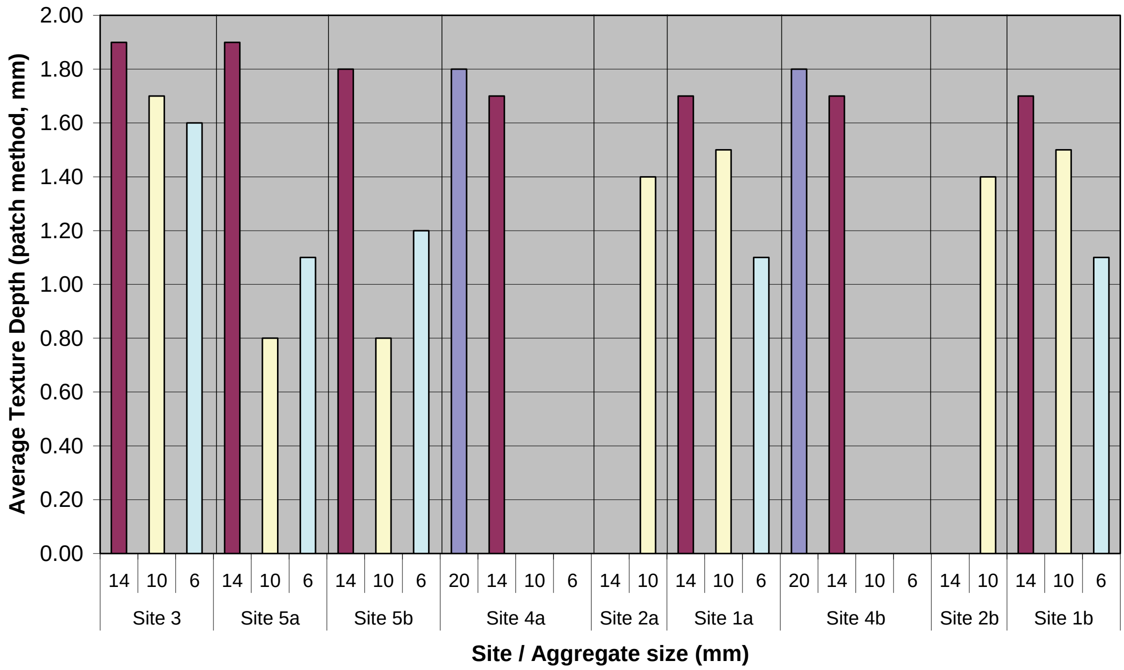

Figure 6.4 Average texture depth (patch method) on the trial sections when new
Sites are arranged from left to right in order of decreasing traffic flow

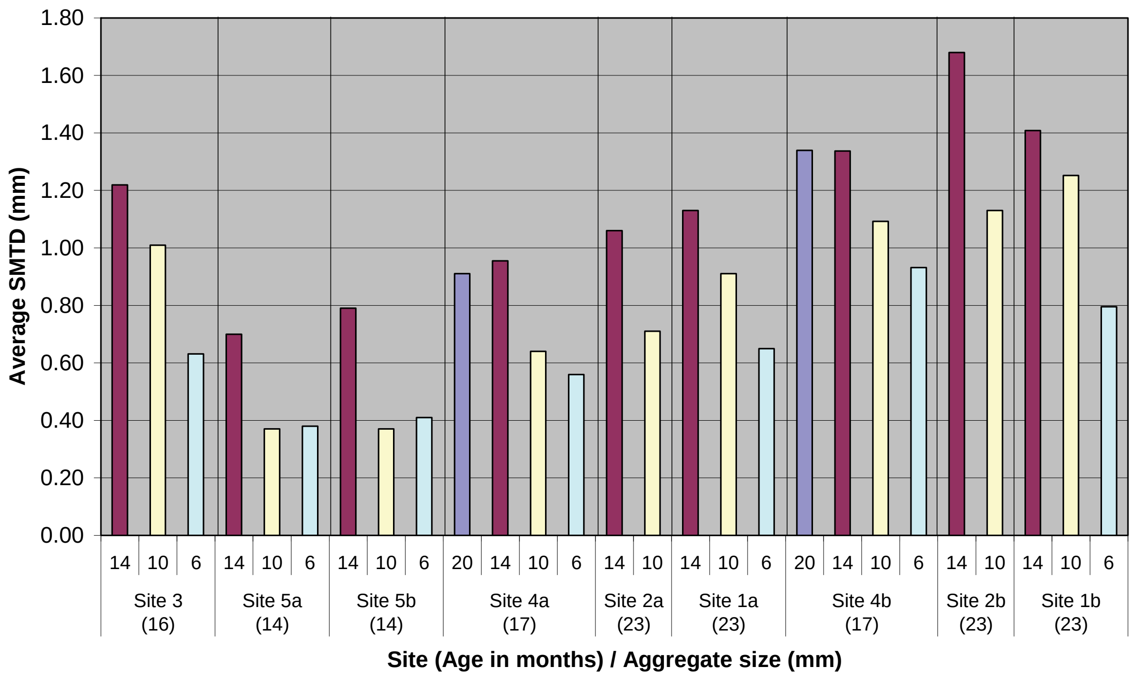

Figure 6.5 Average texture depth (as SMTD) on the trial sections (Autumn 2007)
Sites are arranged from left to right in order of decreasing traffic flow

As would be expected, for the as-new condition (Figure 6.4) the sections with larger aggregate sizes were generally above the then Highways Agency minimum requirement of 1.5 mm (now 1.3 mm for thin surfacing systems such as those used here) but the smaller sizes tended to have less texture, particularly (and not surprisingly) the 0/6 mm materials. Of potential concern was the low texture depth on the 0/10 mm material on Sites 5a and 5b which, at 0.8 mm was already approaching the level where a relatively greater reduction in high speed skid resistance might be expected (Roe, Parry and Viner, 1998).

After some time in traffic, again as would be expected, the texture has changed and Figure 6.5 shows clearly that the smaller-sized aggregate results in much lower texture depth in-service and that increasing traffic also seems to be associated with reduced texture depth. The materials on Sites 5a and 5b have lower texture than their equivalents on all the other sites; the texture on the 0/10 mm and 0/6 mm materials is unusually low.

6.2.3 Wet friction and speed

The results from the wet friction PFT measurements are many and complex and because the sites have not yet reached their equilibrium skid resistance, it would be premature to analyse them too deeply at this stage. In this section, therefore, some illustrative results are presented.

6.2.3.1 Low-speed wet friction

Before considering the effects of increasing speed, it is of interest to consider the friction performance of the trial surfacings at low speeds. This can be assessed using the results from the PFT at 20 km/h. Table 6.2 summarises the average friction measured with the PFT at 20 km/h; the table also includes the numerical values for the average SCRIM Coefficient on each section for comparison (SCRIM effectively measures at a speed of 17 km/h); the results from SCRIM were shown graphically in Figure 6.3.

The PFT measurements at 20 km/h generally show reasonably high levels of wet locked-wheel friction, which would be expected on surfacings that have not yet reached their equilibrium level. As time passes, the differences associated with different levels of traffic and different PSV might be expected to become more apparent.

The trend observed with SCRIM for the smaller coarse aggregate sizes to show higher values than the larger sizes is also observed here. There are exceptions, however: the 0/10 mm material had lower friction than the 0/14 mm on Site 2b and on Site 5b the two smaller sizes show lower friction than the 0/14 mm.

Table 6.2 Low speed friction measurements from the Oct/Nov 2007 visits

Location/Site		Aggregate size (mm)	Average PFT friction at 20 km/h target speed	Average SCRIM Coefficient (at 50 km/h)
A5 Gibbet Hill	Site 1a	0/14	60	0.54
		0/10	60	0.57
		0/6	65	0.61
	Site 1b	0/14	66	0.63
		0/10	66	0.62
		0/6	68	0.65
A5 Tamworth	Site 2a	0/14	†	0.49
		0/10	†	0.53
	Site 2b	0/14	70	0.54
		0/10	67	0.58
A14 Creating St Mary	Site 3	0/14	65	0.53
		0/10	65	0.56
		0/6	72	0.61
A43 Brackley	Site 4a	0/20	58	0.50
		0/14	58	0.51
		0/10	61	0.53
		0/6	72	0.61
	Site 4b	0/20	81	0.55
		0/14	74	0.54
		0/10	80	0.55
		0/6	81	0.60
A14 Thrapston	Site 5a	0/14	64	0.58
		0/10	68	0.64
		0/6	67	0.64
	Site 5b	0/14	76	0.61
		0/10	71	0.63
		0/6	73	0.64

†The data from Site 2a have been omitted because an equipment fault led to anomalous results on that visit

6.2.3.2 Wet friction at higher speeds

To illustrate the effects of friction and speed, results from Sites 5a and 5b have been used. This is the location where two different aggregates have been used, each in three sizes, in the same lane. These sites have been chosen for this illustration because to date they have shown the greatest changes in texture depth since they was laid.

Figure 6.6 shows the friction/speed relationship in November 2006, when the surfaces were about seven weeks old and, judged visually, much of the bitumen on the surface of the aggregate had been removed by traffic action. Figure 6.7 shows the same sites a little over a year later. In both graphs, the aggregate sizes are identified by different symbol shapes and the two Sites with different aggregate sources are delineated by different colours.

For comparison purposes, the graphs include an indication of the band within which HRA surfaces typically fell in earlier research, shown by solid black lines. These lines are derived from empirical models based on the work in Roe, Parry and Viner (1998). They represent ranges and not individual surfaces; the lower bound represents conditions observed in the research, which included older well-polished roads, some with low texture depth.

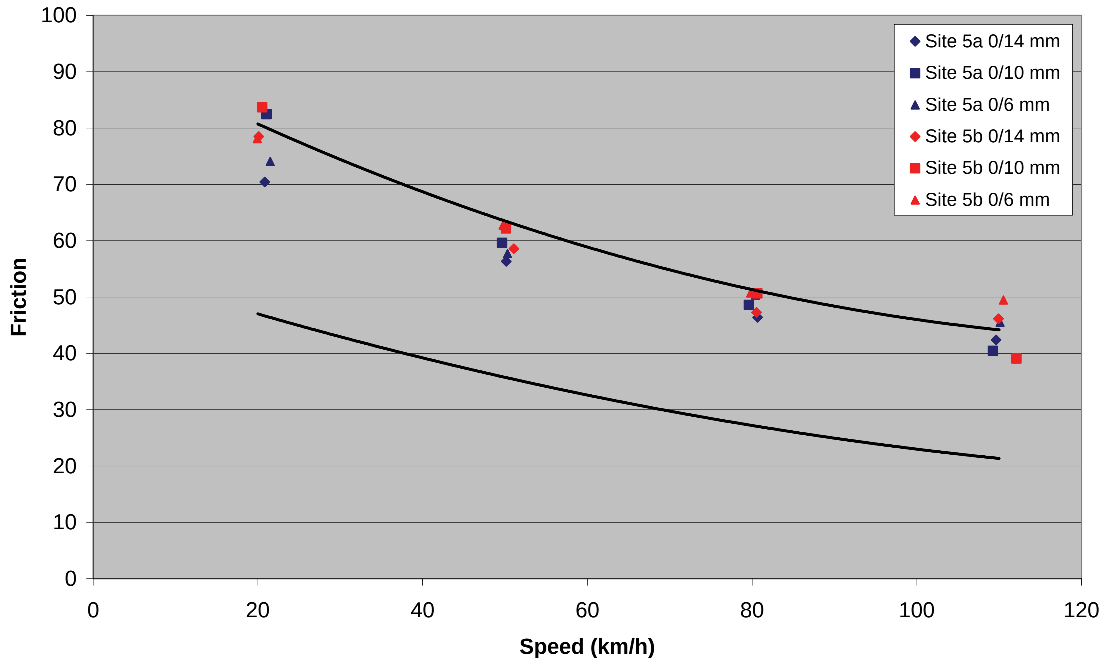

Figure 6.6 PFT locked-wheel wet friction versus speed for Site 5, November 2006

At this stage the surfaces were about 7 weeks old. The black lines show the band within which HRA surfaces were typically found in earlier research.

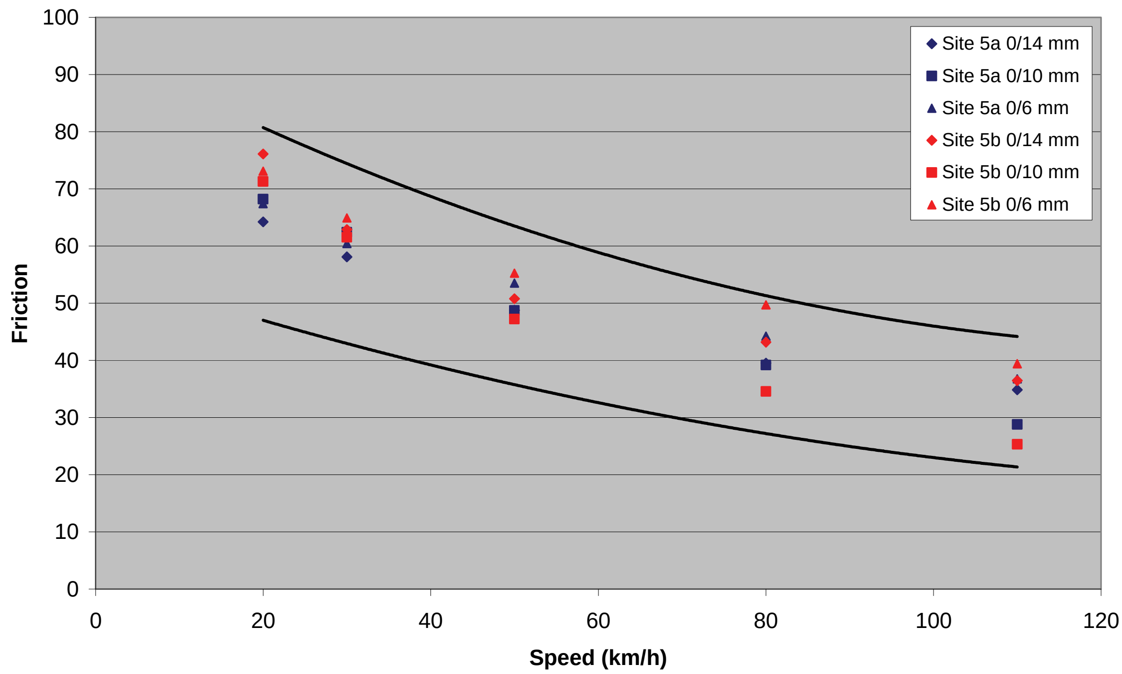

Figure 6.7 PFT locked-wheel wet friction versus speed for Site 5, November 2007

At this stage the surfaces were 14 months old. The black lines show the band within which HRA surfaces were typically found in earlier research.

The graphs show typical behaviour in terms of the relationship between friction and speed. At the 7-week stage (Figure 6.6), the two sites were performing similarly, especially at higher speeds, towards the higher level of the HRA band.

After a further year of traffic, however, the friction generally had decreased, now in the centre of the typical HRA band (Figure 6.7). However, at this time the 0/10 mm material on both sites was beginning so show rather poorer performance at the highest speeds than the other two sizes. This is likely to be an effect of the very low texture depth observed on these two surfaces. Also, the form of the texture on these 0/10 mm sections is not typical of the other trial sites. It will be important to continue to observe these sites, especially during the summer period when friction is generally lower.

Figure 6.8 illustrates the way in which friction has changed over time. For this illustrative example, Site 3 was chosen because it carries heavy traffic. The change in friction with speed can be seen, with the pattern changing gradually as the bitumen wears off and aggregate polishing progresses, with slightly different patterns for the different aggregate sizes and speeds.

