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THE EARLY LIFE SKID RESISTANCE OF ASPHALT SURFACES

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Executive summary

When an asphalt road surfacing is newly laid, the aggregate and mortar are covered with a film of bitumen binder. For some years it has been suspected that new asphalt surfaces may exhibit different skid resistance properties compared with roads that have been in service for some time. Any effects have probably always been present but, until recently, there has been no suitable equipment available to investigate them and help determine what impact they might actually have on accident risk.

In recent years, new surfacings have been introduced on the network that provide advantages such as safer construction techniques, improved ride and reduced tyre/road noise. However, these materials often have a thicker initial binder film than traditional materials, which may have increased both the risks of possible problems occurring and the time that any effects last. There has also been an increase in anecdotal comment related both to dry and wet skidding resistance in the first few months of service, reinforced by police comments on lower than usual dry friction found in their routine stopping-distance skid tests on some relatively new surfacings. These factors have led to a raised awareness of the topic both in the Highways Agency (HA) and in Local Authorities.

The issue of early life skidding resistance is important to HA, particularly because of its implications for the Trunk Road skidding standards: a provision to formulate improved advice on this topic was included in work to implement the recent revision of the HA Skidding Policy. To assist with this, the HA commissioned TRL to carry out an initial assessment of the skid resistance effects occurring on asphalt surfaces in their early life, with some in-kind assistance and a small financial contribution from CSS (formerly the County Surveyors Society). Interim advice was prepared in 2003 based on early observations from this work while a further phase of measurements and assessments continued. It was envisaged that a more detailed investigation of the implications for accident risk would follow.

The report reviews the background to the study in some detail before describing the programme of measurements. The latter was based upon measurements of locked wheel friction in both wet and dry conditions over a wide range of speeds, using the Pavement Friction Tester.

The work included an initial investigation of the effect of speed on both wet and dry skidding resistance on new Stone Mastic Asphalt (SMA) surfaces, followed by further phases in which a more limited range of measurements were made on a greater number of sites in order to extend the study to cover a wider range of surfacing types of different ages, roads and traffic conditions.

Measurements have been made with the PFT on some 25 sites, including single and dual-carriageway trunk roads, motorways and principal roads. The programme has included examples of eleven types of proprietary thin surfacing and generic SMA materials, varying in age from new to 18 months old. Wherever possible, older, well-trafficked, traditional surfacings were included for comparison. On all but one of the sites SCRIM (sideway-force routine investigation machine) was used to measure low-speed wet skidding resistance. This is the equipment normally used to monitor skid resistance on the network. On two sites, some comparative locked-wheel stopping distance tests were made by the Police using their decelerometer device.

The primary purpose of the work was to gain a better general understanding of the physical effects and to determine how long they last. It was not designed to compare the performance of different proprietary or generic materials: there are far too many variants and different conditions on the network for that to be practical.

The report provides an overview of the results of the various tests and goes on to discuss the findings in some detail, both in the context of the physical phenomena observed and the implications for accident risk.

The measurements made as part of this project have demonstrated that:

- Low-speed wet friction is high, even though a binder film covers the microtexture on the aggregate.
- Wet skid resistance decreases with increasing speed, as would be expected. The new surfaces have lower wet skid resistance at higher speeds than would be expected for surfacing materials for

which the aggregate is unpolished and the texture depth is good but the levels are similar to many materials after some time in service.

- Dry friction reduces with speed but does not follow the same pattern as for wet roads: the minimum level is reached at about 50km/h and does not decrease further at higher speeds.
- Compared with the high levels generally obtained on older surfaces from which the binder film has worn off, dry friction on new asphalt can be lower, by up to about 20 percent at low speeds and by about 30-40 percent at intermediate and higher speeds.
- At low and intermediate speeds, dry friction is similar to wet friction. At very low speeds, the high level of wet friction can exceed the dry friction.
- Although sliding friction levels at high speeds on binder-coated surfaces are lower than that found on dry roads with aggregate exposed, they are nonetheless much higher than wet friction.
- The effects can be observed on any new surfacing, but the length of time for which they persist will vary depending upon local conditions and traffic levels. Typically, most effects have disappeared after six months but they may persist longer and have been observed for up to 18 months on surfaces with light traffic and thicker binder films.

The measurements in this project have indicated that low-speed wet skid resistance on new surfaces is high, and can be very high in the very early life. However, other workers have observed reductions during the first few days that later recover. The levels observed in these other studies were such that the wet skid resistance may be below investigatory levels for higher-risk sites for a short time.

The work has confirmed the suggestion that these “early life” phenomena can be attributed to the presence of a film of binder that can adhere to the surface of the aggregate for a significant period of time. The binder film appears to have three main effects:

(i) It prevents the microtexture on the aggregate particles making contact with the tyre, resulting in lower wet friction at higher speeds than would normally be expected.

(ii) It appears to provide a different adhesive mechanism to provide high friction at low speeds even though the microtexture is obscured.

(iii) In a dry skid, the bitumen can “melt” as a result of the heat generated in the tyre contact area, reducing the friction compared to a dry surface on which the aggregate is exposed.

On the basis of the information available at present, it is concluded that in most circumstances, on most roads, the increased risk of accidents associated with these effects on new surfacings is likely to be small. However, in some circumstances these effects may lead to an increased accident risk. It is concluded that the interim advice provided by Highways Agency in IAN49 remains the best advice regarding the management of new surfacings that can be provided at present.

However, in the light of this research, the following further recommendations are made:

1. Specific research into any link between new surfacings and accident risk should be carried out: such work is already in hand.
2. Consideration should be given to alternative methods of ameliorating the residual risk in those locations where the properties of new surfacings may have a significant adverse effect. In particular, a review should be made of appropriate warning signs that will better inform drivers as to the nature of the risk.
3. Consideration should be given to improved education regarding new surfacings so that drivers are better informed. This might include additional advice in the Highway Code regarding driving on new surfaces.
4. The literature shows that other workers have found that modern new surfacings may be unusually slippery in the first few hours or days after they are laid. This effect has not been observed in this study but further research to assess this aspect more thoroughly should be considered.

1 Introduction

When an asphalt road surfacing is newly laid, the aggregate and mortar are covered with a film of bitumen binder. For some years it has been suspected that such surfaces may exhibit different skid resistance properties compared with roads that have been in service for some time. Any effects have probably always been present but, until recently, there has been no suitable equipment available to investigate them and help determine what impact they might actually have on accident risk.

In recent years, new surfacings have been introduced on the network that have a thicker initial binder film than traditional chipped hot-rolled asphalt (HRA) or dense macadam. This thicker binder film may have increased both the risks of possible problems occurring and the time that any effects last. There has also been an increase in anecdotal comment related both to dry and wet skidding resistance in the first few months of service, reinforced by police comments on lower than usual dry friction found in their routine stopping-distance skid tests on some relatively new surfacings. These factors have led to a raised awareness of the topic both in HA and in Local Authorities.

The issue of early life skidding resistance is important to the Highways Agency (HA), particularly because of its implications for the Trunk Road skidding standards. For this reason, work to implement the revision of the HA Skidding Policy recently undertaken included a provision to formulate improved advice on this topic for inclusion in the Design Manual for Roads and Bridges (DMRB).

To assist with this, the HA commissioned TRL to carry out an initial assessment of the effects occurring on asphalt surfaces in their early life. Support for the work was also provided by the CSS (formerly the County Surveyors Society) in the form of in-kind assistance and a small financial contribution. The observations from this work were utilised in preparing interim advice while a further phase of continuing tests and assessments extended the study to cover a wider range of roads and traffic conditions, on which to base improved advice that could eventually be incorporated into the DMRB. It was envisaged that this work would then be followed by a more detailed investigation of the implications for accident risk.

The primary purpose of the work reported here was to gain a better understanding of the effects and to determine how long they last. The report is based upon practical measurements of skid resistance on a number of sites, including asphalt surfacings from new to 18 months old. It covers both wet and dry skidding resistance, includes an initial investigation of the effect of speed on both wet and dry skidding resistance, and also gives an idea of how long the effects can last.