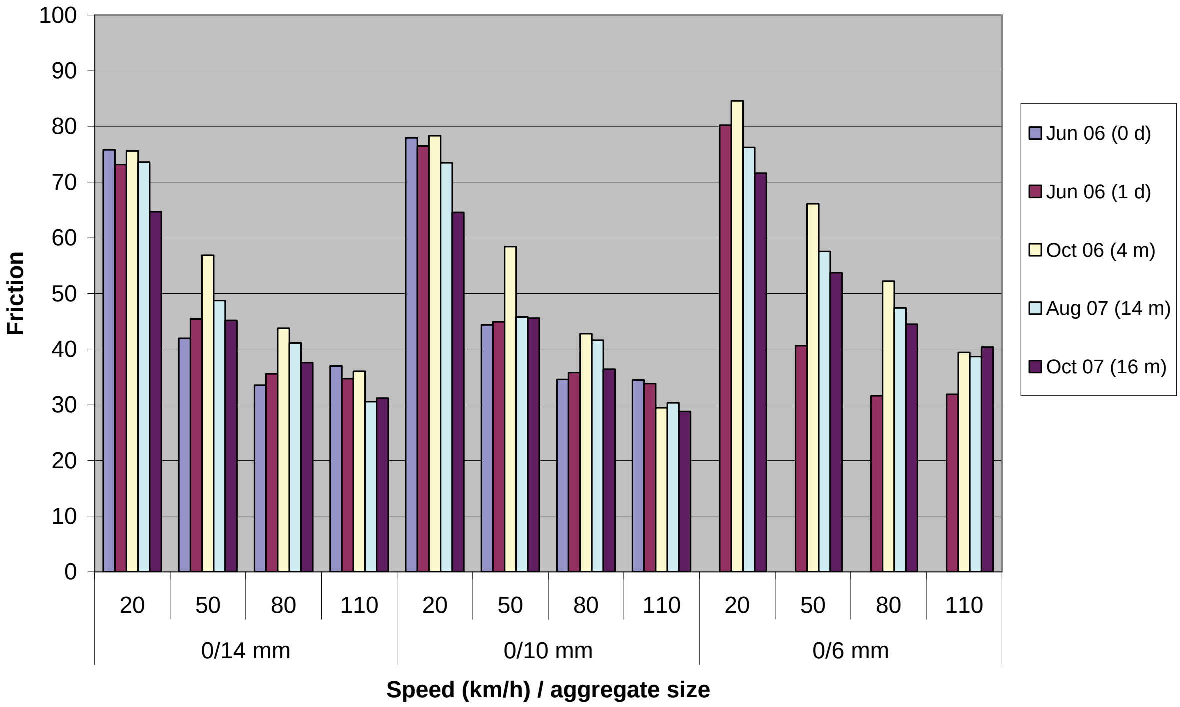

Figure 6.8 Wet PFT measurements from each of the visits to site 3

It can also be seen in Figure 6.8 that the 0/6 mm material has generally higher friction than the 0/14 mm material except at the highest speed when the surfacings were new. Also, the 0/6 mm material shows an apparent increase in friction after 4 months that is maintained or slightly increased whereas at that speed the friction decreases more noticeable after the first few months for the 0/14 mm and 0/10 mm sizes. It is too early to make inferences about these effects but they are likely to be associated with the rate of removal of the initial bitumen coating and subsequent polishing of the aggregate (the 0/6 mm material used a polymer-modified binder that is known to take longer to wear away).

Overall, the values in 2007 fall roughly in the middle third of the “typical HRA” band across the speed range for all three aggregate sizes.

6.3 Results from the laboratory study

6.3.1 Resin mosaics

The results of friction testing carried out in the Wehner-Schulze machine after accelerated polishing (90,000 roller passes) for each of the aggregates tested are shown in Figure 6.9. Each bar represents the average of the measurements from duplicate specimens; the wide white bars in the background represent the grand average value across all aggregate sources. Measurements on the source D specimens in the 6 mm particle size were anomalously low, and this is thought to be due to a higher proportion of a low friction component of the aggregate in this size fraction. In general, the trend is for an increase in coefficient of friction with decrease in nominal aggregate size.

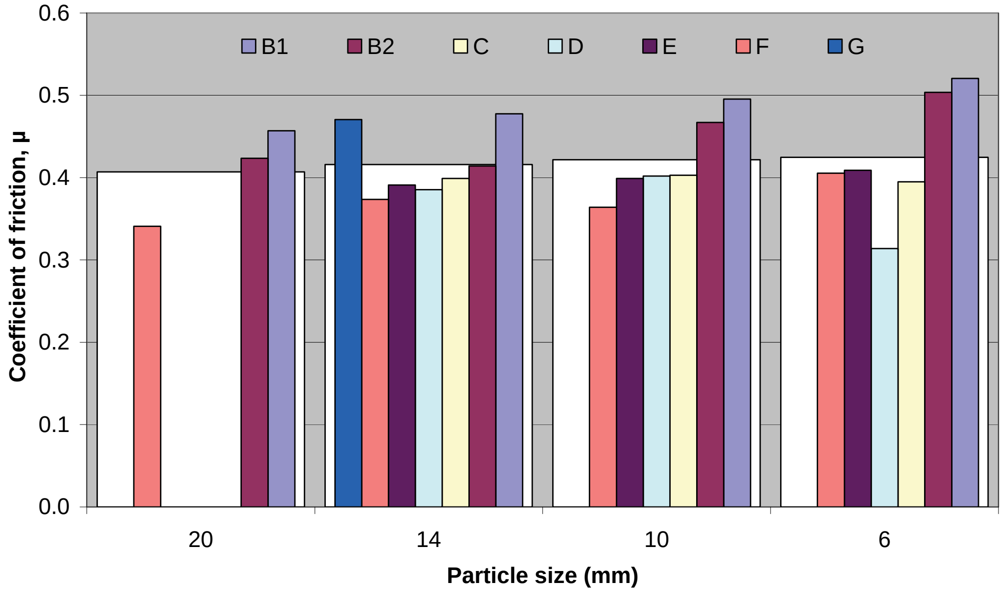

Figure 6.9 μ_{PWS60} against particle size for resin mosaic specimens from different aggregate sources

Comparing the friction measured on 14 mm specimens with that on 6 mm specimens, the increase attributable to the stone size is approximately 0.03 on average, with a maximum increase (stones from source B2) of approximately 0.09. Correlation equations for Wehner-Schulze measurements and pendulum measurements (as used in the polished stone value test) can be found in the literature (Huschek, 2004) and one such equation states $\mu_{pendulum}$=56.3μ_{PWS} + 30.1. It is of interest to note then that the average increase, and maximum increase in friction due to particle size may be of the order of 1.7 and 5 respectively on the scale of PSV measurements.

Figure 6.10 shows the average texture depth measurements made on the various samples using the circular texture meter, which uses a rotating head with a laser sensor. Two values are compared for each stone size. The Mean Profile Depth (MPD) represents the average depth below the peaks of the aggregate particles in the line followed by the laser spot, and so is analogous to the volumetric or patch method used on road surfaces. The root mean square (RMS) texture depth is analogous to the SMTD measurement made on roads. As would be expected, both measurement parameters show an approximately linear decrease in texture depth as the stone size decreases.

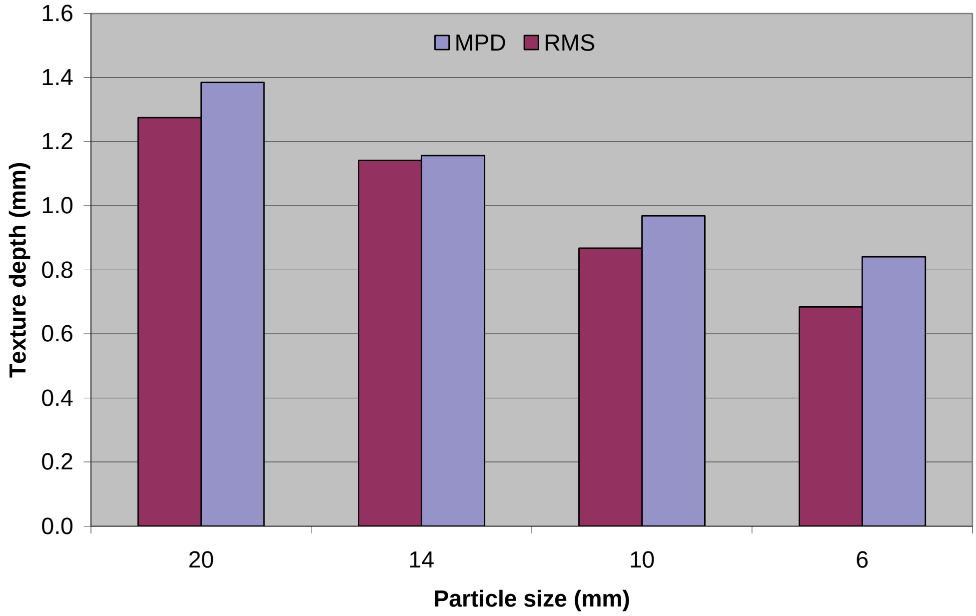

Figure 6.10 Texture depth on resin mosaic specimens

As well as reporting the coefficient of friction at a standard speed, the Wehner-Schulze machine records the coefficient of friction measured throughout the test process, at speeds from 5 km/h to 95 km/h, although the measurements at the outer limits of this range tend to show a significant amount of “noise” in the data. In order to assess whether the texture depth might have an influence on the measured friction, the average coefficient of friction measured on all the samples was calculated for each particle size and plotted against speed in Figure 6.11. The vertical, dashed, black line shows the speed (60 km/h) at which measurements are normally reported (as in Figure 6.9).

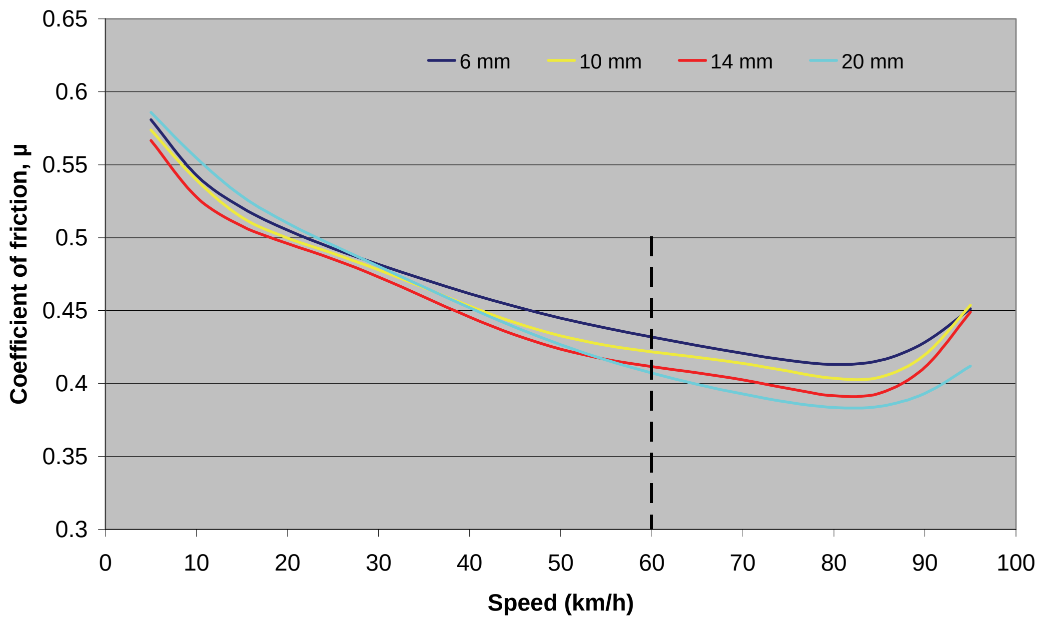

Figure 6.11 Coefficient of friction against test speed

At the standard 60 km/h speed at which measurements are made in the Wehner-Schulze machine the friction increases to a small extent with decreasing particle size. As might be expected, the measured friction decreases as speed increases. The slopes of the curves – that is to say, the rate at which friction decreases as speed increases – are broadly similar for all four particle sizes, but it can be seen that the curves diverge as speed increases and the 20 mm size shows a higher level of friction than the smaller sizes below about 25 km/h (although this curve is based on fewer tests).

It appears that, if there is an effect of greater loss of friction with speed at lower texture depths on the Wehner-Schulze test similar to that observed on the road, it is not obvious in these data. However, this is perhaps not surprising because the range of textures measured on the test specimens were generally above the levels at which marked differences have been observed on the road. Further, it would appear that the increase in friction with the smaller particle size may have offset any small effect due to lower texture depth.

In viewing Figure 6.11, it should be borne in mind that the "friction" axis has been deliberately expanded to show some of the detail in the graph but in practical terms the differences discussed here are generally small; it is unwise to draw too many inferences from this limited data set.

6.3.2 Cores from Site 1

The results of the friction measurements made in the Wehner-Schulze machine on cores taken from Sites 1a and 1b in August 2007 are shown in Figure 6.12. All the cores were tested without accelerated polishing. One from each pair taken from the wheel path also underwent the full Wehner-Schulze procedure and the friction measurements immediately after the second phase of polishing are shown. In addition, error bars show the range of measurements made where more than one core was tested.

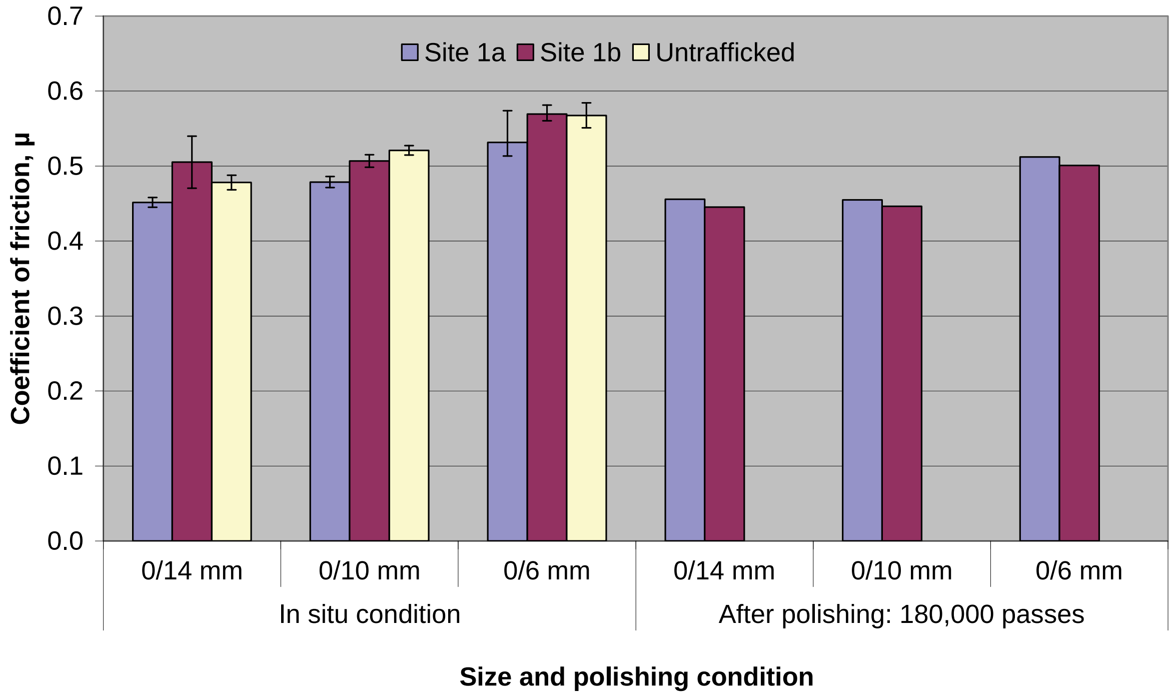

Figure 6.12 Friction measurements on cores taken from Trial Sites 1a and 1b

The results in Figure 6.12 show the same general trend identified in the trial site measurements for 0/6 mm material to have higher friction than the 0/10 or 0/14 mm materials. Table 6.3 compares the µPWS measured on the extracted cores with the skid resistance measured on the trial site at about the same time as the cores were extracted in August 2007. For this purpose, friction measurements from the PFT have been shown at target speeds of 50 and 80 km/h to encompass the tangential speed of 60 km/h used in the Wehner-Schulze measurement.

Table 6.3 Comparison of μ_{PWS} with in-situ skid resistance measurements

Lane	Coarse aggregate size (mm)	μ_{PWS}	PFT wet friction at 50 km/h	PFT wet friction at 80 km/h	SC at 50 km/h
1	0/14	0.445	47	43	0.52
	0/10	0.513	53	46	0.55
	0/6	0.574	55	49	0.58
2	0/14	0.540	58	52	0.62
	0/10	0.581	54	50	0.61
	0/6	0.560	59	53	0.63

The skid resistance measurements were made in August 2007, at about the time that the cores were extracted

As would be expected, the PFT measurements are lower than the SCRIM measurements because of their higher slip speeds. In Table 6.3, the PFT measurements at 50 km/h are higher than the µPWS values and the PFT measurements at 80 km/h are higher than the µPWS values, suggesting a good level of agreement between the two measurement techniques. However, it must be borne in mind that the PFT measured the average friction along lengths of road between 14 and 22 m long whereas the Wehner-Schulze test measured part of the surfaces of two cores.

The μ_{PWS} after the full polishing procedure was generally lower than μ_{PWS} in the as-extracted condition for the trafficked cores (Figure 6.12). This suggests that the standard Wehner-Schulze test induces a greater amount of polishing of the aggregate than had occurred by just over 20 months in traffic. It remains to be seen whether further polishing will occur in situ before the equilibrium level is reached and how this will be compare with the results of the standard Wehner-Schulze test.

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7 Spray

As explained in paragraph 2.2.4, the purpose of this sub-task was to assess the generation of spray on thin surfacing materials, with a particular emphasis on assessing whether different types of thin surfacings had different spray-reducing properties. An initial review of the literature would provide a guide to potential methods for measuring and assessing spray and hence a methodology that might enable the development of a "spray index" for comparing the different surfacings.

7.1 The literature review

The literature review (reproduced in Appendix D) found that extensive past work at TRL had been concerned mainly with the suppression of spray by modification of the vehicles themselves, rather than the effect that the road surface on spray generation.

Spray generation is influenced by a large number of variables that are difficult to control, including:

- Vehicle characteristics.
- Rainfall intensity at the time of measurement.
- Previous rainfall affecting water already on the road.
- Road surface characteristics.
- Road geometry (slope, crossfall, width etc).

Previous work has concentrated on static measurements with passing vehicles to investigate differences between spray vehicle-mounted suppression devices. No standard or established method of measurement was found that could be used in traffic.

The most recent work on spray measurement carried out at TRL (Knight et al, 2005), investigated the suggestion, in literature reviewed for that project, that video showed several potential advantages over traditional laser methods.

7.2 Preliminary trial

Given the resource constraints and specific focus of the Collaborative Programme, a comparatively simple method was needed that could provide a subjective generation spray ranking of different surfaces on the public road, in live traffic.

In the light of the literature review it was decided initially to explore the use of video photography to record spray generated by a vehicle ahead of a car in rainfall under normal traffic conditions.

To test the feasibility of using a photographic recording method from within a car, an observation run was performed around a selected route on a wet day.

7.2.1 Route

A circular route was devised that used motorways and principal roads local to TRL which would present lengths of both HRA and thin surfacings. This comprised a circuit of the A329(M), M4, M25, M3, and A322, to be driven clockwise in Lane 1, as listed in Table 7.1 and illustrated in Figure 7.1. The figure shows the surfacings for the HA managed part of the circuit for Lane 1 in both directions, as derived from the HAPMS. The HAPMS database has the capability to sub-divide thin surface course materials into categories. These include those with polymer-modified bitumen ("Polymer"), fibre additives ("Fibre") or a general category, presumably where the greater level of detail is not known ("Generic"). In the case of the sections on the study route, sections were allocated either to the "Polymer" or the "Generic" categories; for convenience, in Table 7.1 and Figure 7.1 these are combined under the general heading "Thin surfacing".

Table 7.1 Route description – clockwise circuit

Road	Approx distance (km)	Predominant surface type in Lane 1
A329(M) (Bracknell – M4 J10)	4.5	HRA
M4 (J10-J4b)	29.2	HRA
M25 (J15-12)	12.2	Thin surfacing
M3 (J2-3)	9.7	HRA
A322 (M3 J2 – B3430)	5.0	Thin surfacing
Total	60.6	

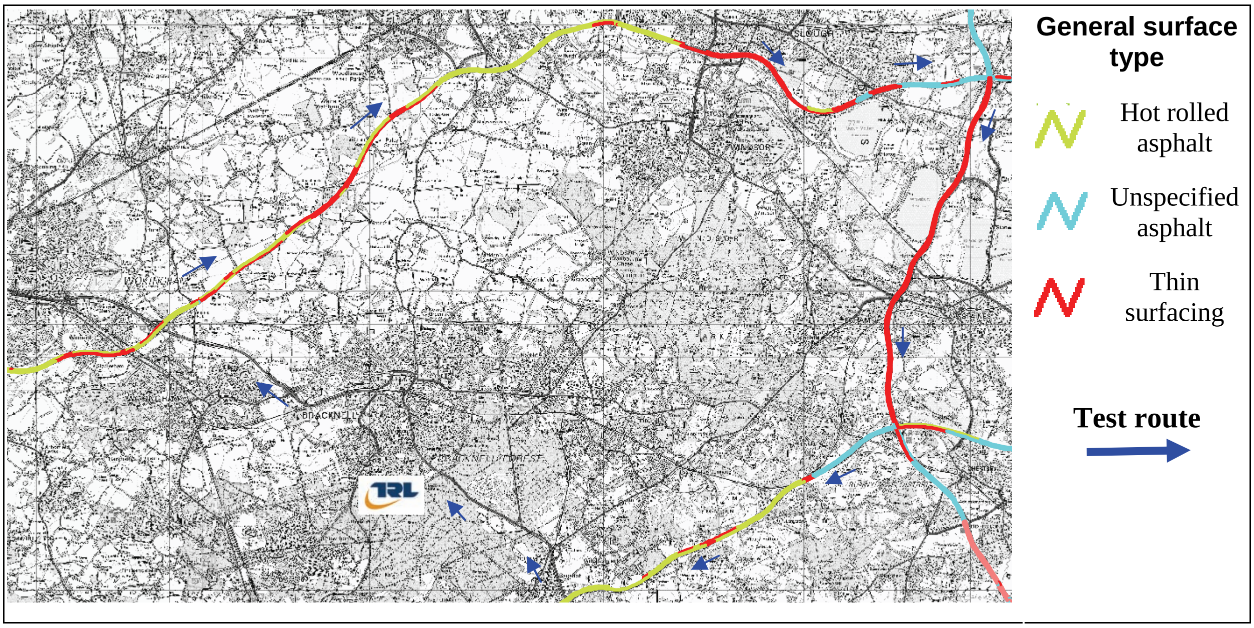


Figure 7.1 Map of trial route with general surface type

7.2.2 The trial recording run

A mini digital video (DV) camera was mounted in a car, facing forward through the swept area of the passenger-side windscreen wiper. The camera recorded continuously throughout the run, while the car followed a variety of vehicles. The resulting video recording was transferred to a DVD disk for ease of viewing on a computer.

A natural difficulty in this type of work is that it is not possible to control the weather conditions. Although a wet day was chosen, it was found that during the trial circuit the rainfall intensity varied markedly, from very heavy rainfall to virtually dry conditions.

Notwithstanding the variation in rainfall conditions (and the consequent level of spray generated by vehicles), this exercise showed that photography was a viable method of recording the conditions throughout a run. However, it also highlighted the inherent difficulties in visually assessing the effect of spray when following a random selection of vehicles even under essentially similar rainfall conditions.

7.3 Choice of method for further investigation

Given the limitations of video recording shown by the preliminary run, a methodology was sought for further investigation. A possible approach was to use a target vehicle with a fixed target board on the back that could be filmed and the effects of spray assessed against that.

A paper of particular interest in the literature review was that by Puclin and Watkins (1996) which had investigated video methods and the best type of target to use. With a uniform black target, the “grey level” was measured and it was found that the calculation method used produced consistent measurements of spray density across varying ambient lighting levels.

Puclin and Watkins’ paper was based on work with vehicles passing a static camera and target but it was considered that the technique might work in a mobile context. As a calibrated digital luminance camera system was available at TRL, it was decided that less-subjective results might be obtained by using this to photograph a large plain black target mounted on a leading “target” vehicle.

The use of a calibrated luminance camera was expected to eliminate some of the problems caused by variations in the ambient lighting level (Knight et al, 2005). Retaining the video camera would simultaneously provide a complete visual record of the spray during the run.

7.3.1 Target and target vehicle

A suitable target vehicle was identified from within the TRL fleet in the form of a mini-bus that already had been modified with the fitting of a roof platform and access ladder for use in other photographic studies. A rectangular target board that could be attached to the rear of this mini-bus was fabricated from plywood and painted matt black. Cut-outs provided the legally required visibility of the number-plate and rear lights. The bottom edge of the target was supported on steel brackets at rear bumper-bar level and the top was extended to reach the base of a pair of amber beacons which were mounted on the roof platform. The target was securely bolted in position; the bolts and washers were also painted black. Figure 7.2 shows the target mounted on the vehicle as seen from behind during a test run in wet conditions.

Figure 7.2 Target board mounted on mini-bus (during a trial run)

7.3.2 The luminance camera

The luminance camera is part of an “LMK Mobile” system supplied by Techno-Team Bildverarbeitung GmbH. The system comprises a photopically calibrated digital camera and “LMK 2000” luminance analysis software.

The photopic calibration is to a standardised spectral weighting curve designed to represent human sensitivity in daylight. The camera contains a Charge Coupled Device (CCD) image sensor which is divided into 1280 x 1024 square pixels. Each pixel responds to the amount of light which falls on it during an exposure. Each pixel is behind an element of a “Beyer Matrix” filter which is green, red or blue, arranged in square groups of four (two green, one red and one blue). The camera digitises the captured level for each image pixel on a 10-bit scale and the resulting “raw” data is stored. No further processing is carried out by the camera.

From the raw data, software can create a colour photographic image. However, the LMK 2000 luminance software applies calibration data to the raw data from each pixel of the image and creates a numerical map of the luminance calculated from each group of four colour pixels. The luminance resolution of the resulting image is therefore half the full resolution of the CCD. The luminance map can be displayed in either a greyscale or a false-colour representation. The luminance at any point can be read, as can be the average luminances of multiple regions defined on the image by the user.

When remote-controlled the luminance camera can acquire an image to a host computer every 30 seconds.

7.3.3 Arrangement of the cameras in the following vehicle

The luminance camera was mounted alongside the mini DV camera in a car which would follow “target vehicle” around the test route under wet conditions to record the luminance of the target. The arrangement is illustrated in Figure 7.3.

Figure 7.3 Cameras mounted on an “Autopole” in front of the passenger seat looking through the windscreen

The mini-DV camera could record continuously for about 1 hour on a standard tape, which was sufficient for a typical circuit of the designated route. A laptop computer was used to run the remote control software for the camera and store the resulting images. Initial concerns with rechargeable battery life for the cameras and computer were eliminated by providing DC/DC converters for each, running on the 12V DC available in the car.

The preliminary run with the video camera had demonstrated that interference from the windscreen wipers was minimal as was, in moderate rain, interference from water on the windscreen. This arrangement was used to make traverses on the test route (the number of successful runs being limited by the occurrence of both rainy conditions and the co-incident availability of the test team), using the methodology described in Section 7.4.

7.4 Measurement and initial analysis methodology

7.4.1 Measurement runs

Three successful measurement runs around the test route were performed: two on the 14 August 2006 during moderate rainfall and one on the 9 October during very heavy rainfall. Of the two runs on the 14 August, the second was selected for analysis because the rain was heavier and there was more spray during this run.

The camera car followed the target vehicle around the route at as constant and as safe a distance as possible for the prevailing conditions. The digital clocks in the car, the computer and the video camera were synchronised to within a few seconds before the runs so that all the records could be aligned for analysis.

As well as making the photographic recordings, an observer in the camera-car noted marker-post distance labels and the time of day at frequent intervals on each run. (Marker posts are positioned at 100 m intervals alongside the hard shoulder, labelled with their distance from the start of the motorway.)

7.4.2 Video

The video camera was used to record throughout each run. It was aligned and set to record mode at the start of each run and needed no further attention. During subsequent analysis the video could be used to cross-check positional information and the locations of luminance images using the elapsed time display in the playback software and recognisable features of the route.

7.4.3 Luminance camera

The luminance camera was aligned so that the captured image was approximately centred on the target. During each run the camera was used to take a single frame every 30 seconds. The saved files were automatically named using the date and time to the nearest second, providing a reference which could be correlated with the manually-recorded marker-post transit times.

The camera remote-control software was used to set the maximum focal length and automatic exposure control. This arrangement worked satisfactorily for most of the exposures.

7.4.4 Analysis of spray measurements

After the measurement runs, the luminance images were listed sequentially in a spreadsheet together with their time of acquisition. The recorded marker-post chainages were then inserted against this list using their observed transit times. It was found that marker posts were not recorded for all of the images and marker posts did not occur exactly at the times of the images. This caused some scatter in the plot of position versus elapsed time, so a smoothed curve was fitted and used to interpolate position data for all of the images. This was expected to improve the accuracy of the location data.

The position of the first luminance image was found in the video recording to establish the elapsed time during the run prior to this image being taken. This time was then used as a basis for calculating the elapsed times in the video recording corresponding to each luminance image. The video could then be used as a cross-check on the interpolated image locations.

7.4.5 *Luminance analysis*

For analysis, the target on the vehicle in each image was divided into a number of rectangular areas representing different spray and lighting conditions. These are shown in Figure 7.4, which shows two examples of calibrated false-colour images produced by the luminance camera system.

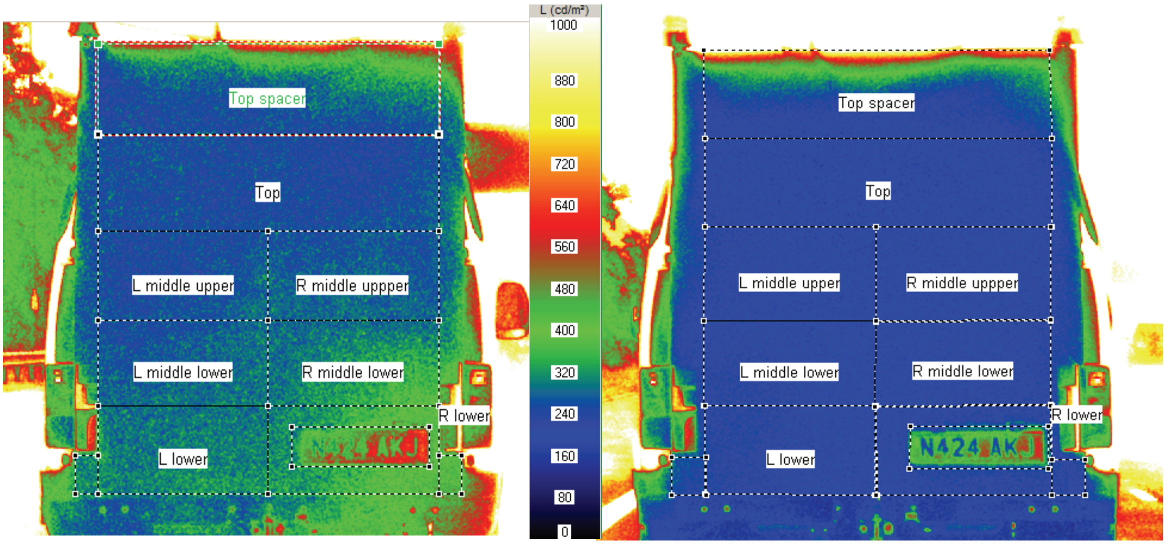


Figure 7.4 Comparison of false-colour luminance images
with spray (left) and without spray (right)

For each run, selected images were processed and the average luminance of each illustrated rectangular region was calculated by the software. These values were transferred to a spreadsheet for further analysis.

The concept of the assessment method is that the luminance of the spray seen against the black target will be a function of the density of the spray. However, the luminance will also be affected by the ambient illumination. The technique would be unlikely to work if the lighting was direct sunlight, due to the angle of the illumination varying around the route. With the diffuse illumination provided by full cloud cover, the lighting is from all directions thus providing more uniform conditions. As there is likely to be complete cloud cover during prolonged rainfall events, the effect of direct sunlight is not likely to be a problem and proved not to be during the trial runs which have been analysed.

The effect of the varying level of natural illumination was eliminated by dividing the luminance of each measuring region by the luminance of a relatively spray-free region near the top of the target, labelled “Top” in Figure 7.4[2]. The resulting ratio provides an index value correlated with the density of the spray (“normalised luminance”). The value for zero spray on this scale is therefore 1.0, while the upper end of the possible range is limited only by the luminance range of the camera.

7.4.6 *HAPMS surface-type data*

The surfacings for the part of the route managed by the HA are recorded in HAPMS in general terms (see 7.2.1) and these were extracted and correlated with the marker post locations. For the non-HA

[2] The upper region labelled “Top spacer” was not used because “bleeding” of luminance from the sky around the top edge of the target, which can be seen in the images, would cause an error. It is believed that this bleeding is due to the scattering of bright light by the camera lens.

sections, which were the A329M and the A322 the surface types were determined by visual inspection.