This report covers the initial assessment phases of the work: the phase to consider accident risk in more detail is now in hand.

2 Background

2.1 Principles of skid resistance and its state in the early life of a surfacing

When a vehicle is braking, accelerating or cornering it relies upon friction between its tyres and the road surface to provide an opposing force that enables the vehicle to slow down, speed up or follow the line of the curve.

If the combined braking and cornering forces required exceed the available friction, the tyre will slide over the road surface. In the extreme case, the rotating wheel may lock and the vehicle will skid, or the tyre may slide sideways. If combined acceleration force and cornering forces exceed the available friction, the driven wheels may spin and may also slide sideways.

It is generally considered that the coefficient of friction between a tyre and a dry, well-trafficked road is usually high (typically around 0.7) and almost unaffected by vehicle speed. However, when a road is wet, the friction is markedly reduced compared with the dry condition and also decreases with increasing speed.

The actual coefficient of friction that applies in any particular situation will depend not only on the nature of the road and tyre but also on other factors that are unique to that situation, such as the possible presence of contaminants. For this reason, the underlying contribution to friction made by the road, its “skid resistance”, is usually assessed in wet conditions using standardised test methods.

Skid resistance is mainly governed by “microtexture” on the surfaces of the particles making up the road surface. In wet conditions, the microtexture penetrates the water film to make contact with the tyre and develop adhesion that provides friction at all speeds. However, as speed increases, wet skid resistance decreases, partly because water has less time to escape from the contact area.

When a road surface is new, the aggregate is unpolished by traffic and so the skidding resistance is expected to be high. The effect of traffic, particularly heavier vehicles, is to gradually polish the aggregate, thus reducing the microtexture; as a result, skid resistance decreases. Dry friction usually remains high (although it may be reduced compared with fresh aggregate) but wet skid resistance decreases to an equilibrium level that depends upon the nature of the aggregate and the amount of traffic using the road.

Skid resistance also varies with the time of year, generally being higher in winter than in summer. During the summer months, when the roads are drier, fine deposits built up on the road surface that act as a polishing medium so the skid resistance tends to fall. During the winter, when roads are wetter for longer, the detritus is coarse and tends to roughen the surface. This cyclic process is continuous, but its effects are not always the same from one year to the next. For example, in a dry winter there may be less recovery, and this may lead to relatively lower skid resistance the following summer. For this reason, the UK skid resistance standards include a methodology to take seasonal variation into account.

Most new asphalt surfacings have a thin layer of bitumen binder covering the aggregate, so there will be a period of time during which the microtexture is not fully exposed to make contact with the vehicle tyres. It is the presence of this binder film that is thought to be the main factor affecting the skid resistance of surfacings early in their lives.

2.2 History

It had always been thought that skid resistance in the early life of an asphalt surfacing might be affected by the presence of a binder film on the surface of the aggregate. The main concern was that, by “blinding” the microtexture, the tyre would react as though the surface of the aggregate was smooth (as an aggregate that has been heavily polished by traffic might be) and in consequence the skid resistance would be reduced. However, it was generally observed that the surface bitumen was either rapidly worn away by traffic or weathered and "early life" effects were not raised as a contributory factor in accidents.

The issue was brought to greater prominence in the late 1980s following a serious accident on the M4 motorway. The incident was not caused by the road surface in question: following an incident on the eastbound carriageway, a van carrying young people home from a music festival crashed over the central reserve into the path of traffic on the opposite carriageway. Vehicles on that carriageway then ran into the wreckage and passengers on the road from the van. However, that carriageway had recently been resurfaced (with chipped hot-rolled asphalt). When the investigating police officer carried out routine skid tests (in which a police car was braked with locked wheels and the stopping distance measured), he found longer stopping distances and lower friction values and than he expected. In his statement to the inquest, he suggested that the bitumen was melting, thus reducing the friction.

Road engineers treated this with some scepticism at the time, particularly when follow-up tests with SCRIM (sideway-force coefficient routine investigation machine) showed relatively high values of wet skidding resistance for the new road. This kind of accident was (and still is) rare and at that period no suitable equipment was available to measure both wet and dry skid resistance over a range of speeds. Therefore, detailed research on the topic was not pursued at that time.

More recently, there has been renewed interest in the UK in "early-life skidding resistance", as the effect has become known, particularly as police officers have increasingly commented on dry skid measurements made during their routine investigations that give lower values than expected. This has been associated with more widespread use of modern types of asphalt materials, such as Stone Mastic Asphalt (SMA) and a range of proprietary "thin surfacings". These surfacings offer a number of advantages, particularly in regard to reduced tyre/road noise. However, as a result of the way in which they are made, there is generally a thicker binder film on the new road than occurs with traditional materials. For a history of the development of these new materials and their introduction in the UK, see Nicholls (2002) and Nicholls and Carswell (2004).

In 1997, some examples of the new types of surfacing were included in a wider study by TRL of the influence of texture depth on skid resistance (Roe, Parry and Viner, 1998) and some of these had their skid resistance measured relatively early in their lives. However, within the context of that research, measurements were focussed on wet skid resistance and only one site was measured on the day on which it was laid. In that case, wet skid resistance at low speeds was high. At higher speeds, it decreased, as expected, but perhaps rather more than might have been expected for older surfaces with similar texture depth. Little difference could be seen between a section that had been gritted and one that had not. Although the skid resistance at higher speeds on the new surface appeared to be lower than might be expected, it was still higher than was typically obtained on many in-service roads that had polished under traffic action.

In the light of the potential concerns, when, in 1998, the Highways Agency announced a review of its skidding resistance standards for trunk roads, it was decided that the subject of early-life skid resistance would be included in the review, with the intention of providing some specific advice to engineers in any revised standard.

In 1999, at about the time that the review of the Skidding Standards was started, the CSS (formerly the County Surveyors Society) began a small preliminary research project to assess early life effects but the work was confined to wet skid resistance. A number of newly-laid local authority roads were studied, measuring the wet skid resistance (with either a Grip Tester or SCRIM) in the first few days after laying and then over a longer period. It was found that, in many cases, wet skidding resistance started high but was reduced (compared with what would be expected of an unpolished aggregate) in the first week after laying and opening to traffic. It then increased again until it eventually began to decrease, presumably following the normal expected cyclic process of aggregate weathering and polishing under the action of traffic. The levels of wet skidding resistance measured initially were well above any likely requirements for the sites, but in the short period when the skidding resistance was reduced, this may not have been the case. A recent study of SMA surfacings on rural roads in Dorset has shown similar effects (Bastow et al, 2005), as has an unpublished study in Australia.

In 2001, Derbyshire County Council asked TRL to investigate two sites in that county that had been resurfaced with SMA recently and which had been the subject of comment by the Police regarding apparently-low dry skid resistance. This short investigation confirmed that, although wet skidding resistance was generally above any likely required levels, in some circumstances dry friction values could be similar to those found in wet conditions.

The phenomena had not only been noticed on British roads. In the Netherlands, for example, the problem was first observed on newly-laid, dry porous asphalt in 1991. It had been assumed that this surfacing would have similar skid resistance characteristics to their traditional dense macadam. However, an accident demonstrated that this was not so and that braking distances could be extended. It was observed that, when braking with locked wheels in dry conditions, the temperature of the contact area between the tyre and the road increased above the melting temperature of the bitumen and created a sliding surface. Research showed that this primarily affected cars without anti-lock braking systems (ABS). The problem on porous asphalt was found to last from 4 to 8 months and, during this period, warning signs were placed to warn the driver. Results from more recent work on SMA showed that gritting or sanding of the newly laid material did not improve the dry skidding resistance and therefore the warning signs were required even after gritting or sanding treatment (Fafiė, 2004). An ongoing study in the UK that has included infra-red imaging has demonstrated the effect of high temperatures in the tyre/road contact patch during a locked-wheel skid with associated extended stopping distances (Bullas, 2005).