The surface types were transferred to the analysis spreadsheet and aligned with interpolated image positions. The histogram function in the spreadsheet was then used to plot frequency histograms of the luminance ratios

7.4.7 HAPMS texture depth

It is reasonable to suppose that spray generation is likely to be influenced not by surfacing type *per se* but by the texture depth, its shape and form. Texture depth is recorded in routine surveys on the HA network and average values for SMTD (sensor measured texture depth) are stored in HAPMS for 100 m lengths of route.

These values were extracted for the test circuit. It was observed that there is often considerable variation in the texture depths between adjacent lengths of the same surface. As the accuracy of the positions of the luminance images for the trial runs was unlikely to be better than several hundred metres, it was decided to use the average the texture depth of three adjacent sections to represent the texture depth associated with each image.

7.5 Results from luminance camera runs

7.5.1 Data from the 14 August 2007 trial run in moderate rain

It was clear from the analysis of the trial data from the 14 August 2007 that, as might be expected, the lower corners of the target board were the areas most affected by the spray generated by the target vehicle. It was therefore decided to limit the analysis to the results obtained from two small regions of the target located in these corners, as this would demonstrate the maximum possible sensitivity of the method. These areas were designated the "Left" and "Right" "Extensions" and are marked, but not labelled, on Figure 7.4. The normalised luminance ratios for these two target regions are shown in Figure 7.5, plotted against surfacing type (for thin surfacings and HRA) as recorded in HAPMS.

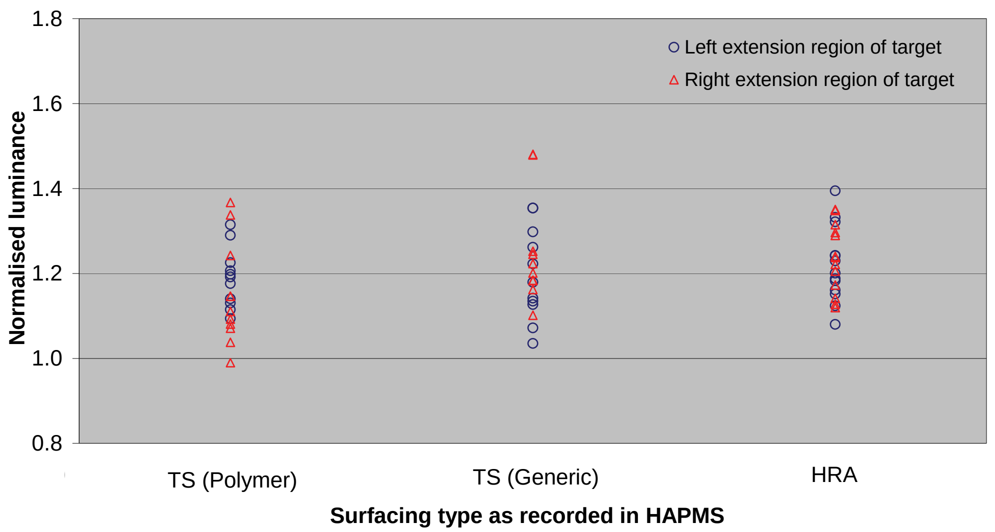
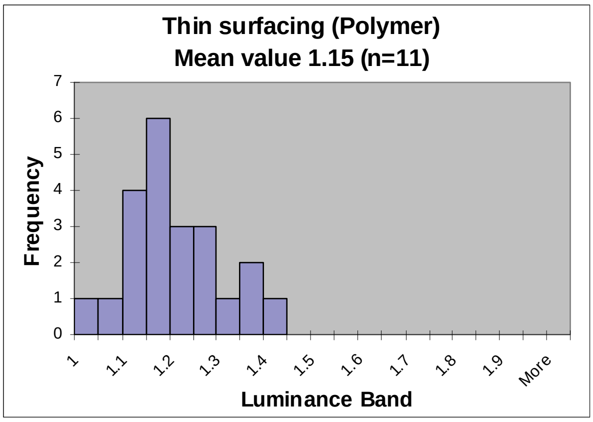
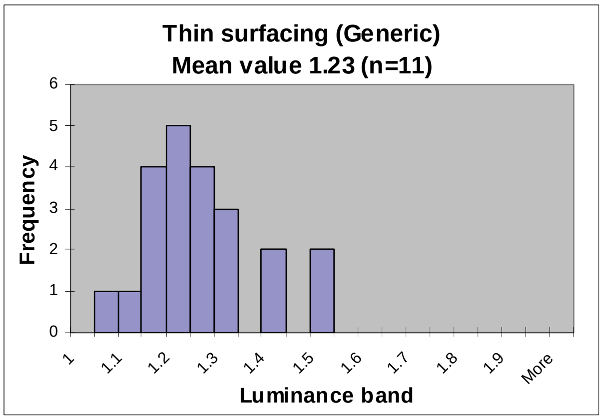


Figure 7.5 Luminance ratios of left and right extension target regions versus surface type

Not surprisingly, there is considerable scatter within each surface type and little difference can be seen between the left and right extension region data. There appears to be a slight trend towards HRA producing higher values than the thin surfacings and for thin surfacing (Generic) to produce higher values than thin surfacing (Polymer) as recorded in HAPMS. However these differences are not significant due to the wide scatter and the number of higher points being very small.

Given the spread of results for each surface type in Figure 7.5, it is helpful to visualise the shapes of the distributions of the luminance ratios for each HAPMS surface type. Therefore, in Figure 7.6, the normalised spray luminance data for have been plotted as a frequency histogram (together with mean values and total number of points) for each surfacing type.





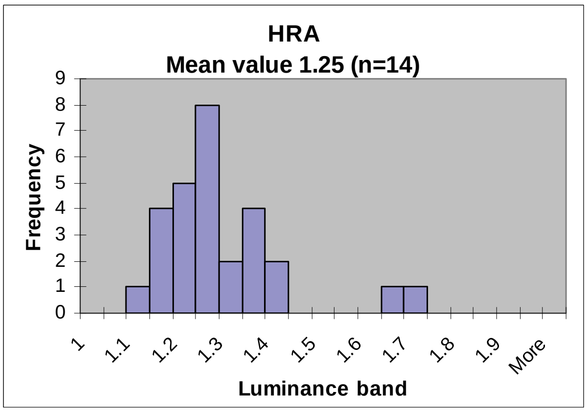


Figure 7.6 Frequency distributions for normalised spray luminances on three surface types
(n = total number of observations)

To allow these distributions to be compared more easily they were normalised to a peak value of 1.0 and superimposed, as shown in Figure 7.7.

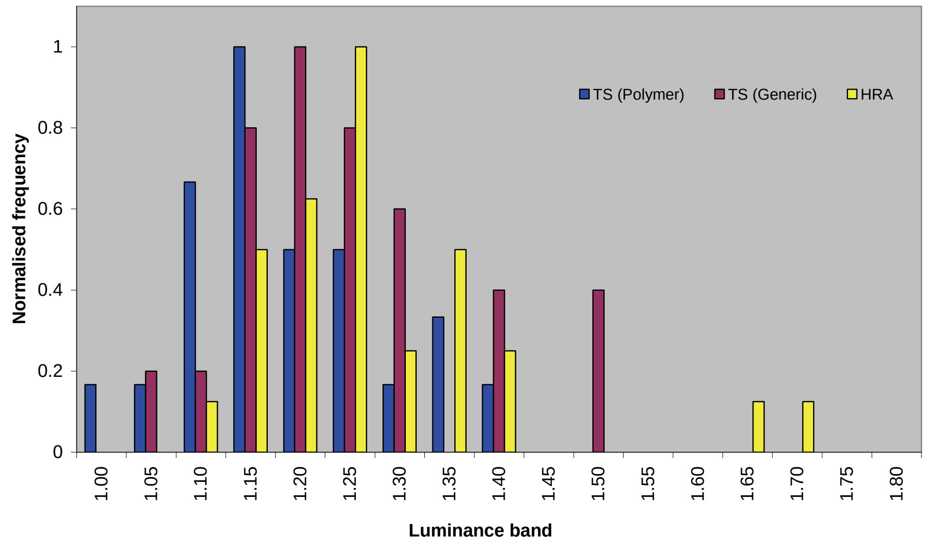


Figure 7.7 Comparison of normalised frequency distributions

This comparison shows that the measured distribution for the HRA is shifted slightly to the right (higher normalised spray luminance band) than the thin surfacings and the distribution for the TS (Generic) is slightly to the right of the TS (Polymer). However these effects are very small. This suggests the order of spray generation ranking for these data.

The normalised luminances were also plotted against the texture depth (see Section 7.4.7) for the images that had been analysed where the texture depth information could be found in HAPMS. Figure 7.8 shows the normalised spray luminance ratio for the average of the left and right extensions plotted against the average SMTD in the area for the image. As can be seen from the horizontal trend line, there is no correlation, which implies that texture depth had no influence on spray generation in the conditions of this survey run.

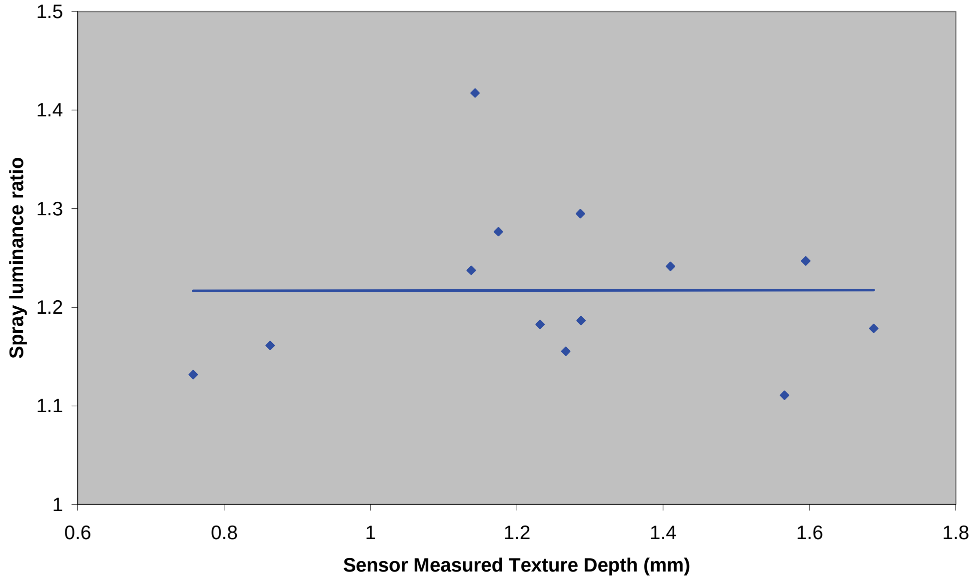


Figure 7.8 Average spray luminance ratio in "lower extension" zones for a range of texture depths

7.5.2 Results of the 9 October 2007 trial run in heavy rain

The trial run in heavy rain on 9 October 2007 provided very different conditions from those encountered in the August run. This is illustrated in the colour photographs, taken from luminance camera images, shown in Figure 7.9 to Figure 7.12. These photographs compare the conditions on two types of surface during the two survey runs. The pictures represent the same general length of surfacing in each case (based on the elapsed time and marker post information described earlier), although they are not in exactly the same place.

The rain on the 9 October was extremely heavy and the surface texture was full of water in nearly all locations. The wheel-tracks, just visible in Figure 7.11 and Figure 7.12, demonstrate this. The flooding of the surface texture resulted in very heavy spray generation. It was found that the luminance ratio method no longer worked in these conditions because the intensity of the spray meant that there was little gradation of luminance from the bottom to the top of the target.

Visual assessment during the run and of the video record suggested that, as can be seen in the examples illustrated, there is negligible difference between spray generation on the HRA and the thin surfacing when the texture is flooded.

Figure 7.9 HRA on M4 in moderate rain

Figure 7.10 Thin surfacing on M4 in moderate rain

Figure 7.11 HRA on M4 in heavy rain

Figure 7.12 Thin surfacing on M4 in heavy rain

7.6 Discussion of the results from the spray study

It was clear that the luminance ratio method was able to detect spray when the rain was moderate and the surface texture was not flooded, however it failed when the rain was heavy, because the spray generation was so great that the whole target area produces a similar luminance. There was no longer an area with minimal spray near the top of the target to use as a reference for the ambient light level.

However it was also clear that the texture of all the surfaces was flooded with water during the run in heavy rain and no subjective difference in spray generation between different surfaces was visible.

Improvements which might improve the method include:

- Use a white and black chequerboard target and measure the contrast between the white and black as the measure of visibility. This has the potential to be effective even during very heavy spray. Contrast is also the visual parameter by which drivers are able to detect objects.
- Use a target vehicle which generates more spray, such as a heavy lorry. It is clear from the videos and observation during the runs that heavy vehicles produce many times as much spray as light vehicles.
- The interval between photographs could be shortened, although this would generate larger data volumes and would have implications for the analysis time required.
- More accurate location data could be obtained by recording co-ordinates from a GPS system mounted on one of the vehicles.
- Better control of the camera to target distance.
- Use of Met. Office rainfall radar data, which has 1km spatial and 5 minute temporal resolution, to determine the rainfall in a short period immediately preceding the passage of each grid square traversed by the route.

8 Concluding remarks

Topic 1 of the 2004/07 HA/QPA/RBA Collaborative Programme set challenging objectives for this three-year project. Although significant progress has been made over the three years, the nature of the work means that this is necessarily an interim report. Therefore it is premature to attempt to draw conclusions at this stage. Nevertheless, some comments may be made to summarise the work and points that are emerging which should become clearer as the next phase of the Programme proceeds.

8.1 The database study

This component of the project was intended to make use of existing data to compare the performance of modern thin surfacings in-service with the current requirements for the PSV of the coarse aggregate related to traffic levels. The concept was to draw together information from routine skid resistance monitoring with data regarding the make-up of the surfacings.

Unfortunately, as had been anticipated as a possibility at the outset, this proved unsuccessful. Despite the quantity of thin surfacing materials that have been used on UK trunk roads in recent years, records (both within the surfacing industry and the Highways Agency) were inadequate to enable enough relevant information to be brought together. This inherent difficulty was compounded by the fact that only a relatively limited range of aggregates had been used on the network and this limited the scope of any potential analysis.

An attempt was made to compare the data that were available with information from past research on traditional surfacings (which had suffered similar data-collation difficulties). This showed a slight tendency for thin surfacings to give greater equilibrium skid resistance at low speeds than older HRA surfaces using chippings from the same nominal sources, but the differences were not statistically significant and no rigorous conclusions could be drawn.

8.2 Trial Sites

An important part of the project was the establishing of a number of trial sites in which thin surfacings using the same aggregate in different coarse aggregate sizes could be compared under the same traffic and environmental conditions. The original intention was to use data from these sites primarily to validate any predictive models that might have emerged from the database study but in the event they have become a major focus of the work.

As well as enabling a direct comparison of the low-speed skid resistance (as measured by SCRIM, the device used for network maintenance assessment) of the different aggregate sizes, the sites provided an opportunity to study the friction performance of the materials at higher speeds. This would be particularly important where smaller aggregate sizes were concerned because of the relatively lower texture depth that typically results. An expected effect of low texture depth is greater reduction in wet friction at high speeds; it will be important therefore to establish whether smaller aggregate sizes show this effect and whether it might be offset by any increased skid resistance provided by the smaller aggregate.

In the event, five sites were established, covering a range of traffic conditions and aggregate PSV. By laying the trial sections on both lanes of dual carriageways in some instances, two levels of traffic could be compared at one location. A sixth site which combined relatively low PSV with very heavy traffic was established, but this entered service too late to be monitored in this phase; it is envisaged that it will be included in the next phase of the Collaborative Programme.

Construction of the new asphalt surfaces allowed their early-life skid resistance to be assessed; this proved to show similar behaviours to that observed in or inferred from earlier research.

At the time of writing, the sites are at different stages of the process of wearing away the bitumen from the surface to expose the aggregate and for the aggregate to polish to its equilibrium skid resistance level. For this reason it is not possible to draw general conclusions but it appears that all sites are showing a trend for 0/6 mm mixtures to provide higher skid resistance than 0/14 mm materials both at low and high speeds, even with relatively low texture depth on the 0/6 mm surfaces. However, it remains to be seen whether these differences will still exist or will be of practical significance once the surfaces have polished to their equilibrium levels.

8.3 Laboratory studies

It was recognised that it would not be possible to study a full range of aggregates in different sizes on the road and therefore a procedure was needed that might make it possible to study factors such as aggregate sizes over a wider range of PSVs in the laboratory.

At about the time that the scope of the 2004/07 Programme was being established, a new procedure that had been developed in Germany was being assessed at TRL for Highways Agency. It was therefore decided to include a small programme of tests with this equipment in the Topic 1 programme.

Samples of the aggregates that had been used in the trial sites were used for this work and the tests on specimens prepared using aggregates only have suggested that in the laboratory smaller aggregates give greater friction after polishing, although the differences seen to date have been small.

Tests on cores taken from the trial sites are being used to compare the measurements made in the laboratory with skid resistance measurements on the roads and early indications are that the laboratory friction test gives broadly comparable results to those from the test vehicles.

It remains to be seen how the friction developed through the standardised polishing procedure compares with the equilibrium skid resistance achieved on the road under varying traffic conditions, but the work suggests that this technique could be a useful standardised method for further study of a wider range of aggregates, both as aggregates alone and in asphalt mixtures.

8.4 Spray

This small component of the overall programme was intended to assess whether it might be possible to make an objective comparison of the amount of spray generated by traffic on different types of thin surfacings.

A mobile photographic method was trialled and this was found to provide a feasible way of measuring spray in traffic under moderate rainfall conditions when the surface texture is not flooded with water. However, it failed when the rainfall was heavier and the surface texture appeared flooded.

The system was used on a circuit comprising mostly motorways that included both HRA and thin surfacings. No significant differences in spray generation by the target vehicle were detected between the different surfaces, either in moderate or heavy rainfall conditions.

9 References

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Appendix A. Summary of the review of lighting requirements

A.1 Introduction

A feature of thin surfacing systems that was considered as a possible topic for inclusion in the 2004/07 Collaborative Programme was the way in which the surface characteristics might affect lighting requirements in comparison with traditional surfacing materials. An initial review was therefore carried out as part of the scoping phase of the Programme. Although some suggestions were made for further ideas to include in the scoping process, it was decided not to pursue these or to take this topic further in the 2004/07 programme. For the record, the findings of that initial review are summarised here.

The requirement for the first stage of the work covering lighting was to review the current advice on lighting design and, specifically:

- to assess the level of information available about different road surfaces;
- to determine the conditions where further information about surface characteristics is needed for lighting design purposes.

Although the project Steering Group decided not to pursue this topic further within the 2004-07 Collaborative Programme, some initial ideas for future work were suggested in the original review and for completeness these have been included.

A.2 The current situation regarding surface properties and lighting design

A.2.1 The concept of "luminance" and use of "r-tables"

The design of street lighting for trafficked streets is based on how well-lit a road surface is, as seen from the viewpoint of drivers of vehicles. This is primarily affected by the light-reflecting properties of the road surface but they are also greatly influenced by other physical factors. For example, the light output of the lamps and the design of the luminaires that house them determine the intensity distribution of the light leaving the luminaire. The height and spacing along the road of the columns affect the amount and intensity of light reaching the road, the way it varies from point to point and how it appears to a driver some distance away.

Current standards are based on a parameter representing the appearance of the road surface known as "luminance". This is a complex concept that takes into account the quantity of light reaching the driver's eyes and how it is scattered by the surface.

Although the theory is complex, for design purposes, luminance at any particular point of the road is calculated from three parameters: "r" (the "reduced luminance coefficient", representing the properties of the road surface); "i" (a parameter representing the intensity of light from the luminaire) and "h", the height of the luminaire above the road. Values for r and i are set out in tables (known colloquially as the "r-tables" and "i-tables") that have values for each point on the road. An r-table contains 396 values and covers an area of road 17h long by 5h wide, where h is the height of the luminaire above the surface.

The total luminance at any particular point is a superposition of the contributions to the light levels made by adjacent lighting columns and this must also be taken into account in the design of the lighting scheme.

In addition to the average luminance of the surface, other parameters that are taken into account include longitudinal and overall "uniformity", which provide an indication of how the luminance varies along and across the road. Current British Standards for lighting design recommend minimum thresholds for average luminance values and overall and longitudinal uniformity values for six classes of road.

A.2.2 Classification of road surfaces for lighting design

In principle, there could be a different "r-table" for every road surface but, in practice, this has been simplified and the British Standard (BSI, 2003) sets out two generalised tables based upon "average" surfaces. Road surfaces are allocated to "classes" depending upon their "specular factors", described by a parameter known as "S1". Specularity describes a scale from mirror-like (highly specular, light reflected in only one direction) to fully diffuse (light reflected in all directions equally) reflection. For lighting design purposes in the UK, all road surfaces (except porous asphalt) are placed in one of two classes (known as C1 and C2) depending on whether or not their S1 level is less than 0.4 (higher S1 = more specular). Porous asphalt has been placed in a class of its own. An earlier approach to classification with different classes (R and N) and a larger number of classes is still much used in Europe.

Each r-table is normalised using a further scaling factor, the "average luminance coefficient", Q_o. This parameter represents the "lightness" of the road surface and may be affected by the colour of the aggregate and bitumen, their relative proportions exposed in the road surface and the surface texture.

In the British Standard the first of the r-tables presented is for the "representative British road surface". It is, in effect, based upon an average perception of traditional rolled-asphalt and surface-dressed roads and is placed in class C2. This table is drawn for a nominal Q_o of 0.07. The second table in the Standard is for "the concrete road surface" which, is also taken to lie in class C2, but with the higher Q_o of 0.10.

The international document from which the tables are taken notes that;

"the normalised values of Q_o are selected to represent roughly the average Q_o value of road surfaces occurring in each class. Since variations of more than 30% from the normalised Q_o values may occur, it is advisable to rescale the values for the actual road surface."

The British Standard reflects this dilemma in that, even though it presents r-tables to represent "average" roads, it also states that *"Care should be taken to ensure that the r-table used does in fact represent the road surface that exists or is to be provided."*

Due to the lack of a simple method of measuring Q_o quickly and easily, it is believed that, in practice, the published r-tables are almost invariably used as given, without this adjustment. The table for Class C2 is published in the Standard normalised for $Q_o = 0.07$. There is very little data available on actual measured values of Q_o and S1. This is likely to be leading to design weaknesses with modern thin surfacings which may not be adequately represented by the "average" values. Their reflection characteristics may be more akin to porous asphalt than to hot-rolled asphalt, but this has yet to be established and this is therefore one of the issues that the research in this sub-task will need to address.

A.2.3 The problem of wet roads

It is observed that some types of thin surfacings are able to "store" water within the surface structure and this means that the surface can remain wet or damp for longer after a period of wet weather than older types of material and this may also have implications for lighting design.

However, there are no standard r-tables for wet roads, although the CIE/PIARC document recognises that *"all road surface conditions between completely dry and completely flooded will be encountered in practice"*. As the reflective properties of a surface will change continuously throughout this range, this presents a design difficulty. The British Standard recognises that the problem exists and says that both wet and dry conditions should be considered where a road is likely to be wet for a significant part of the hours of darkness. However, apart from indicating that calculations should use r-tables appropriate for wet roads, there is no guidance as to the source of such tables.

A.2.4 Recent work at TRL

In recent work carried out by TRL, the reflective properties of different types of thin surfacings and established road surfacing materials were studied. A total of 84 cores of 9 materials from 19 in-service pavements were obtained. Measurements were made of the average luminance coefficients (Q_o) and the specularity parameters (S1).

It was found that Q_o ranged from 0.043 to 0.051 for asphalt road surfaces, including "negative-textured" surfacings, while values of 0.078 and 0.081 were obtained for concrete surfaces. There was little variation in Q_o values between sites for the bituminous materials, except for surface dressing. However, the average HRA result of 0.05 was similar to those obtained for the thin surfacings and porous asphalt and was well below the value of 0.07 normally assumed in lighting design.

The values measured for S1 ranged from 0.32 to 0.74 for the asphalt materials and this would place several of these materials in Class C1, whereas following the British Standard they would commonly be assumed to be in Class C2. Clearly, there are implications here for the appropriate "r-table" values to be used.

A.3 Measurement of reflective properties of road surfaces

It is likely that, in order to develop improved standards for lighting design to cover a wider range of surfacings, measurements of actual surfaces will be necessary, but a constraint regarding work in this field is the difficulty of measuring the actual reflective properties of road surfacings in situ. At present, measurement of Q_o requires a laboratory test, which is carried out on cores extracted from road surfaces. All 396 reduced luminance coefficients are measured in a precision automated test rig.

Few laboratories are equipped to do this and, as far as is known, none are in the UK. Known laboratories are in France (at LCPC's central laboratory in Paris and a regional (LRPC) laboratory at Claremont Ferrand) and at Urbis Lighting in Belgium. It is understood that in previous work, tests at LRPC Claremont Ferrand were commissioned, at a cost of approximately €900 for the first sample, thereafter at a lower rate.

If work involving measurements of Q_0 is to be included in this research, up to date costs will be needed and established in the next stage of the project: initial indications are that an extensive programme of testing to determine Q_0 values will be expensive.

There are potential practical difficulties with measuring S1 in the field. This requires measurements of light directly under the luminaire and at a fixed point a defined distance from the column. A particular issue is that on an actual road there are likely to be several street lights influencing the surface at any particular point. The implications of this problem and ways to overcome it need to be considered.

It should be noted that the reflective properties of a particular surface depend on a large number of factors:

- Aggregate colour.
- Binder colour.
- Aggregate surface (micro-)texture.
- Aggregate shape.
- Pavement macro-texture.
- Wear (polishing).
- Weathering (of binder).
- Soiling (oil, rubber dust, silt, other debris).
- Surface deformation (rutting, excess bitumen on surface).

Furthermore, the process of coring the road surface for representative samples may alter some of these properties.

An alternative method that could be considered is the measurement of Q_d, the “reflectance co-efficient under diffuse illumination”. This parameter is currently used in the measurement of the reflective properties of road markings. Portable equipment does exist for measuring Q_d and it is understood that this is commercially available. A programme of Q_d tests would therefore be more viable within the scope of a project of this type.

However, there is no published relation between the coefficients Q_o and Q_d but it is understood that there is some useful information in a more recent CIE document. It has been suggested that characterising road surfaces using the diffuse reflectance (Q_d) rather than the specular (Q_o) method may have other advantages.

A.4 Initial ideas for future work

It is clear that the process of determining what “r-tables” should be used is not immediately straightforward. Therefore, the following ideas could be explored further:

- A literature review to collect existing data on road surface reflection measurements. However, this is not expected to be very fruitful and we do not propose to commit extensive resource to this.
- A sensitivity study to find how much practical effect variations in Q_o and S1 have in the design of street lighting. This would identify which of the road surface parameters affecting lighting performance has the largest effect and would allow subsequent research effort to be concentrated effectively.
- Assess the practical aspects of making in situ measurements of S1.
- Obtain up-to-date estimates for costs of conducting laboratory measurements of Q_o.
- A study to discover whether it would be possible to use measurements of Q_d and S1 to calculate Q_o and whether Q_d could be used as an alternative to Q_o as a design parameter. Establish cost of acquiring a suitable measurement system, if appropriate.

A.5 Lighting review reference

BSI (2003) *Code of practice for the design of road lighting — Part 1: Lighting of roads and public amenity areas.* British Standard BS 5489-1:2003 Incorporating Corrigendum No. 1. British Standards Institution.

Appendix B. Description of the Wehner-Schulze test and procedure

This Appendix provides a brief description of the Wehner-Schulze (W/S) test equipment and test procedure. More details can be found in TRL report PPR144 (Woodbridge et al, 2006), the report on its initial evaluation in the UK.

The W/S test equipment, shown in Figure 9.1, 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 in Germany, 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. Since then, however, the reproducibility of the PSV test has been much improved and, especially in the UK, considerable experience of the relationship between PSV and skid resistance has been developed.

Figure 9.1 The Wehner/Schulze test equipment

As with the PSV test, the W/S procedure is designed to simulate accelerated polishing on road surfacing materials and test the friction provided by the specimen before and after that polishing. An important difference between the PSV test and the W/S procedure, however, is that the latter 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 now available commercially.

There are essentially three processes involved in the complete W/S procedure: friction testing, polishing and grit-blasting. The specimen (a 225 mm core or a 320 mm by 260 mm rectangular slab) is held in an aluminium mould and attached firmly to the mounting table in the machine so that the table and specimen surfaces are accurately parallel. The mounting table can slide between the friction testing station and the polishing station.

The friction measuring head comprises a metal support onto which three sole plates with attached rubber sliders are fitted at a regular spacing, each slider being 30 mm long and 14.5 mm wide. 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 at 10°C is sprayed on to the test surface to attain a theoretical water film thickness of about 0.5 mm and the assembly is dropped onto the surface of the test specimen 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 test head decelerates to a stop while a proximity sensor system records the rotation of the head and torque transducers in the mounting table continuously measure the reaction force. The data is sent directly to a dedicated computer that automatically calculates the coefficient of friction (using an assumed static load) and speed at any instant and generates a smoothed friction/speed curve for the test. The single values, reported as standard, are the values of coefficient of friction at 60 km/h. Before each friction test on a sample, a friction test on a 'calibration plate' of rippled toughened glass is carried out. The latter should generate readings within closely defined boundaries.

At the polishing station, three rubber-covered conical form rollers are lowered into contact with the test surface. 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 (58psi), 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 about 2 mm wide, 2 mm deep and about 20 mm apart are cut in the roller rubber, running from the apex to base of the rollers, to simulate tyre treads. In the standard test, the roller head is rotated at 500 rpm for 1 hour, giving a total of 30,000 revolutions of the head and 90,000 roller passes over the sample surface. A suspension consisting of about 5% quartz powder in 95% tap water is mixed at a controlled temperature of 20°C in a separate tank and is pumped onto the specimen during this process. This replicates the detritus on a road surface and assists in the polishing process.

The grit blasting stage is usually used to 'roughen' the specimen surfaces in order to simulate the action of winter weather. 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. The grit blasting process can also be used to clean excess bitumen from new asphalt specimens.

A full cycle of the test (as developed by TUB) for specimens taken from the road has the following stages:

- Friction test new core. *Determine in situ friction.*
- Polish for 1 hour. *Simulate summer polishing.*
- Friction test.
- Grit blast. *Simulate winter weathering.*
- Friction test.
- Polish for 1 hour.
- Friction test.
- Friction test 'to the limit'. *Determine lowest friction.*

The test on the new core is carried out because, in Germany (unlike the UK), there are contractual requirements for skid resistance on newly-laid surfaces.

Experience with the equipment in Germany has suggested that the final level of friction, after both polishing stages have been carried out, simulates the state of skid resistance that occurs after four to six years of traffic on aggregates in situ. Further experimentation in Germany has mirrored findings using the PSV test in the UK and observations on the road: the level of skid resistance drops very quickly to an equilibrium level that reduces only slowly over the remainder of the test, or road service life.

Appendix C. Details of Validation Trial Sites

C.1 Location 1 – A5 Gibbet Hill

This location is on the A5 on the dual-carriageway part of the section between the Gibbet Hill and Cross-in-Hand roundabouts near Lutterworth, Leicestershire. The trial surfacings were laid by Lafarge in late November 2005 using materials from their "Axophalt" and "Axophone" ranges.

The trial sections are located on the Northbound carriageway and extend across both lanes, providing two sites denoted 1a (lane 1) and 1b (lane 2). Both sites comprise four test sections. Three are trial sections: the fourth is part of the main contract included for comparison purposes (see Table 9.1 and schematic diagram Figure 9.2) and uses a different aggregate from the main trial sections.

Repair works necessitated by a problem with the underlying construction were carried out in July 2007, affecting part of the 0/6 mm material in Lane 1 (Section 1.2a). The replacement surface course is of the same material as the original test section but some time will need to elapse before it is performing similarly to the remainder of the section.