The University of Ulster has also been carrying out some studies of early-life effects (Woodward, Woodside, and Jellie, 2005). They, too, observed some similar effects to those found in the CSS work on sites that they measured with a GripTester. They have also carried out some laboratory studies, in which a modified version of the accelerated polishing machine (as used in the Polished Stone Value test, BSI 812-114:1989) was used to assess how bitumen adheres to the surfaces of aggregate particles. The tests showed that binder could adhere to the aggregate for some time, unless higher stresses were applied at the surface (by setting the polishing tyre at an angle, thus inducing a skidding action at the surface of the test specimens). It was found that polymer-modified binders that are used in many modern proprietary surfacings remained on the aggregate surfaces for much longer than ordinary bitumen.

It was in this wider context that the research reported here was begun. Interim advice was prepared by the Highways Agency in 2003 in the light of the results available at that time; a study to assess more directly how the observed early-life skid resistance phenomena relate specifically to accident risk is now under way.

3 Objectives and scope of the measurement programme

3.1 Objectives

The primary objectives of the research covered in this report were:

- To obtain a greater understanding of the wet and dry skid resistance of newly-laid asphalt surfacings. This would include proprietary "thin surfacings", such as those approved through HAPAS (Highway Authorities Product Approval Scheme) used on the Trunk Road network and generic SMA materials used by some local authorities.
- To assess wet skid resistance on new surfacings in comparison with trafficked surfaces.
- To develop an improved understanding of how long any observed effects might last.
- Based on the observations, to consider possible approaches to dealing with any issues arising and to improve the advice provided to engineers.

3.2 Overview of the measurement programme

The programme of measurements was developed in three stages:

(i) An initial assessment exercise, in which detailed measurements of the wet and dry skid resistance of a small number of recently-laid surfacings were made. Since they were fundamental to identifying the phenomena observed, these are reported in some detail in this report, in Section 5.

(ii) Building on the knowledge gained in the initial phase, the range of measurements was expanded in a programme of "snapshot" measurements which enabled a greater number of sites to be included. In this "snapshot" programme, only one visit was made to each site and measurements were made in less detail than in the first stage of the work. However, using this approach it was possible to cover a wider range of types of road with surfacings of different ages. In particular, in this phase of the work the programme was expanded to incorporate "HAPAS approved" surfacings rather than the generic SMA materials used on the sites in the first phase. Tests on motorways and trunk roads and other county roads were included at this stage.

(iii) In the final stage, the "snapshot" technique was developed to investigate in more detail the very early life of a new thin surfacing on a heavily-trafficked motorway. This work was carried out to complement the original study that had looked at a generic SMA on a lightly-trafficked road. This stage of the work also included a short programme of tests to investigate how locked-wheel friction values might vary with different types of tyre and different load conditions.

The results of this research would then feed into the ongoing programme to assess associated accident risk.

4 Equipment used for skid resistance measurements

4.1 SCRIM

The TRL SCRIM (Figure 4.1) was used to obtain basic measurements of low-speed wet skid resistance. SCRIM measures skid resistance continuously using an angled, smooth-tyre test wheel and records a "SCRIM Reading" for each 10m length of road. This is the ratio between the measured average sideways force and the 200kg vertical load, multiplied by 100. Measurements are normally made at a standard test vehicle speed of 50km/h, in the nearside wheel track. Because the test wheel is set at an angle of 20°, the effective slip speed at which the tyre contact patch passes over the surface is approximately 17km/h.

Figure 4.1 SCRIM – principle and test wheel detail

SCRIM is the standard device for monitoring skid resistance on the UK Trunk Road network and is also used by many local authorities. The measurements from this device provided a baseline that could be used to compare the surfacings with previous experience and, if required, with possible skidding standards for the sites concerned. The TRL SCRIM is also equipped with a laser-based sensor to measure texture depth and this was used to assess that property when road surface conditions were suitable.

4.2 Pavement Friction Tester (PFT)

The PFT (Figure 4.2) is owned by HA and operated on its behalf by TRL. The PFT measures skid resistance using the locked wheel method. This means that the tyre slips over the surface at the same speed as the test vehicle, so it can measure the skid resistance at any practical speed up to about 130km/h. The load and drag forces on the tyre are measured every 0.01 seconds throughout the lock-and-release braking cycle. The average coefficient of friction is calculated over a period of one second after the wheel has locked and settled into the skid. The measurements are normally made on a wet road surface, for which purpose water is pumped from a tank in the towing vehicle through a nozzle in front of the test wheel. However, it is also possible to turn off the water supply to make dry measurements; both techniques were used in this research.

Figure 4.2 The Pavement Friction Tester

In the UK, this device is used for research work rather than routine surveys. The PFT was the main tool used for this work because it made it possible to make measurements of both wet and dry friction at different speeds. A standard smooth tyre is normally used for these measurements and this was the case for most of the measurements made for this study. Alternative tyres can be used including normal commercial car tyres, as were used for a component of this research programme.

4.3 Skidman

This type of test is a standard method used by Police accident investigators in routine assessments following road traffic accidents. The data are usually used to assess road surface friction at a specific accident location close to the time of the event, and are most often carried out when the road is dry.

"Skidman" is a proprietary unit[1] containing accelerometers and control electronics that is placed inside the police car. To undertake a test, the antilock braking system (ABS) is usually disabled. The vehicle is driven at a chosen speed and then subjected to emergency braking, skidding with locked wheels to a standstill (Figure 4.3). The deceleration of the car is recorded from the moment the brakes are applied until it stops. The average deceleration, divided by the acceleration due to gravity and corrected for slope in the road where necessary, provides a measure of the average coefficient of sliding friction in the area of the skid.

It is important to recognise that the police measurement technique records the average coefficient of friction arising from four normal vehicle tyres, from moving at a chosen target speed until the vehicle stops. In an accident investigation, the line for the test is normally chosen to represent that thought to have been followed by the vehicle involved and wherever possible, measurements are made in conditions similar to those thought to have pertained at the material time. Thus, the measurement is made on whatever alignment the skid takes the car (not necessarily following the normal traffic wheel paths), whatever the condition of the road surface (wet, dry or contaminated). For these reasons, these measurements are not directly comparable with the standardised "road" assessment tests.

A small number of Skidman measurements were incorporated into this study to provide some comparison with the routine police tests that have given rise to previous comment about low values of dry friction. Tests were made by the police on two of the study sites; where possible they were timed to coincide with TRL visits.

Figure 4.3 Police car conducting a "Skidman" dry test

(Note that in this case the car is sliding at a slight angle to the line of the road, offset from the wheel paths. The skid marks in the left wheel path, visible in the right foreground, come from PFT measurements made earlier during the visit to the site)

[1] "Skidman" was used here – other Police forces may use alternative proprietary devices to measure the deceleration, but the tests operate on the same principle.

5 Measurements, Stage 1: initial assessment on SMA surfaces

This part of this study consisted in carrying out a detailed programme of measurements on three different sites. These included further measurements on the two roads studied in the initial work for Derbyshire County Council and a site on a new section of road on the Derbyshire/Leicestershire border which on which measurements were made from the day of opening.

This part of the work was intended to:

- assess the effects first seen in Derbyshire from an earlier stage in the life of the surfacing;
- assess the influence of speed on both wet and dry friction measurements;
- assess the rate at which conditions appeared to return to “normal”.

5.1 Sites investigated

The roads studied in this phase of the work were chosen for convenience, taking advantage of contacts already made with the County Councils. They were all lightly-trafficked principal roads and since it was thought that an important factor in the longevity of any effects would be the amount of traffic that might wear away the surface bitumen, they would provide an approximate “worst case” scenario. Their lightly-trafficked nature also simplified the measurement process by making it easy to arrange the necessary combination of frequent test visits and PFT measurements over a suitable speed range.

5.1.1 A621, Car Top and A618, Pebley

The A621 at Car Top and the A 618 past Pebley Ponds were the two sites initially investigated for Derbyshire County Council.

The A621 site is on the route across the eastern edge of the Peak District between Sheffield and Baslow. The main surfacing studied here was an SMA material that had been laid in July 2001. South of this was a length of a proprietary surfacing, "Thinpave", that had already been in service for some years and this was used as reference surface to assess any local seasonal effects. This site is not heavily trafficked (see Table 6.1) but it is exposed to moorland weather conditions.