Table 9.1 Trial sections at Location 1 A5 Gibbet Hill (Sites 1a and 1b)

Section		Lane	Material	Aggregate	PSV	As-laid texture depth (patch method)	Approximate Length (m)
1.1	a	1	0/10 mm Axophalt	B	65	1.1 mm	~300
	b	2				1.1 mm	
1.2	a	1	0/6 mm Axophone	B	65	1.5 mm	~300
	b	2				1.5 mm	
1.3	a	1	0/14 mm Axophalt	B	65	1.7 mm	~300
	b	2				1.7 mm	
1.4	a	1	0/14 mm Axophalt (main contract)	H	68	-	~300
	b	2				-	

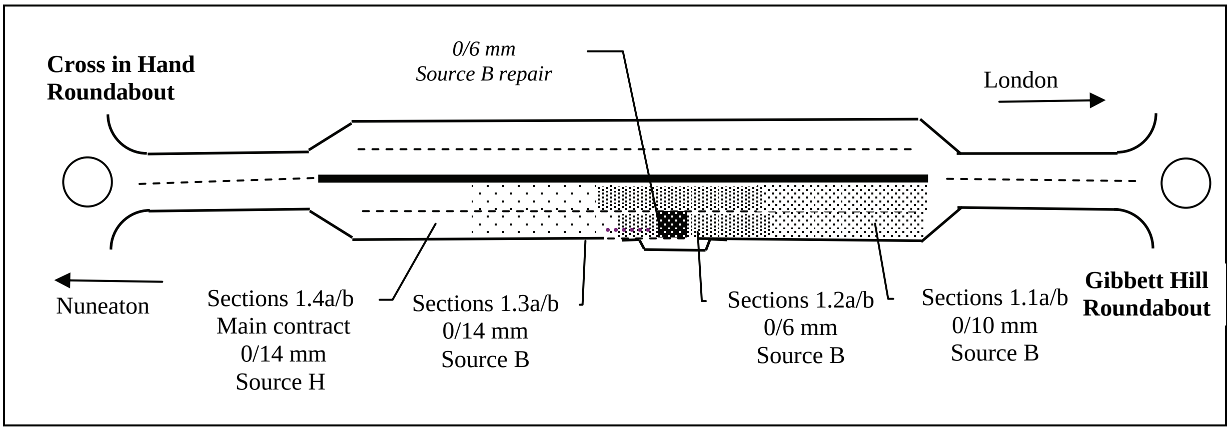

Figure 9.2 Schematic diagram of Location 1, A5 Gibbett Hill
Site 1a in Lane 1; Site 1b in Lane 2

C.2 Location 2 – Tamworth by-pass

This location is on the A5 at the western end of the Tamworth by-pass. The trial surfacings were laid by Tarmac in early December 2005 using materials from their "Masterpave" range.

The trial sections are located on the Northbound carriageway, in both lanes between the A453 off-slip and the on-slip from the A453/old A5, providing two sites, 2a (lane 1) and 2b (lane 2). There are two test sections in each of the two lanes. The first is a length of the main contract surfacing. The second, a purpose-laid section using 0/10 mm coarse aggregate, is 300 m long (see Table 9.2 and schematic diagram Figure 9.3).

Table 9.2 Trial sections at Location 2 A5 Tamworth (Sites 2a and 2b)

Section		Lane	Material	Aggregate	PSV	Approximate Length (m)
2.1	a	1	0/14 Masterpave main contract	C	60	~300
	b	2				
2.2	a	1	0/10 Masterpave	C	60	300
	b	2				

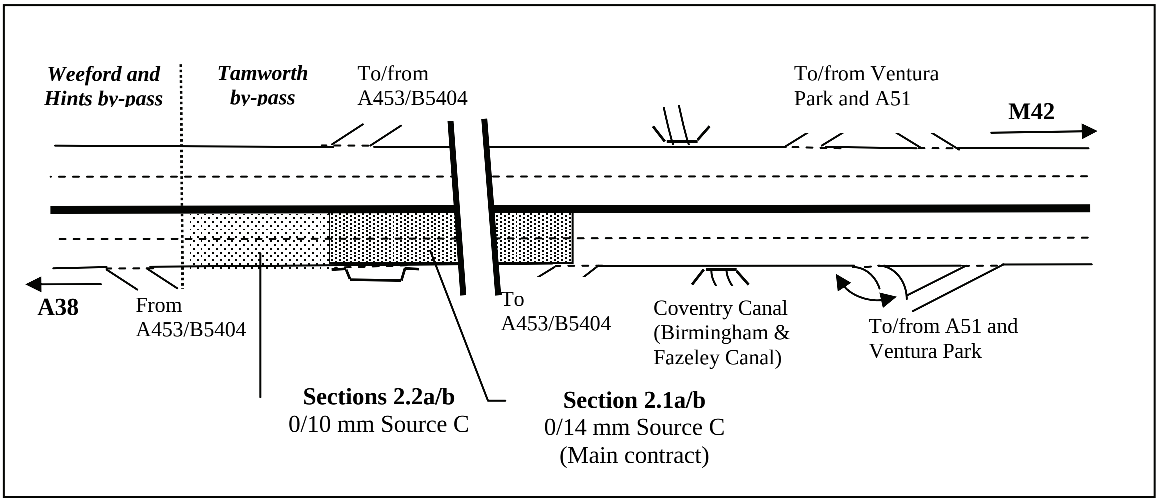

Figure 9.3 Schematic diagram of Location 2, A5 Tamworth by-pass
Site 2a in Lane 1; Site 2b in Lane 2

C.3 Location 3 – A14 Creeting St Mary

This location is on the A14 near Creeting St Mary, between Needham Market and Stowmarket, Suffolk. The trial surfacings were laid by Lafarge in early June 2006 using materials from their "Axophalt" and "Axophone" ranges with the same coarse aggregate and that were used at Location 1. The trial sections are located on the northbound carriageway between junctions 51 (A140) and 50 (A1120) between MP 17/26 and 17/19. There are three trial sections in Lane 1 only, designated Site 3. The sections vary in length but are approximately 250 m long (see Table 9.3 and schematic diagram Figure 9.4).

Table 9.3 Trial sections at Location 3, A14 Creeting St Mary (Site 3)

Section	MP Position (all Lane 1)	Material	Aggregate	PSV	As-laid texture depth (patch method)	Approximate Length (m)
3.1	17/260 – 17/235	0/14 Axophalt	B	65	1.9 mm	~250
3.2	17/235 – 17/215	0/10 Axophalt	B	65	1.7 mm	~200
3.3	17/210 – 17/190	0/6 Axophone	B	65	1.6 mm	~300

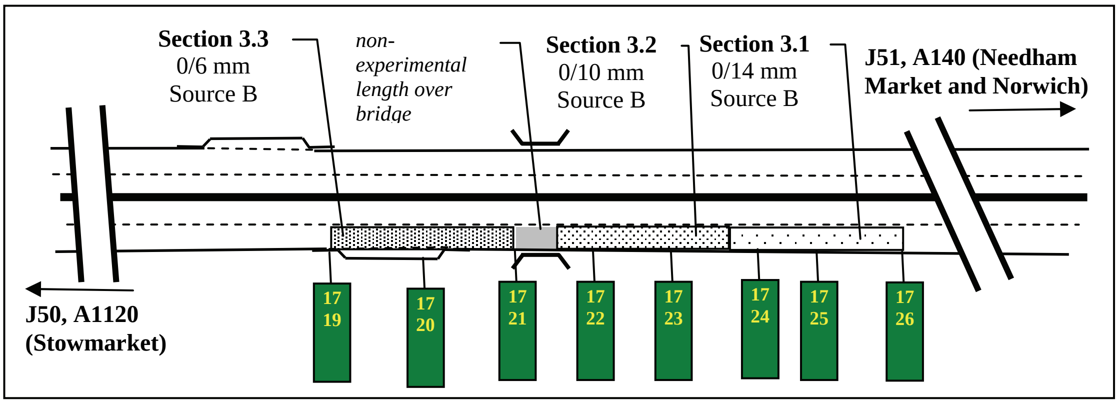

Figure 9.4 Schematic diagram of Site 3, A14 Creeting St Mary

C.4 Location 4 – A43 Brackley

This location is on the A43 in Northamptonshire between the Brackley by-pass north roundabout and the Whitfield turn. The trial surfacings, which are on the northbound carriageway, were laid by Tarmac in July 2006 using materials from their "Masterpave" and "Masterflex" ranges. The site comprises 5 test sections in both lane 1 and lane 2, to give Sites 4a and 4b respectively (see Table 9.4 and schematic diagram Figure 9.5). The 0/6 mm surfaces (Section 4.4) use the same coarse aggregate as that usedon Sites 1a/b and 3. Sections 4.1 and 4.5 originally replicated one another to allow for the limited acceleration length from the roundabout exit. However, due to a problem at the time of construction, shortly after opening to traffic, Section 4.5a and the first 200 m of Section 4.1b were resurfaced with a similar material but a different aggregate.

Table 9.4 Trial sections at Location 4, A43 Brackley (Sites 4a and 4b)

Section		Lane and start position (metres from roundabout)	Material	Aggregate	PSV	Length (m)
4.1	a	1 (0 - 450)	0/14 Masterpave	A	65	450
	b	2 (200 - 420)				425
4.2	a	1 (450 - 640)	0/10 Masterpave	A	65	193
	b	2 (420 - 620)				201
4.3	a	1 (640 - 850)	0/20 Masterpave	A	65	207
	b	2 (620 - 860)				237
4.4	a	1 (850 -1210)	0/6 Masterflex	B	65	365
	b	2 (860 – 1210)				353
4.5	a	1 (1210 – 1600)	0/14 Masterpave	G	66	388
	b	2 (1210 – 1360)		B	65	150

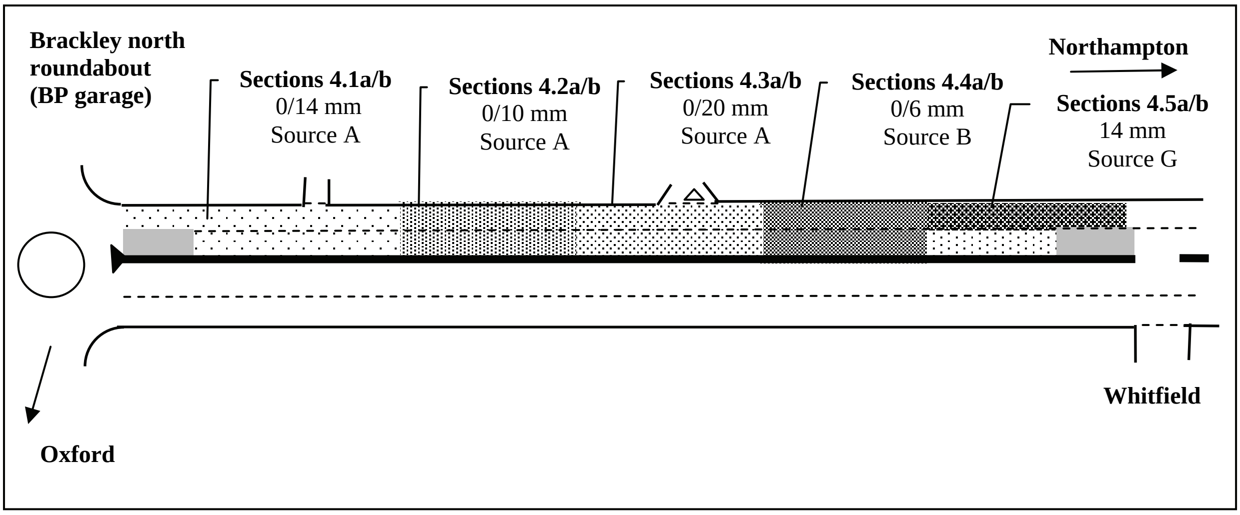

Figure 9.5 Schematic diagram of Location 4, A43 Brackley
Site 4a in Lane 1; Site 4b in Lane 2

C.5 Location 5 – A14 Thrapston

This location is on the A14 near Thrapston, east of Kettering, Northants. It comprises two adjacent sites in lane 1 (designated 5a and 5b), each using a different aggregate, that are located between J13 (A45/A605) and J16 (B660) and are tested as one. The trial surfacings were laid by Aggregate Industries in late September 2006 using materials from their “Hitex”, “Superflex” and “Urbanpave” ranges with two different aggregates. The six test sections are on the southbound carriageway in Lane 1 between Marker Posts 54/29 and 57/29. Each section is approximately 500 m long.

Table 9.5 Trial sections at Location 5, A14 Thrapston (Sites 5a and 5b)

Section		MP Position (all Lane 1)	Material	Aggregate code	PSV	Approximate Length (m)
Site 5a	5.1	54/290 – 54/789	0/6 Urbanpave	D	60	500
	5.2	54/789 – 55/264	0/10 Superflex	D	60	500
	5.3	55/264 – 55/788	0/14 Hitex	D	60	500
Site 5b	5.4	55/788 – 56/326	0/6 Urbanpave	E	55	500
	5.5	56/326 – 56/836	0/10 Superflex	E	55	500
	5.6	56/836 – 57/290	0/14 Hitex	E	55	500

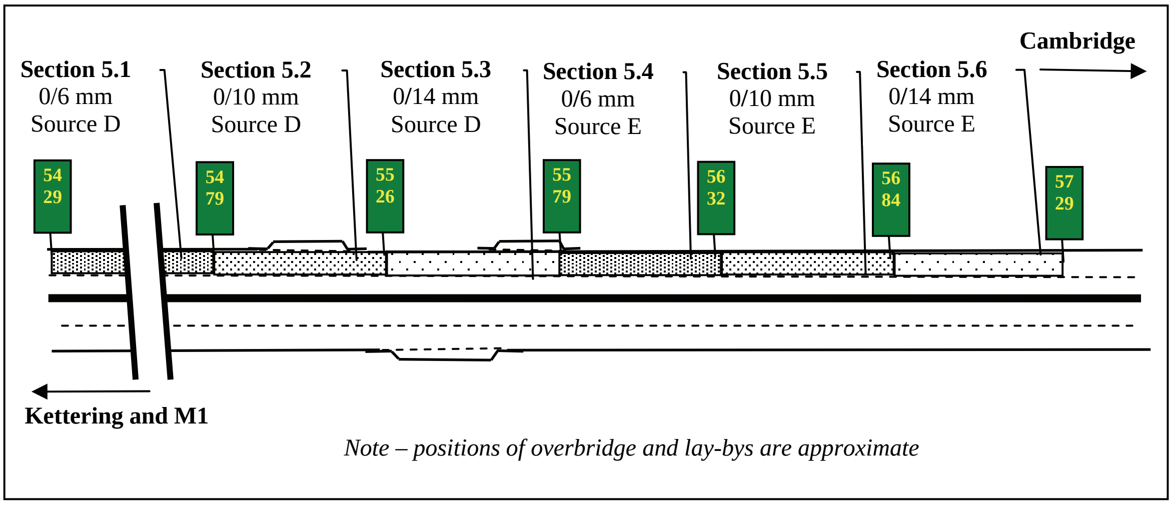

Figure 9.6 Schematic diagram of Location 5, A14 Thrapston
Site 5a sections 5.1-5.3; Site 5b sections 5.4-5.6

C.6 Location 6 – A14 Stanford

This location is on the A14 near Stanford on Avon, between Junction 2 and the interchange with J19 of the M1 late in August 2007 and comprises two similar sites, one in Lane 1 and one in Lane 2 (designated Site 6a and Site 6b respectively). The location was added in order to include a relatively-low PSV aggregate under both heavy traffic and lighter traffic but its late completion means that no measurements were made during the 2004/07 Collaborative Programme.

However, it is intended to include in the monitoring programme in 2008 as part of the next phase of the Collaborative Programme. The trial surfacings were laid by Lafarge, again using materials from their “Axophalt” and “Axophone” ranges. There are three trial sections in 0/6 mm, 0/10 mm and 0/14 mm sizes in each lane. Sections are located on the westbound carriageway between Junction 1 and the M1 interchange at MP4.6 to 3.7.