The A618 past Pebley ponds is part of the route south from Rotherham to Clowne. It is a lightly-trafficked, typical rural "A" road with frequent rises, dips and bends. The generic SMA surfacing, similar to that used on the A621, was laid in April 2001. There were no suitable older surfaces for comparison on this site.

It was on these sites that the effects of lower-than expected dry skid resistance were first observed using the PFT. As part of the first stage of the research, as well as the original visit in September 2001, further visits were made to these sites until September 2002 in order to observe any changes in measured friction that might occur as the surfacings aged.

5.1.2 A511 Ashby de-la Zouche

The new by-pass on the A511 at Ashby de-la Zouche opened to traffic in March 2002. The road is divided into two sections by a central roundabout where it crosses a radial route from the town. The eastern section has sweeping curves, combined with a rise and fall to the intermediate roundabout. The western section is generally level, again on a sweeping curve, until it climbs up for about half a kilometre to rejoin the original route at the western roundabout. The road is generally lightly trafficked, but the eastern section provides access to an industrial area and so carries rather more heavy vehicles than the western section.

The surfacing on the new road is SMA (to the local authority’s specification) with a section of older well-trafficked HRA linking the new by-pass route to the main road network at the eastern end. The approaches to both the intermediate roundabout and that at the western end were treated with a high friction surfacing from the outset. Monitoring began on the day the road opened to traffic and continued at intervals for about six months.

5.2 Measurements carried out

Each site was visited before making any measurements in order to establish a pattern of measurement locations for the site, taking into account the general layout and road features. This was particularly important for the PFT, which records discreet skids rather than a continuous measurement. On repeat visits with the test devices, measurements could then be made in the same pre-determined locations. Measurements with SCRIM were usually made as a continuous pass throughout each site.

Experience during the initial work for Derbyshire showed that frequent repeat tests with the PFT in the same location could affect the surface condition. It was also found that dry tests sometimes left marks on the surface that could affect any wet tests carried out on the same spot. Therefore, for the later work, care was taken by the equipment crews to avoid making repeat measurements wholly on previous skid marks. It was observed that previous skid marks largely disappeared between visits.

5.2.1 Measurements on the A621 and A618

The original dry friction measurements with the PFT on the A621 and A618 (made for Derbyshire CC in September 2001) were confined to tests at 50km/h because they were only intended to provide an indication of possible effects in dry conditions (which at that stage were not known). On subsequent occasions, dry friction measurements were also made at 20km/h. Wet tests were initially made at 20, 50 and 80km/h but the speed range was extended to include 100km/h in later visits. In addition to the visit in September 2001, further visits were made in April, July and September 2002.

Table 5.1 and Table 5.2 list the skid locations and types of measurements which were made on the A621 and A618 respectively: Appendix A includes schematic diagrams showing their relative positions on the sites.

Table 5.1: List of PFT skid locations for site A621

Direction	Skid location	Test speeds (km/h)		Material tested	Dates of visits
		Wet	Dry		
Northbound	CN1 CN2 CN3	20, 50, 80, 100	20, 50	SMA	24 & 25 September 2001 15 April 2002 2 July 2002 4 September 2002
Southbound	CS1 CS2 CS3	20, 50, 80, 100	20, 50	SMA	
Southbound	CS4 CS5	20, 50, 80, 100	20, 50	Proprietary thin surfacing	

Table 5.2: List of PFT skid locations for site A618

Direction	Skid Location	Test speeds (km/h)		Material tested	Dates of visits
		Wet	Dry		
Northbound	PN PN1	20, 50, 80	20, 50	SMA	24 & 25 September 2001 15 April 2002 2 July 2002 4 September 2002
Southbound	PS1 PS2	20, 50, 80	20, 50	SMA	

As well as the measurements with the PFT, on each visit to these two sites a standard 50km/h SCRIM measurement pass was made and, on some occasions, supporting measurements with Skidman were made by the police.

5.2.2 Measurements on the A511

The first measurements on the A621 and A618 had provided an indication of the general nature of the phenomena observed but the tests had been made when the surfacings were already two and six months old respectively. The measurements on the A511, therefore, were planned to build on these initial tests by studying the friction of a new surface in more detail, starting from its first opening to traffic. A particular objective here was to assess the friction levels in the first few weeks after opening. A further objective at this site was to assess the effect of speed on measured friction on the new surface, both wet and dry. Measurement visits were made on the day after the new road was opened to traffic, then again at intervals for approximately six months: at ten days, then at 3, 5, 8, 15 and 24 weeks.

The surface courses on the two sections of the A511, although of similar material, were actually laid three weeks apart, the western section being the last to be laid, a week before opening to traffic. Because the two sections were expected to carry different levels of traffic, they were treated differently in planning the measurements.

On the eastern section, the skid positions were located taking the site's topography into consideration. It was of potential interest to observe whether the bends, dips or rises had an effect on the results. For this part of the site, therefore, spot-check measurements were made with the PFT at two speeds (20km/h and 50km/h) in both wet and dry conditions. The test positions included both the new SMA surfacing (with groups of test points being chosen to occur at different points on the road in relation to its topography), together with the older HRA for comparison. SCRIM measurements were made in a continuous pass throughout the section, excluding the high friction surfacings. Table 5.3 lists the PFT skid locations and tests carried out at each point.

Table 5.3 PFT Skid locations and test pattern on A511 site (eastern section)

Direction	Skid Locations	Test speeds (km/h)		Material tested	Dates of visits
		Wet	Dry		
Eastbound	E1 E2	20	20	Generic SMA	18 March 2002 27 March 2002 10 April 2002 22 April 2002 14 May 2002 1 July 2002 3 September 2002
	E3 E4	50	50		
	E5 E6	20	20		
	E7 E8	50	50		
	E9 E10	50	50	HRA	
Westbound	W11 W12	50	50	HRA	
	W13 W14	50	50	Generic SMA	
	W15 W16	20	20		
	W17 W18	50	50		
	W19 W20	20	20		
	W21 W22				

The western section, which was laid closest to the time of opening and had a more suitable topography, was used to investigate the effects of speed. The opportunity was taken to cover a wider range of speeds with the PFT. However, in order to accommodate the need for acceleration and deceleration, as well as to avoid too many tests in the same place, a number of test positions around the site were defined and tests were made at one speed only at each one, on the assumption that the surfacing was generally homogeneous. Replicate positions were provided for each speed. The measurements were carried out in a series of circuits (westbound, then eastbound) between the two roundabouts with the test locations and circuits grouped so that measurements at the different speeds could be made as efficiently as possible. Table 5.4 lists the skid locations used on the western section. Schematic diagrams showing the layout of the measurement locations and their grouping on both sections of the A511 site can be found in Appendix A.

Table 5.4: PFT Skid locations and test pattern on A511 site (western section)

Direction	Skid Location	Test speeds (km/h)		Material tested	Dates of visits
		Dry	Wet		
Westbound	WS1 WS2	20	20	Generic SMA	18 March 2002 27 March 2002 10 April 2002 22 April 2002 14 May 2002 1 July 2002 3 September 2002
	WS3 WS4	50	50		
Eastbound	ES5 ES6 ES7	50	50		
	ES8 ES9	20	20		
Westbound	WS10 WS11	80	80	Generic SMA	
Eastbound	ES12 ES13	100	100		
Westbound	WS14 WS15 WS16	40	40	Generic SMA	
Eastbound	ES17 ES18	90	90		
Eastbound	ES19	120	120	Generic SMA	

6 Measurements, Stage 2: widened range of surfacings and conditions

The first stage of the measurement programme had provided an indication of the likely levels of friction that could be encountered during the early life of new SMA surfacings. These measurements covered the first six months or so of the life of roads that were lightly trafficked. However, it was recognised that although generic SMA surfacing was used on many local authority roads, on other roads, particularly trunk roads and motorways, only materials in the “thin surfacing” category as certified through the British Board of Agrément Highway Authorities Produce Approval Scheme (HAPAS) were permitted.

Further, the traffic levels on many routes on the motorway and trunk road networks are much greater than on the roads studied initially. Therefore, the second stage of the programme was developed to assess the extent to which the effects that had been observed in the first stage would be found on HAPAS-approved thin surfacings and over what period of time they might last, especially under heavier traffic.

6.1 Sites investigated

For this part of the study, the emphasis was on assessing whether the effects could be observed in different combinations of conditions, traffic levels and surfacing age. It was decided, therefore, to carry out “snapshot” measurements, that is, a single visit to a site to record its condition at that time, over a range of sites to represent most conditions. In order to cover the possibility of more-severe weather conditions influencing the behaviour of the surfacings, many of the new sites were in the north of England.

Table 6.1 lists the sites that were included in the “snapshot” programme. Further visits were made to the A621 and A618, to provide measurements on those sites after a longer period in service, and eighteen new sites were added. Although they had been made at an earlier stage of the work, the original visits to the A621 and A618 were also included as “snapshots” since, in effect, that is what they were. As background information, Table 6.1 indicates the general material types measured at each site, which included examples of eleven proprietary thin surfacing materials and some generic SMAs. In some cases more than one lane was tested to provide data at different traffic levels. No attempt was made to make direct comparisons between materials since conditions on every site were different and even nominally similar materials may have used different aggregate sources; indeed, there were one or two locations where changes of aggregate were clearly visible along the length of the site and in some cases the different materials were tested. In some places it was possible to include nearby lengths of well-trafficked HRA for comparison.

All the thin surfacing materials utilised 10mm or 14mm nominal size coarse aggregate, with the exception of one site: the three surfacings on the A259 were based on a 6mm main aggregate size. The three surfacings on this site were experimental materials, laid as part of a demonstration trial and an investigation into the performance of small aggregates that is still under way. They were included here so that early-life information could be taken into account when assessing their overall performance at the end of the trial or in future trials of materials of this type.

6.2 Measurements carried out

The earlier tests on the A621 and A511 the influence of speed on friction had shown two characteristic patterns of behaviour on those surfacings. For wet friction, the behaviour was broadly that expected from a well-trafficked surface but with some variations (discussed in section 8.3.1) Dry friction, unlike well-trafficked dry roads, showed an effect of speed (section 8.4.1), but one that was different to a wet road. These behaviours could be explained by the presence of the thicker bitumen film on the newer surfaces (see the discussion in section 9). Although the materials used on the A621 and A511 were of the generic SMA type, general observations of the additional types of surface to be studied at this stage suggested that their surface characteristics in early life would be similar and that therefore the general influence of speed on these materials was unlikely to be markedly different from that found in the first stage of the work. Differences in actual measured friction might be expected from the different materials at different ages or levels of traffic, but the characteristic behaviour would be similar.

It was therefore decided to limit the range of speeds to be used for the measurements with the PFT on most of the “snapshot” sites. Given the cost and practicalities of arranging a complex test programme, particularly on heavily-trafficked roads (which would involve road or lane closures for high-speed and low-speed tests), this had the advantage of allowing a greater number of sites to be included. Dry and wet skid measurements were therefore carried out with the PFT at 50 and 80 km/h; on some sites where this was feasible, wet measurements were made at other speeds. A minimum of 3 skids at each target speed was undertaken but rather than make additional repeat passes, the surfacings were assumed to be generally homogeneous, and replicate measurements were undertaken along the site rather than at specific locations.

As a result of practical difficulties in maintaining a supply of test tyres (repeated dry skids can rapidly destroy a tyre), in stage 2 it was necessary to use ribbed rather than smooth test tyres on the PFT on some of the sites in the north of England. On the basis of previous experience it was considered that this practice was unlikely to significantly affect the measurements. Earlier work (Viner, et al, 2000) had shown that the ribbed tyre (which has a series of unconnected grooves around the circumference of the tread) effectively adds to the texture depth: on surfaces that already have adequate texture (as would be the case with which the surfacings to be studied), the use of a ribbed tyre has little effect on wet skid resistance measurements. On dry surfaces, however, expulsion of water from the tyre/road interface is not a factor and the friction developed has to do primarily with interaction with the areas of rubber in direct contact with the road. The contact areas of both a ribbed tyre and a smooth tyre present similar smooth surfaces to the road in the direction of travel, so it was argued that the “texture” provided by the tyre would have little effect on the dry friction. Nevertheless, some local comparative tests were made to verify that this was the case when it was necessary to use a ribbed tyre. Where a ribbed tyre only was used for dry tests, it was also used for the wet tests, as was, a smooth tyre.

In addition to the PFT measurements, texture depth (Sensor Measured Texture Depth, SMTD) was also measured at each site using the sensor on SCRIM, which, with one exception, also measured wet skid resistance at the standard 50km/h test speed.

Table 6.1 Sites included in the Stage 2 "snapshot" measurement programme

General location	Road type[1]	Surface[2]	Direction and Lane(s) tested	PFT Tests made[3]		Date of visit	Age[4]	Traffic level[5]	
				Wet	Dry			Flow	HGV
M6 Killington	M	TS	SB L1	50, 80 RS	50 R		8m	19900	22%
M6 Tebay	M	TS	SB L1	50, 80 RS	50 R		10m	17900	22%
M6 North of J41	M	2xTS, C	SB L1	50, 80 RS	50 R		3m	19800	25%
A66 Carleton Hall	D	TS, C	WB L1	50, 80 RS	50 R		10m	6800	20%
A66 Highgate Farm	S	2xTS	EB[6]	50, 80 RS	50 R		18m	85500	7%
A66 Lowside	S	TS, C	WB[6]	50, 80 RS	50 R		12m	9500	11%
A595 Loop Road South Whitehaven	S	TS	SB	50 RS	50 R	between 28/7/03 and 30/7/03	27m	11700	5%
A595 Ravenglass	S	TS	SB	50 RS	50 R		23m	4300	6%
A595 Bigrigg	S	TS	SB	50 RS	50 R		12m	13800	3%
A590 Ayside	S	TS	SB	50, 60, 80 R; 50 S	50 R		8m	14000	8%
A590 Greenodd Bends	S	2xTS, C	WB	50, 80 RS	50 R		22m	1600	7%
A590 High Newton A590 Low Newton	S	TS TS	EB EB	50, 60 R, 50 S 50 RS	50 R 50 R		19m	14000	8%
A5092 Penny Bridge	S	TS	EB	50 RS	50R		10m	3400	10%
A5092 Lowick Green	S	TS	EB	50 RS	50R		24m	3400	8%
M3 between J3 and J4	M	TS TS C	SB L1, 2 NB L1, 2 NB L3	80 S 80 S 80 S	- - -	26/04/03	3m	H	H
M3 between J3 and J2	M	TS, C	NB L1, 2	80 S	-	26/04/03	3m	H	H
A339 Link from A34[7]	D	2xTS, C	SB L1, 2	20, 80 S	20, 80 S	13/03/03	1m	M	L
A182 Seaham link road	S	2xTS C	NB Both	20, 30, 40, 50, 80 RS 20, 50 , 80 RS	50 RS 50 R	26/07/03	4m	L	VL
A689 W. of Wynyard	D	TS TS TS C	WB L1	50, 80 RS 50, 80 RS 50, 80 RS 50, 80 RS	50 RS 50 RS 50 RS 50 S; 80 R	26/07/03	2m	M	L
A259 Pevensey Levels	S	3x TS (6mm), C	Both	20, 40, 50, 80, 100 S	50, 80 S	28/10/03 01/12/03 02/03/04	2w 3m 6m	M	M
A621 Car Top	S	SMA, C	Both	See Table 5.1	See Table 5.1	25/09/01 01/05/02 06/07/02 04/09/02 23/05/03	2m 10m 12 m 14m 22m	L	VL
A618 Pebley	S	SMA	Both	See Table 5.2	See Table 5.2	25/09/01 01/05/02 06/07/02 04/09/02 23/05/03	5 m 13 m 15 m 17 m 25 m	L	VL

Notes
[1] M = 3-lane motorway; D = 2-lane dual carriageway; S = single carriageway, 1 lane in each direction.
[2] "TS" indicates a proprietary thin surfacing, including SMA-derived thin surfacings.
"SMA" indicates a generic SMA to a local specification.
"C" indicates an adjacent existing well-trafficked surfacing, tested as a control.
[3] Speed (km/h) and test tyre used: R= ribbed tyre; S=smooth tyre,.
[4] Approximate age in months (m) or weeks (w) at the time of testing
[5] Traffic flows expressed as Annual Average Daily Traffic and proportion of heavy goods vehicles if known; otherwise, general indicators (H=heavy/high %, M=medium/medium%, L=light/low %, VL=very low %) are given.
[6] At this site tests were also made in the centre of the trafficked lane (the "oil lane").
[7] No SCRIM measurements were made at this site.