Table 9.6 Trial sections at Location 6, A14 Stanford (Sites 6a and 6b)

Section	Lane and approx. MP Position (westbound carriageway)	Material	Aggregate	PSV	As-laid texture depth (patch method)	Approximate Length (m)
6.1a 6.1b	1 (4/600 – 4/300) 2 (4/600 – 4/280)	0/6 Axophone	F	53	2.2 mm 1.9 mm	~290 ~320
6.2a 6.2b	1 (4/300 – 4/020) 2 (4/270 – 4/010)	0/10 Axophalt	F	53	1.9 mm 1.9 mm	~280 ~250
6.3a 6.3b	1 (4/000 – 3/690) 2 (4/000 – 3/710)	0/14 Axophalt	F	53	1.1 mm 1.2 mm	~320 ~280

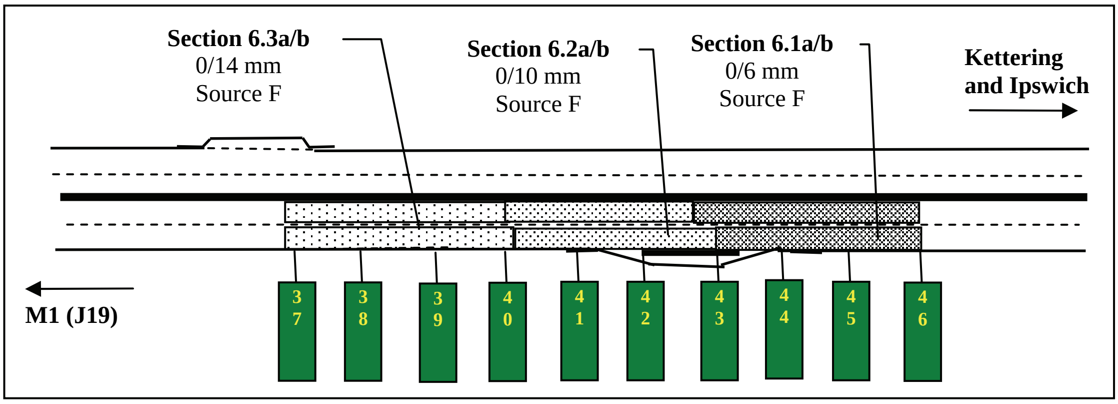

Figure 9.7 Schematic diagram of Location 6, A14 Stanford
Site 6a in Lane 1; Site 6b in Lane 2

Appendix D. Initial Literature Review on Spray

D.1 Introduction

There have been varying anecdotal reports regarding the spray generation characteristics of modern asphalt surfaces, with some suggestions that certain proprietary materials are better at spray suppression than others. This is of particular relevance to surfacings with smaller aggregate sizes and lower texture depths which may have the potential to increase spray in comparison with coarser positively-textured materials. A component of the collaborative programme was to assess the scope of this phenomenon so that it can be taken into account in the context of the results of other parts of the project.

The first stage, therefore, was to carry out an initial review of the published literature in relation to spray generation and measurement. This Appendix summarises the findings of this literature review.

Of particular interest are papers that relate to the classification of spray, how it is generated, and how it can be measured. Also relevant are ways of simulating spray conditions, either for assessing surfaces or evaluating test techniques. The extent of the literature identified was limited.

Some early work was carried out by Maycock (1966) at the then Road Research Laboratory and there were various studies in the 1980s and 1990s both in the UK and elsewhere. It was found that most papers were concerned mainly with vehicle aspects of spray generation (and ways of reducing it) rather than detailed studies of the road surface. The most recent report identified was a review paper published in the last few months by another team at TRL, again primarily with the emphasis on spray suppression on heavy vehicles.

For convenience, this summary has been divided into three broad aspects covered by the literature:

- Spray generation.
- Measurement techniques.
- Spray simulation.

D.2 Spray Generation

D.2.1 Splash and Spray

The water thrown up by vehicles can be classified in two categories: splash and spray. The large droplets are classified as Splash. Splash droplets follow a low trajectory and fall quickly; consequently they do not contribute greatly to visibility deterioration. Smaller droplets are classified as Spray. These droplets are carried in the turbulent air flow around a vehicle at a height similar to car windscreens. This then impacts on driver visibility due to the misting effect and also due to droplets hitting the windscreen.

D.2.2 Steady Spray Cloud

Spray is generated by the tyres from passing vehicles and is affected by a number of variables (see D.2.3 below). As there are so many variables, the spray cloud generated by a vehicle is difficult to quantify. It has been found that a vehicle needs to run on the wet surface for a considerable distance before spray builds up to a steady-state suitable for measuring.

Therefore, in studies to quantify spray, it may be necessary to keep the variables consistent, not only for the measurement run but also the build up time as well. Weir et al (1978) found 60 m was necessary for this build up, and Koppa et al (1990) and SAE (1994) recommended a length of approximately 120 m.

In their studies of porous asphalt surfaces, Nicholls and Daines (1992) noted that spray is carried over, from non-porous on to porous surfaces, by up to 100 m. This effect was thought to be caused by water carried under the wheel-arches of vehicles. Clearly, it would have implications for the length of any study sections to be used in comparative assessments.

D.2.3 Spray Variables

The main variables or general conditions to consider when investigating spray are:

- Water depth.
- Road surface.
- Vehicle speed.
- Vehicle design and load.
- Tyre tread design and depth.
- Weather.

D.2.3.1 Water Depth

As would be expected, it has been found that water depth has an effect on spray generation. The level of spray generated increases as water depth increases, because more water is available. However, once a critical depth has been reached this relationship reduces in its impact. Koppa et al (1985) noted a reasonably linear relationship between water depth and spray production at the water depths of approximately 0.5 mm, 1.3 mm and 2.5 mm. In a further study, Koppa et al (1990) found no significant differences in spray generated from water depths of 0.5 mm and 1.3 mm.

Weir (1980) found that water depths between 1-1.5 mm were the best for artificially wetted tracks. This allowed for good spray conditions without excessive splash.

Water depth in any particular situation will be affected by a great many factors, including the geometry of the road, which influences drainage path lengths and the build-up of water on the surface after or during rainfall (Roe, et al, 1996).

D.2.3.2 Road Surface

The majority of research relating to the effect that the road surface has on spray focuses on how a layer of permeable (now known as porous) surfacing affects the water depth and spray generation. Maycock (1966) carried out spray collection tests, as described in D.3.2.1 below, on six types of asphalt surface (4 impermeable, 1 slightly porous, 1 porous). He found that, on exclusion of the porous surface, the mass of water collected did not vary by more than a factor of 2.

Porous surfaces provide better results in terms of spray reduction than impermeable surfaces because water is removed from the surface more quickly. However, heavy downpours can negate this effect as the water will not be drained quickly enough. Also, over time, porous surfaces become clogged and no longer provide spray reducing properties. Daines (1992) found that the drainage paths through porous asphalt can be considered to be effectively closed-up when the hydraulic conductivity has reached $0.02s^{-1}$. Daines (1992) also observed a strong linear relationship between outflow time in the Hydraulic Conductivity test and the age of the surfacing.

Most of the research has focussed on the ability of a surface to allow water to drain away from the surface where it can be picked up by tyres. The surface texture also has an effect on the way in which water remaining on the surface drains across the road, affecting the water depth and hence the potential for spray generation. An issue for thin surfacings, which has not been studied in the literature, is the extent to which water held within the texture, rather than the depth of water above it, influences spray.

D.2.3.3 Vehicle Speed

Maycock (1966) using a spray collection device, found that the spray effect is very low below 30 mph. This then increases very rapidly as speed increases. At a distance of 30 ft (9.1 metres) behind the spray-producing vehicle, and in the speed range of 45 to 75 mph it was found spray followed a power function. Maycock calculated this and found Spray was proportional to speed raised to the power of 2.8 (Spray Density ≈ Constant x Speed$^{2.8}$). Maycock also observed that at speeds less than 30 mph the bulk of the water did not break up into spray, but merely fell back to the ground as large drops (splash).

In the United States, Koppa et al (1984) found that the relationship between vehicle speed and transmittance (see D.3.1) is approximately linear in the speed range from 35 to 60 mph, with speeds above 60 mph producing unacceptable levels of spray. This was confirmed by Baughan and Byard (1997) who found an approximate linear relationship between speed and spray in the range 40-60 mph.

The above references vary in their findings due to the measurement methods used, Maycock (1966) was measuring the mass of the spray, whereas Koppa et al (1984) and Baughan and Byard (1997) were measuring transmittance of the cloud. Differences in vehicle and tyre design between the times of the studies or in the different countries may also have had an influence.

D.2.3.4 Vehicle Design and Load

Differences in design will affect the aerodynamics of a vehicle and consequently the turbulence pattern in its wake. This in turn will affect the size and duration of any spray cloud that the vehicle creates.

Increased loads on the vehicle may also influence the spray cloud (either positively or negatively). A higher load may increase tyre contact area which in turn increases tread pick up and spray. On vehicles without self levelling suspension, this increased load would compress the suspension, and reduce the gap between the mudguards and the road. Also, the distance between the wheel guard valance and the tyre would be reduced, which some research indicates reduces spray (e.g. Maycock 1966).

However, Weir et al (1978) and Allen and Lilley (1981) found that no significant difference could be found in Transmissometer readings (see section D.3.5.1) as a result of a change in load.

D.2.3.5 Tyre Tread Design and Depth

Maycock looked at three different tyre treads (with a water depth of approximately 0.3mm) and found that the differences in spray generated were not significant. Weir et al (1978) state that, for low water depths, the tread design affects the amount of spray generated. Large groove volumes reduce the amount of sideways splash, and cause more water to be picked up. This, in turn, increases the amount of tread-thrown water (which is the main cause of spray).

When the water depth reaches approximately 3 mm the grooves become completely filled. At this point the amount of tread-thrown water remains constant, with the remainder of the water being displaced as bow and side waves.

D.2.3.6 Weather

Weather affects both spray generation and measurement. Clearly the weather will affect spray generation since rainfall is the source of water. However, a number of factors are involved, including for example, the intensity and duration of a storm. Apart from this, prevailing weather conditions also affect the way in which a spray cloud behaves and the measurement process.

As spray is effectively a mist, wind will affect the shape and position of a spray cloud. Cross winds will affect any measuring device which is set up parallel to the test surface. This can be partially counteracted by placing a duplicate measuring device on the opposite side of the test surface and then taking the average between the two. Headwinds and tailwinds also affect the spray cloud by making the wake more variable.

In Sweden, Sandberg (1978) used only data recorded when the wind speed was less than 4 m/s, with a maximum average side wind component of 2.6 m/s for an entire measurement series. He observed that on averaging measurements from either side of the test track, the influence of wind could not be detected. He also notes that transverse measurements were not affected by winds. In a later paper, Sandberg (1980) used data with the wind speed component in the direction for driving of less than 4 m/s, and side wind component of less than 2 m/s, providing the spray intensity measured on one side of the test track or road is less than 4 times as great as the other side. The sides wind speed component could be increased to 3 m/s so long as one side measures less than twice the size of the other. Sandberg (1980) also observed that tailwinds reduced spray measurements by 2-3% per m/s, and headwinds increased spray measurements by a similar amount.

Whilst the spray droplets are in the air they will be subject to evaporation. This will cause the overall mass of the spray cloud to decrease along with the size of individual droplets. The speed of this evaporation is affected by temperature and humidity. To counteract this, Koppa et al (1990) specified a simple correction in which the transmittance changes by 0.0008 for every percentage point change in humidity. They also note that changes in relative humidity of less than 30 percentage points during the course of the day can be neglected as being within the bounds of experimental error.

However, TRL in the UK and Koppa in the US used different Transmissometer configurations and indices and for this reason this correction can not be universally applied. Baughan and Byard (1997) looked at a spray cloud producing a Transmittance index value (see D.3.5.1) of around 0.25, and found no apparent effect of humidity in the range of 64 to 86 percent.

As well as affecting spray generation and the behaviour of the spray cloud, changing weather conditions can affect measurements in other ways. Knight et al (2005) (using video image processing) found that variable lighting conditions caused difficulties in keeping the camera exposure control at the right setting to avoid clipping. (Clipping occurs when the image is too bright or too dark for the sensors in a digital camera to differentiate some parts of the image). They suggested testing in near constant ambient lighting conditions and changing the lens aperture to keep within the operating range of the camera.

D.3 Spray Measurement

D.3.1 General principles

The methods for measurement of spray identified in the literature use a number of different principles. These fall into four main categories:

(i) *Spray collection/detection:* A number of techniques have been used, including the fitting of collectors (absorbent paper, plastic bottles, etc.) or detectors to a vehicle following the spray inducing vehicle.

(ii) *Direct observation/Photography*: the subjective analysis of the spray cloud produced, either by direct observation or the study of photographic or film records.

(iii) *Calculation*: analysing properties of the pavement or the environment (e.g. hydraulic conductivity, amount and duration of rainfall) and apply an equation to calculate the spray generated. However this approach would need to be validated by comparison with measurements from one (or more) of the other approaches.

(iv) *Effect on Light*: measuring the effect of the spray cloud on the transmission of light. The main affects of spray on light are:

- Transmission Loss. Transmittance is defined as the proportion of image-forming light that remains after passing through a given thickness of spray.
- Veiling Luminance. Some light from sources other than the target is scattered by the spray so that it appears to come from the target. Its contribution to the apparent luminance of the target is called veiling luminance.
- Contrast Change. Acting together transmission loss and veiling luminance reduce the luminance contrast between the target and background or between areas of the target.
- Narrow-angle scattering. Narrow angle scattering, may cause light from a bright area of the target to appear to come from a nearby dark area, thus reducing the apparent contrast.

These approaches are discussed in a little more detail in the following sections of the paper.

D.3.2 Collecting or detecting spray

D.3.2.1 Spray collection

This approach involves fitting collection devices to a vehicle following the spray producing vehicle. Maycock (1966) attached absorbent paper (which is weighed before and after the run) and plastic bottles to the trailing vehicle. The absorbent paper measured the level of spray and the bottles measured the level of splash.

The main advantage of this approach is that it is cheap and simple to carry out. It is also possible to vary the position of the trailing vehicle to obtain results in different parts of the spray cloud. It will however be necessary to keep the distances between the vehicles constant during the runs.

D.3.2.2 Spray detection

It is possible to fit rain or moisture detectors in the windscreen area of the vehicle following the spray generating vehicle. There are several different types of rain/moisture detectors available including ones which work on conductivity, capacitance or pressure (detects droplet impacts). This has the same advantages and disadvantages as Spray collection. It will cost a little more but should produce more accurate results.

D.3.3 Direct observation/Photography

A subjective analysis of the spray cloud produced can be used to determine its severity. This has been done mainly by taking photographs from various angles, but can be done with direct observation. Maycock (1966) found that photography was, in practice, very difficult. This was because the appearance of spray plumes depended very much on lighting conditions at the moment of exposure. Weir et al (1978) took subjective ratings from observers at either end of the test section, and compared the results with objective measurements. It was found that the subjective ratings correlated with the objective measurements, giving confidence that their objective measurements reflect the safety related human visibility elements of the real world spray situation.

Another approach would be to place a video camera inside a vehicle looking through the windscreen. This vehicle could then be driven on the road network in wet conditions and a subjective analysis performed. The analysis can then be cross referenced with data on the surfacings of the road, to facilitate the ranking of surfacings. It will however be important to take account of extraneous conditions/variables that will have influenced spray generation such as differences in weather conditions and the geometry of the surfaces.

D.3.4 Calculation

This approach attempts to calculate the spray that would be generated by using properties of the road and its environment. Nicholls and Daines (1992) performed linear and non linear regressions on spray data (collected using a back scatter device). This created the following approximate relationship:

$$S_y = (r + 0.25.\ r_a)^{2/3} .\ v^{0.5} .\ m_t .\ (8.t_d^{2/3} - H_c/3 - 3.6)$$

where:

S_y = Spray (mV) *(the spray sensor output signal was measured in millivolts)*

r = Rainfall (mm/h)

r_a = total rainfall in the previous 2 hours (mm)

v = Vehicle speed (Km/h)

t_d = texture depth (mm)

H_c = hydraulic conductivity (s)

m_t = 1 for porous asphalt, 3 for hot rolled asphalt

D.3.5 Effect on light

D.3.5.1 Laser Transmissometer

A transmissometer consists of an emitter and a receiver, which is arranged either parallel to or across the direction of vehicle travel in the measurement run. The detector measures the degree to which a laser light beam is attenuated by scattering and absorption, from which the transmission loss can be calculated. A complex mathematical formula is used to calculate “transmittance index”.

Baughan and Hart (1988) found that there was less run to run variation for a cross-track device then for a parallel to the track device. They concluded that this was because the cross-track transmissometer sweeps through a larger sample of spray and is insensitive to the lateral position of the vehicle. Baughan and Byard (1997) also note that so long as the transmissometer beam is long enough, it is insensitive to variations in the lateral position of the spray cloud due to cross winds.

Generally, from a parallel transmissometer the data is used to calculate the minimum transmittance through the spray cloud (this coincides with lowest visibility). However another approach is to take an average over a specific time period (Weir et al, 1978; Allan and Lilley, 1983). The common time period used is two seconds from the moment when the front of the lorry or the front of the spray cloud draws level with the transmissometer. However Baughan and Hart (1988) also showed how the signal from a transmissometer can be used to give the transmittance of any portion of the spray cloud swept by the beam.