7 Measurements, Stage 3: very early life in heavy traffic and other tests

The first two stages of the work had provided clear evidence of the likely levels of skid resistance that would be encountered on generic SMA materials (as used on local roads) and on proprietary HAPAS surfacings on more heavily-trafficked roads from about two months old. However, there was still no direct evidence of how rapidly the skid resistance of new materials was likely to change on more-heavily trafficked trunk roads or motorways in the first few days and weeks of service. This was covered in a third stage of measurements, in which sections of a Motorway that was undergoing a resurfacing programme were measured in a series of “snapshots” designed to establish wet and dry friction levels on the new material in this very early period of its life.

The measurements in the first stages of the work had focussed on standardised locked-wheel friction measurements using the standard smooth (and occasionally ribbed) tyre. A criticism of this approach could be that although the test method was a standard one, the smooth tyre and the trailer weight (500 kg) were rather different from normal car tyres. This was addressed in this third stage by making additional comparative measurements on the new motorway surfacing with standard patterned car tyres fitted to the PFT trailer with a reduced load.

7.1 Site description

For this third stage, a series of measurements were made on a section of the M3 between junctions 4 and 4a which was undergoing a programme of resurfacing in lane 1. Measurements were made on the southbound carriageway. This busy section of the motorway, which carries local commuters and longer-distance traffic from London to Southampton and the South-West, is generally straight and is very heavily trafficked, with a traffic flow in each direction of about 50,000 AADT including about 3500-4000 heavy goods vehicles.

The resurfacing work was carried out overnight, planing out the old HRA and replacing it with the new thin surfacing, with approximately 400 m being treated on each occasion before re-opening the lane to traffic well ahead of the morning peak. Generally, adjacent sections of road were treated on successive nights but, occasionally, a number of discreet areas such as sections containing detector loops or bridge joints would be treated leaving “gaps” in the sequence.

7.2 Measurements carried out

7.2.1 Measurements of variation in the very early period

The main objective of this work was to assess the changes that might occur very early in the life of the new surfacing. However, because the resurfacing work was being carried out in intensive periods using relatively short lane closures, it was neither practical nor safe to make detailed friction measurements on the new material before opening to traffic, especially at low or very high speeds.

It was decided, therefore to use the “snapshot” technique to make measurements at a speed close to the traffic speed and to take advantage of the staging of the work to obtain data from surfacings of various ages.

It was assumed that, since the material specification was the same each night, the various lengths of newly-laid material could be considered to be both generally homogenous and representative of one another. Being on a motorway, between junctions, the trafficking of the sections would also be consistent. By liaison with the Maintaining Agent’s team, it was possible to follow progress of the work and to time visits to the site so that a series of sections of different ages could be measured. For example, the previous night’s work would give results after just a few hours of traffic, the surfacing laid the night before that would give data at one day old, and so on. Repeat visits at longer intervals could provide measurements after a few days and weeks.

Using this approach, wet and dry friction measurements at 80km/h were obtained at 12 hours, 1.5 days, 4/5 days, 5/6 days, 7/8 days, 8/9 days, 10/11 days, 12/13 days, 13/14 days, 28/29 days from laying, with later visits providing measurements after three and five months.

7.2.2 Measurements with patterned tyres

The objective of these measurements was to make a general comparison of the friction measurements obtained using normal car tyres to assist in subsequent interpretation of the measurements. For this exercise, measurements were made using both smooth and normal patterned car tyres. For these measurements, the load on the trailer was reduced to make the load on the tyre 300 kg, closer to the normal running weight for a European “quarter car” than the normal 500 kg used for standard PFT tests. Measurements were made wet and dry at 80km/h at this reduced level with both the patterned and smooth tyres, with repeat measurements at 500kg load using the standard smooth test tyre being included for comparison with results from the main measurement programme.

8 Results

8.1 General comments

This part of the report presents an overview of the results of the test programme. Section 9 provides a fuller discussion of the results and their possible implications.

The SCRIM measurements in this report are used primarily for ranking purposes or as an alternative assessment of low-speed wet skid resistance. For these reasons, when referred to, they are expressed as “SCRIM Reading” (SR); this is the value recorded by the device, equivalent to the sideway force coefficient x 100. Measurements were either made at 50km/h or have been corrected to that speed where necessary. The SR values do not include either the “index of SFC” factor or an allowance for seasonal variation that would be applied when SCRIM measurements are to be used in conjunction with UK skidding standards.

In the early stages of the investigation, it was noticed that SCRIM measurements made directly on PFT dry-skid marks could be considerably higher than those on the rest of the site. Since the SCRIM measurements were made to provide a general indication of low-speed skid resistance, in order, to minimise any effect this might have on the results, the average SR for each lane on each site was calculated.

All measurements made with the PFT are reported as “Friction Number” (Fn). This represents the locked-wheel coefficient of friction multiplied by 100 and expressed as a decimal integer. It has been used in this form for ease of comparison with SR. Where appropriate, a subscript denotes the test speed, e.g. Fn_{50} is equivalent to the coefficient of friction at 50km/h x 100. Generally, the values given are the average Fn for the set of two or three replicate measurements at that speed, either from repeat tests made in the same location or a sequence of samples of the same surface.

On those sites where “Skidman” measurements were made, reported values have not been corrected for the small effect that the gradient of the road has on deceleration relative to a level road. As explained in Section 4.3, it should be borne in mind that Skidman measurements are made using a completely different technique to SCRIM or PFT and therefore can not be compared directly to results from those devices.

The PFT and SCRIM have been used together in different projects for a number of years. When comparing measurements with the two devices, PFT skid measurements undertaken at 20km/h (Fn_{20}) should be broadly similar to SCRIM Readings for measurements undertaken at 50km/h (Roe, Parry and Viner, 1998).

For convenience, this report sometimes describes speed in general terms: “slow speed” implies speeds around 20km/h, “intermediate speed” implies speeds typically in the range 40-60km/h and “high speed” refers to speeds above this level. It is important to recognise that this refers to sliding speed (i.e. the speed of the vehicle in a locked-wheel situation). SCRIM, which measures sideways force, usually operates at an intermediate speed (50km/h) but the actual measurement is a slow speed one (a theoretical slip speed of approximately 17km/h).

8.2 Scatter in the data

At the outset of the test programme it was recognised that, as is always the case with skid resistance measurements made on short lengths of road, there would be some scatter in the data. To overcome this, it is normal practice to make repeat measurements so that average values of “friction” for the particular condition could be determined. However, particularly for dry tests when the test itself can change the surface, repeated measurements on the same spot were not always practicable. For this reason, as explained earlier in this report, in most cases measurements were made at different points along the same stretch of surfacing on the assumption that the material would be generally homogenous and that a measurement at any point would be representative of that particular surfacing at that time. Thus, the average of replicate measurements along the road could be used to represent the average condition.

That this was a reasonable assumption is illustrated by Figure 8.1 for wet tests and Figure 8.2 for dry tests. These two graphs show the results from groups of individual skids made at different target speeds on selected surfacings that were about the same age at the time that the various measurements were made. No attempt is made to be more specific in analysing the data shown here: the graphs are for illustrative purposes only. It can be seen that there is some scatter in the data, due to the combined effects of small variations in speed and in friction. As might be expected, there was a little more scatter in the dry measurements.

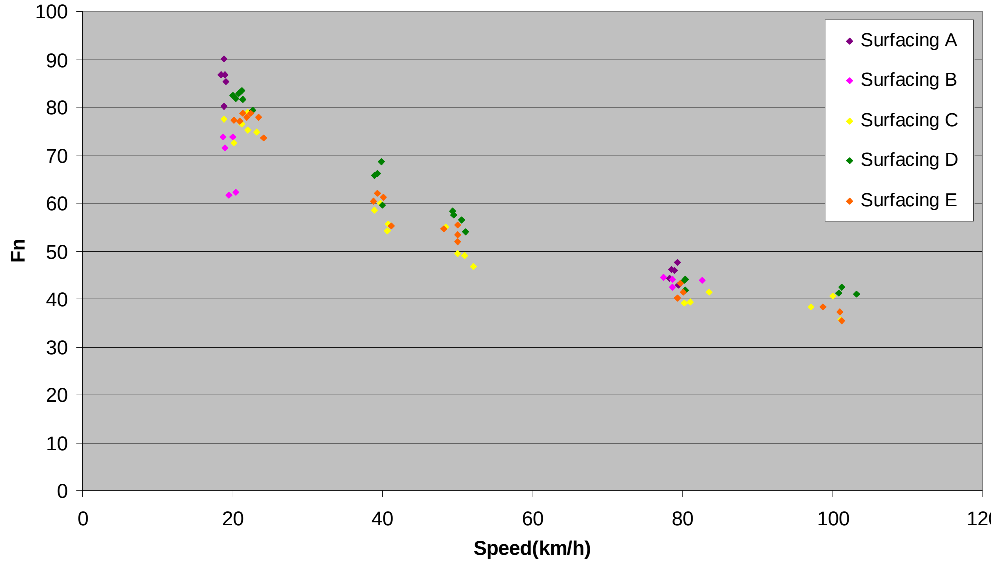


Figure 8.1 Illustration of the scatter in replicate wet friction measurements using the PFT at different speeds on five different surfaces of similar age

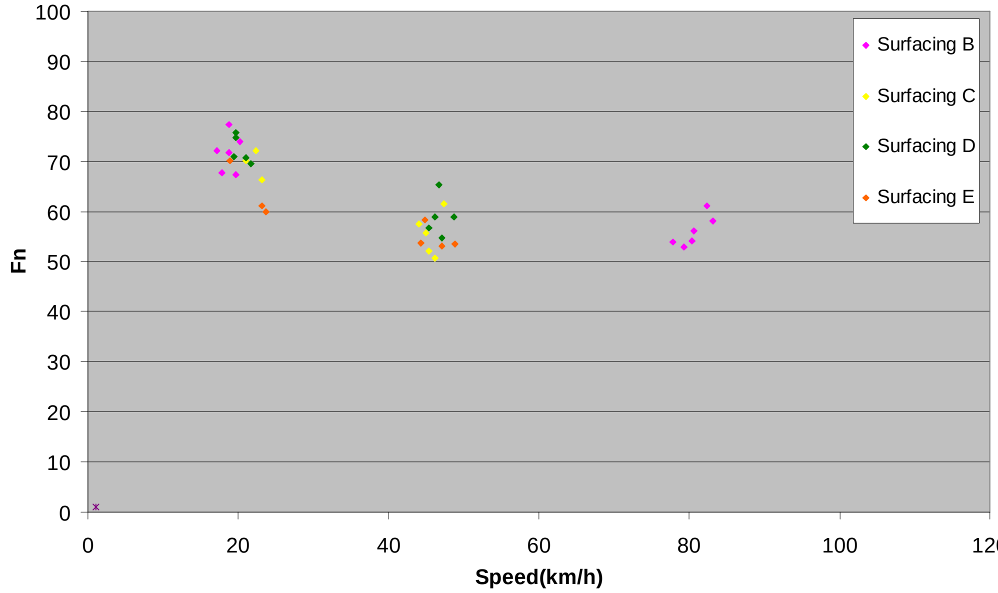


Figure 8.2 Illustration of the scatter in replicate dry friction measurements using the PFT at different speeds on four different surfaces of similar age

Typically, the coefficient of variation of a set of three wet skids sampling the same surface at a given time was around five percent or less. This amount of scatter in the wet measurements is broadly consistent with past experience of measurements of this type when repeat measurements have been made in the same locations.

Although the results from each measurement stage were analysed separately as the work progressed, in the overview presented in the following section of this report, the data have not necessarily been discussed following the pattern of the measurement stages. Rather, the analysis has been broadly structured to address the main issues relating to early-life skid resistance. Section 8.3 summarises the results relating to wet friction measurements and Section 8.4 covers dry friction. In each case, the effects of speed and the way in which skid resistance changes with traffic and time are considered separately. Where PFT measurements are reported or shown in graphs, the average friction value for a particular surface at a particular time and condition has been used. Section 8.5 covers the additional tests, namely the police Skidman measurements and the comparison between the standardised smooth tyre and car tyres.

8.3 Wet friction measurements

The influence of the presence of the binder film in early life may be expected to influence wet skid resistance (or wet friction) by masking the surface of the aggregate and therefore preventing the microtexture from making contact with the tyre. The effects this might have could be different at different speeds. There is also the possibility that, particularly when the bitumen is fresh and relatively un-trafficked, its own surface properties may have an effect on the way in which the surface, tyre and water interact. These properties may than change over time under the influence of traffic.

In reviewing the results of the wet friction measurements for this report, therefore, two aspects have been considered: the effect of speed on wet friction and the changes that occur with trafficking over the first eighteen months of the surfacing's life (the time period covered by most of the measurements made).

8.3.1 The effect of speed on wet friction

It is well known that on a wet road, as speed increases, skid resistance decreases. The effect of speed in wet conditions on the sites studied is summarised in Figure 8.3. Each point in the graph (and there are several overlaid) represents the average Fn value at a particular speed at one visit and the graph includes all measurements made on all of the sites over an eighteen-month period, separated into new thin surfacings and older, established, control sections. The average trend in each case has been represented by curves drawn using a second-order polynomial fit to the data (the form that was found to best represent data of this type in previous work). These trend lines represent the overall "average" effect on the sites during the first eighteen-month period after resurfacing for the thin surfacings and the equivalent trend over the same period for the established control surfaces. They do not represent specific behaviour on particular sites.

This generalised result shows the expected trend for friction to decrease as speed increases and, as was found in earlier studies, the greatest loss of friction tended to occur between 20 and 50km/h on the new thin surfacings. Again, as expected, the typical well-trafficked "control" surfaces showed a trend for skid resistance to decrease with increasing speed but with lower skid resistance at low speeds and relatively higher skid resistance at higher speeds. This is consistent with the concept that the presence of the thicker binder film masks the microtexture on the new surfacings, leading to relatively lower skid resistance at higher speeds.

However, in many cases on the new surfaces, very high wet friction values were found at slow speeds, often much higher than would be found with the fully-exposed aggregate on the control sections. The reasons for this are not well understood but may be due to a different mechanism of interaction between the tyre, the bitumen film and water at these low speeds. The data from SCRIM also indicated very high wet skid resistance at low speed on new surfaces.