Minimum and average transmittances are also used for cross-track devices, however these values cannot be interpreted directly in terms of a car driver’s line of sight. Baughan and Hart (1988) have shown how to use the cross track transmittance data to calculate a longitudinal transmittance.

Transmissometers have seen a lot of use in spray measurement and so there is a good understanding of their use. However, transmissometers have to be lined up very accurately before they can be used to make measurements.

D.3.5.2 Video Image Processing

For this approach, a video camera is positioned to film parallel to the path of the spray producing vehicle. Test cards are placed in the background of the shot (a black and white pattern for contrast and a grey panel for illumination), from which the contrast change can be measured.

Koppa et al (1990) developed a system that analysed a digitised television image of the spray recorded against a chequered background. They concluded that video image processing provided an alternative method to transmissometers and found the run to run variability of the two approaches was about the same. They suggest that there are no compelling reasons to choose one approach over the other, except that video image processing can be directly related to subjectively-assessed loss of visibility.

Puclin and Watkins (1996) carried out initial tests in a laboratory to negate the effect of varying ambient light conditions. They found that a black surface should be used rather than a chequered pattern. A chequered pattern produced unpredictable contrast changes, with a low level of sensitivity when the ambient light level and spray density were varied. When the black target was used, the software produced consistent readings of mean spray density and area, across varying ambient light levels. They also suggest that, for longitudinal set-ups, two cameras, one on each side of the track, would help compensate for cross winds.

Knight et al (2005) identified three potential camera positions, longitudinal, cross-track and on-vehicle. The longitudinal position was found to be impractical on safety grounds and the on-vehicle camera was discarded due to blurring caused by vibrations. The images collected in low light conditions had a blue tint on them. Knight et al suggested that this could be avoided by using the camera as if it were monochrome. It was also found that there was an increased brightness at the top of the target when compared with the bottom. Knight et al found that this could be cancelled out by analysis of images before and after the test vehicle has passed. Careful control of the camera exposure was important because it allowed the effective measuring range of the camera to be adjusted. If the incident light exceed this range then clipping would occur which is seen as over-exposure and lost detail. They suggested that continually adjusting the lens f-stop (the setting that controls the size of the lens aperture and hence the amount of light entering the camera), by using neutral density filters or by adjusting the gain on the video amplifier, would control this effect.

In their work, Knight et al found good consistency between the runs, with the data fitting expected patterns. They also set up a cross-track transmissometer parallel to the camera to perform a comparison. It was found that the video measurement of transmittance was approximately 81% of the laser transmittance, with an excellent linear relationship. The best correlation was found at speeds of 50 kph with the correlation reducing as the speeds increase at 70 kph and 90 kph. Knight et al stated that it implied that the video method does provide a suitable measure of spray but it is measuring other effects as well (most likely veiling luminance). The report suggests improving the method by breaking up the test card into zones correlating to areas of interest (e.g. windscreen height and brake light height).

D.3.5.1 Telephotometers

Telephotometers measure the luminance of a target. It has been shown (Baughan, 1988) that by utilising a pair of telephotometers, the effect of spray on the luminance contrast of neighbouring light and dark targets can be seen. The telephotometers need to be placed very close together as the analysis depends on them seeing the same part of the spray cloud. Telephotometers can be set up either parallel or cross track much the same as with a Transmissometer. Baughan (1988) also shows how values of veiling luminance and transmittance can be calculated from the telephotometer data.

Telephotometers allow for a variety of different measurements, and can be compared with the subjective loss of visibility. However devices of the required quality are expensive, and require extremely accurate alignment.

D.3.5.2 Visibility/Precipitation sensor

Visibility or precipitation sensors consist of an emitter and a receiver. However unlike a transmissometer they are placed at angle to detect either the forward or back-scattered light. More light is scattered forwards than backwards, however a device utilising back scatter can have the emitter and receiver in the same unit. These types of sensors are primarily used to produce visibility ratings for weather reports, but have been used to measure spray.

Nicholls and Daines (1992) used spray data obtained from a back-scatter device. The back-scatter sensor was mounted on the rear nearside of a vehicle, and measured the spray 1.0 m behind and in line with the centre of the nearside wheel. The device utilised infra-red light which was gated electronically from the emitter pulse. This along with a system of optical lenses, filters and diffusers, rendered the detector insensitive to extraneous light.

D.4 Water Application

Any systematic studies of spray generation will eventually need water to be applied to the road in some way in order to generate spray rather than relying on wet weather conditions.

As mentioned earlier, water depth affects the level of spray generated. Some surfaces reduce spray by reducing the water depth; others may use properties of their texture. Since water depth is an important factor to assess or control, means of measuring this parameter are also needed.

D.4.1 Application methods

As might have been expected, work reported in the review documents used one of two basic techniques to apply water to the road surface in order to generate spray: roadside spray bars and application from a tank on a vehicle.

D.4.1.1 Roadside spray bars

The use of roadside spray bars implies a fixed installation (such as that on sections of the TRL test track) or a controlled area in which a transportable system can be used. This approach can have two aspects:

- Using the spray bars to simulate rainfall or create a spray effect.
- Using spray bars to wet the road with passing vehicles generating the spray from their tyres.

Roe et al (1996) simulated rainfall over a flume in a pilot-scale facility via an overhead nozzle system. The nozzles were spaced every 0.915 m along the flume and were held in position by adjustable spray bars. Baughan and Byard (1997) used sprinkler bars set into the TRL test track along each side of the test lane to produce a mean depth between 0.5 mm and 1.5 mm.

This method of application is useful in applying water to the road as it has similarities to actual rainfall. This approach will also allow investigation into the drainage capacity of surfaces from short heavy downfalls, and long slow downfalls. However, controlling the level of flow and ensuring an even distribution will be difficult. Also this method of application is a “fixed installation”, and as such would only be suited for use on test tracks and not real roads.

D.4.1.2 Application from a tank on a vehicle

Application from a tank on a vehicle might be used in conjunction with a measurement technique to assess spray generation in a specific location. There are two main approaches:

- *A separate tanker with spray bars to wet the road ahead of other vehicles.*

  Maycock, G (1966) utilised a commercial water tanker, which was modified by fitting the outlet immediately in front of the offside pair of rear wheels (the resulting spray was measured by a following vehicle). Leech (1998) set up a Bowser so that the water was applied ahead of its nearside wheel (behind which the detector was placed). In this study Leech found that at traffic speeds this arrangement of the Bowser did not permit enough time for sufficient dissipation of water into the road surfacing (producing similar results for porous and non porous surfaces). The calculations performed suggested that a time of 1 min would be required between water application and measurement of spray.

- *A device fitted to a test vehicle that applies water just in front of a wheel in order to generate spray from that wheel.*

  With this type of system, there might also be a measurement device fitted behind the wheel.

  Leech (1998) also carried out tests using a water bowser with the water nozzle offset so that the bowser wheel did not traffic the wetted path. Another vehicle trailing behind it was used to generate (and measure) the spray. Leech found that it was difficult to keep the two vehicles at a fixed distance and to keep the wheels of the following vehicle on the wetted path.

D.4.2 Water Depth measurement

A common method for measuring water depth is to use a simple probe that exploits the electrical conductivity of water. For example, Roe et al (1996) utilised a twin metal wire probe (originally developed by HR Wallingford) to take measurements every 4 to 5 m on the test surface. As the wires become immersed in deeper water a greater current is able to pass between the electrodes which results in an increase in voltage output (water depth and voltage output followed a linear relationship). Baughan and Byard (1997) measured track wetness by periodically removing the water from a marked area of the track with a suction device, and measuring its volume.

In a study that formed part of a larger project studying vehicle, road and tyre interaction, Becci et al (2001) used digital analysis of video images of the water flowing across a section of road to determine water depth. This technique was developed to allow prediction of water film depth from knowledge of the road surface and rainfall conditions during intense rainfall. The team used a fixed installation that incorporated a rain gauge and video camera, with a rainfall-activated switch to turn the camera on when suitable conditions occurred.

D.5 Suggested areas for further investigation

Most of the work identified in the research review was directed at spray generation from a vehicle perspective rather than the road surfacing. Although different techniques were found, the review did not identify any well-established and easily used method of classifying spray. Therefore, any future work will need to rely on purpose-designed methodologies and measuring equipment.

For the specific purposes of the collaborative project, the following issues are of particular interest:

- There is an initial need for a broad assessment of spray generation observed on modern asphalt surfaces in the UK, including the road and weather conditions in which any problems are likely to occur. This assessment is essential in order to determine the scope of any spray-related problems that are more specifically related to modern asphalt surfacings rather than common to all surfacing types.
- For surfaces to be effectively compared, a methodology needs to be devised for ranking spray generation on different surfaces using either a subjective approach or quantitative measurement techniques.

- A suitable measurement technique needs to be established that can be used to measure spray on different road surfaces, both to validate ranking methodologies and to provide a basis for assessing materials in the future.

Essentially, the problem of ranking spray generation can be approached subjectively (i.e. by observation and judgement) or quantitatively, which requires a defined measurement technique.

D.5.1 Using a subjective approach

Ranking spray generation using a subjective approach can give a good indication of the driver perception of spray generation. A suitable approach here could be the use of a front-facing video camera, mounted behind the windscreen of a moving vehicle, whilst driving a defined route, chosen to include different types of thin and traditional surfacings.

An observer in the vehicle passenger seat would classify the different spray intensities, by assigning different categories of intensity to different sections while noting other localised factors such as rainfall conditions. The video record can be reviewed subsequently and different sites compared in order to moderate the operator's assessment or identify other relevant factors. The test route would also have to be assessed in dry conditions in order to identify where the various types of surface are located. A route utilising trunk roads would allow geometric and surface texture data from HAPMS to be used in this process.

With this approach in mind, as a final stage of the review, a preliminary visual survey of the clockwise carriageway of the M25 was made (on a dry day). This demonstrated that a range of surfacings in various states of repair and in various topographical situations would be readily available for this kind of approach within a reasonable working distance of TRL. In addition, sites where spray has been specifically raised as a problem could be included in this type of assessment.

D.5.2 Using a quantitative approach

Setting up a quantitative approach to ranking spray generation will require additional research and the possible development of suitable sensors. A laser scatter technique appears to be the most suitable method for use. The advantages of such a system are:

- The system would be relatively portable and could be mounted on the back of a vehicle, in the wheel path.
- This allows for use of the system under controlled conditions (such as on a test track) and on the road network, as opposed to a road-side mounted system which would have severe limitations as to the scope for its use.
- Such a system could provide information about droplet size and intensity should this be required.

The following issues will have to be considered:

- Selection of a laser back- or forward scatter system which is suitable for mounting on a vehicle and which will allow for the detection of spray particles (droplets).
- Selection of a suitable vehicle, on which the system can be mounted.
- Selection of a suitable mounting position on the selected vehicle, so that a relevant part of the generated spray cloud can be measured.

If tests are to be made under controlled conditions on the test track, suitable sections on the TRL test track will have to be selected and equipped with roadside mounted spray bars, in order to simulate rainfall. The literature review has shown that the minimum length of the test section will have to be at least 60 m and possibly even 120 m, in order for the spray cloud to fully build up. These lengths of test section will have to be equipped with the same type of road surfacing and the spray bars will have to be mounted alongside the entire length of the test section. In order to get a realistic simulation of rainfall, data will have to be gathered about the typical amounts of downfall during different types of rainfall (drizzle, light rain, heavy rain, etc.).

In order to determine a relationship between spray cloud build up and water depth on the road surface, it is recommended to equip the test sections with water depth gauges. Compact conductivity sensors seem to be a good choice, for their compactness, simplicity and robustness.

Once these relationships have been established a further assessment of spray clouds on different types of thin surfacings can be carried out on the main trunk road network. The same sections of the trunk road network, used for the subjective survey, could be used for the quantitative measurements. This would provide further insight into the relationship between the subjective driver perception of spray generation and the quantitative approach.

There will also be a need to be able to gather information about hourly rainfall on the test locations in order to relate the objective spray ranking to the quantitative method. Information can be obtained from the Met Office, for example from their OpenRoad system.

The results of the proposed research will be:

- Insight into driver perception of spray generation.
- Insight in the relationship between water depth and spray generation.
- An objective and quantitative method of ranking spray generation.
- A relationship between spray generation on conditioned test sections and ‘real life’ situations on the trunk road network.
- Insight in the effect of different types of road surfacings on spray generation.

D.6 Summary

To produce a spray cloud which is both steady and repeatable several factors have to be taken into account. A portion of the track has to be given up to allow a steady cloud to be built, a minimum length of 60 m has been suggested, whilst other sources advise 120 m. . The conditions and surface properties of this build up section should be identical to the testing section. When setting up a test the factors effecting spray which will need to be considered are:

(i) Water depth, or level of (simulated) rainfall.

(ii) Road surface.

(iii) Vehicle speed.

(iv) Vehicle design and load.

(v) Tyre tread design and depth.

(vi) Weather, in particular wind, humidity and temperature.

The following methods of spray measurement appear to be of note for further consideration.

1. Laser Transmissometers.
2. Video Image Processing.
3. Visibility/Precipitation sensor (measurement of optical scatter).

It will also be worth considering “calculation of spray” (from properties of the road and environment) at a future date, when there is an accepted method of spray measurement to compare it to.

Laser Transmissometers direct a beam of light through the spray cloud, and then measure the degree to which the beam is attenuated by scattering and absorption. This data is then used to give a value for the level of transmittance. Transmissometers can be arranged either parallel to the run or across the track.

Transmissometers have seen a lot of use in spray measurement and therefore there is a good understanding of their use. However Laser Transmissometers require alignment to high degrees of accuracy and only look at a narrow part of the cloud.

When using video image processing the run is filmed with a stationary camera placed either parallel to the run or across the track. In the background of the shot test cards are placed and the contrast change is measured. A check pattern is usually used but some research suggests that a plain black test card should be used.

Some of the more recent tests have been done using Video Image Processing to analyse a spray cloud. Video Image Processing allows the testing of a larger portion of the cloud. Also alignment of the equipment is not as crucial as with Transmissometers.

Visibility sensors are similar to Transmissometers, however they have the receiver placed at an angle to the emitter. This allows the visibility sensor to detect scattered light (forward or back scatter depending on the angle). A device utilising this principle has been previously used at TRL. The device was fitted to the rear wheel of the vehicle which was producing the spray cloud.

The two basic principles for water application are roadside spray bars and application from a moving vehicle.

Roadside spray bars would be the preferred choice as this bares a closer resemblance to rainfall. However spray bars would need to be fitted and as such this approach would only be suited for use on test tracks.

Application from a moving vehicle gives the flexibility of allowing the testing on real roads. However time is required between the application of water and the generation of spray (this is to allow some seepage in porous materials). Due to this the application of water has to be done by a separate vehicle to the spray producing vehicle. The spray producing vehicle will also have to follow the water applier at a fixed distance to keep the seepage time constant.

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HA/QPA/RBA Collaborative Programme 2004/07: Surface requirements for asphalt roads

This report describes research for Topic 1, "Surface requirements for asphalt roads", of the 2004–2007 phase of the Collaborative Programme sponsored by the Highways Agency, the Quarry Products Association and the Refined Bitumen Association. The primary objective was to assess whether current aggregate specifications related to skid resistance are appropriate for modern asphalt surface courses.

A database study attempted to compare the in-service performance of existing thin surfacings with current specification requirements for Polished Stone Value (PSV) and traffic. However, the main emphasis of the work was on a series of road trial sites where thin surfacings using the same coarse aggregate in different sizes were laid for direct comparison. Monitoring of the development of skid resistance over a range of speeds commenced at nine sites representing different PSV/traffic combinations.

A laboratory study was made of the polishing of aggregates of different sizes using the Wehner-Schulze test, a technique new to the UK. Samples of aggregates used in all the trial sites, plus cores taken from one site after a period of trafficking, were tested.

A short study was also made to assess making comparisons of the spray generated by traffic on different thin surfacings. A mobile photographic method was investigated that provided a feasible way of measuring spray in traffic under moderate rainfall but not when it was heavier and the surface texture appeared flooded.

Currently, the trials are at different stages of polishing towards their equilibrium skid resistance level and this is necessarily an interim report. Monitoring of the trial sites is continuing in the next phase of the Programme.

Other titles from this subject area

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TRL660	Durability of thin asphalt surfacing systems. Part 3: Findings after six years monitoring. J C Nicholls, I Carswell, C Thomas and L K Walter. 2007
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