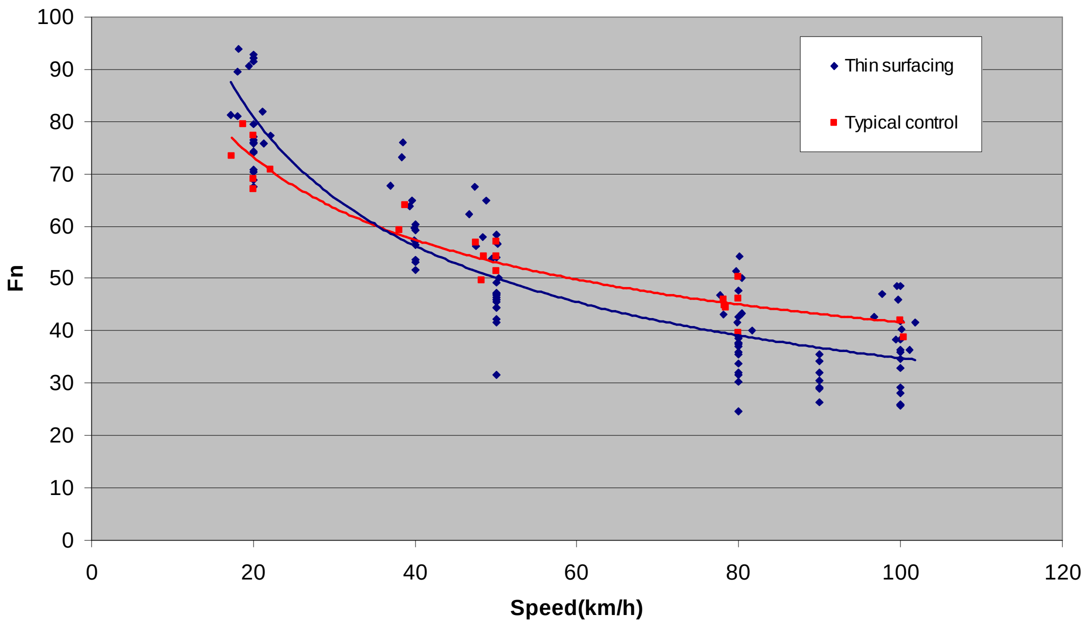


Figure 8.3 Wet friction measurements at different speeds on all sites from 1 day to 18 months old

In order to assess the relative significance of the data illustrated in Figure 8.3, the same results for the new thin surfacings in this study have been superimposed on graphs representing the trends for the ranges of levels of skid resistance at different speeds found on other well-trafficked surfaces, as shown in Figure 8.4. The "other surfaces" trends are derived from previous research at TRL (Roe, Viner, Philipps and Parry, 1998).

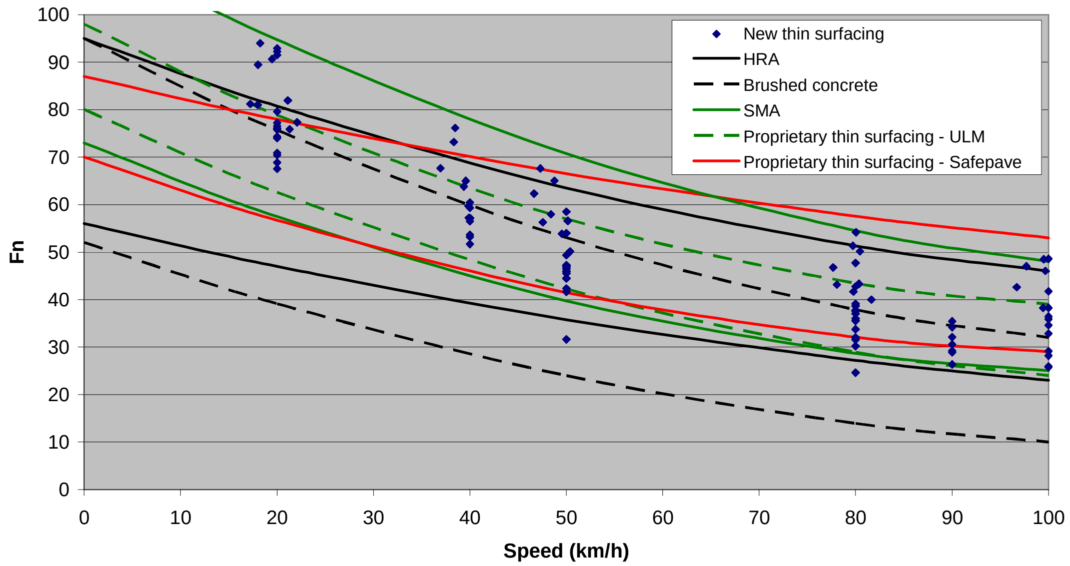


Figure 8.4 Comparison of wet friction and speed for new thin surfacings with typical ranges for different types of well-trafficked surfacing

Although there is scatter in the friction values over the range of sites at every speed, it can be seen that most of the new thin surfacing points fit within the minimum and maximum HRA and thin surfacing trend lines; all were above the lowest limit observed on older, low-textured, brushed concrete surfaces (these older concrete surfaces are not typical of concrete surfaces in good condition). There were some exceptions, with higher friction values at slow and intermediate speeds and lower values at higher speeds.

This comparison demonstrates that, for wet skid resistance, the effect of speed on thin surfacing materials in the first eighteen months of their lives is broadly consistent with expected behaviour on older surfaces. However, on very new surfaces, there may be situations where intermediate and higher-speed levels are lower than might be expected for a typical asphalt road. The lowest points in Figure 8.3 and Figure 8.4, at 50km/h and above, were observed on the A511 two days after opening to traffic.

The relationship between wet friction and speed depends on the texture depth of the surfacing, with a greater loss of friction with speed expected for low texture depths. It is also probable that the scatter in the results along a site and from site to site is in part due to variations in texture depth. The texture depth was measured on many of the sites studied using the laser sensor mounted on SCRIM. The sensor measured texture depth (SMTD) values obtained across the range of sites were in the range 0.9 to 1.8mm. However, overall, all the sites on which texture was measured had texture depths above levels that might be considered to have a marked adverse effect on high-speed wet skid resistance.

8.3.2 Effect of traffic levels and time on wet skid resistance

It is expected that the skid resistance observed early in the life of a new surfacing will change over time as the effects of weathering and traffic progressively remove the excess binder and the aggregate begins to polish. The interaction of these effects is likely to be complex but in order to make a general assessment, the sites studied were categorised by their annual average daily traffic (addt) data, where this was known: light traffic (0 to 1000 vehicles a day), medium traffic (1000 to 10000 vehicles a day) and heavy traffic (over 10000 vehicles a day). The categories were sub-divided by the age of the surfacing at the time the friction measurements were made, into sites from 0-6 months old and 6-18months old.

8.3.2.1 Low-speed (SCRIM measurements)

The results of the SCRIM measurements analysed in this way are plotted in Figure 8.5 and Figure 8.6 for surfacings 0-6 months and 6-18 months old respectively. A general trend line for all of the data has been included in each of these Figures, together with the range of levels expected on typical trafficked HRA surfacings, for comparison.

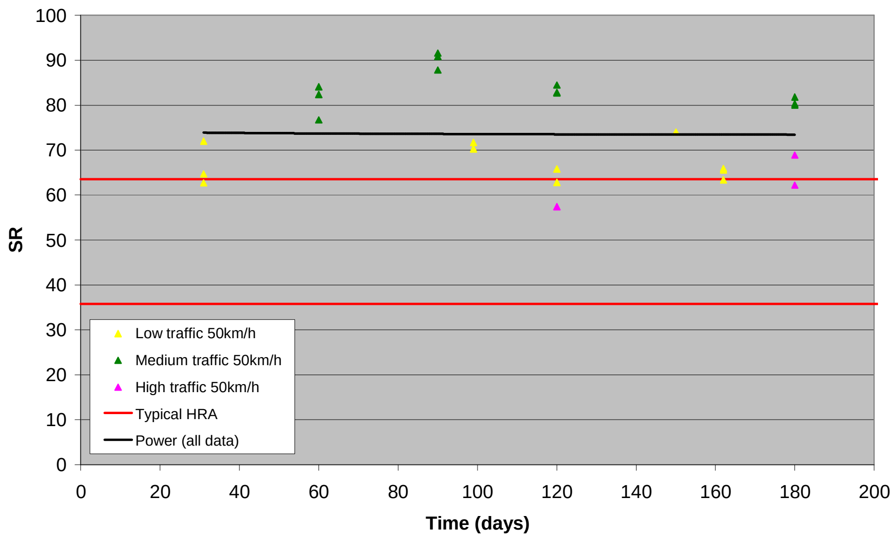


Figure 8.5 Change in low-speed wet skid resistance (SR) over time for surfacings from 0-6 months old

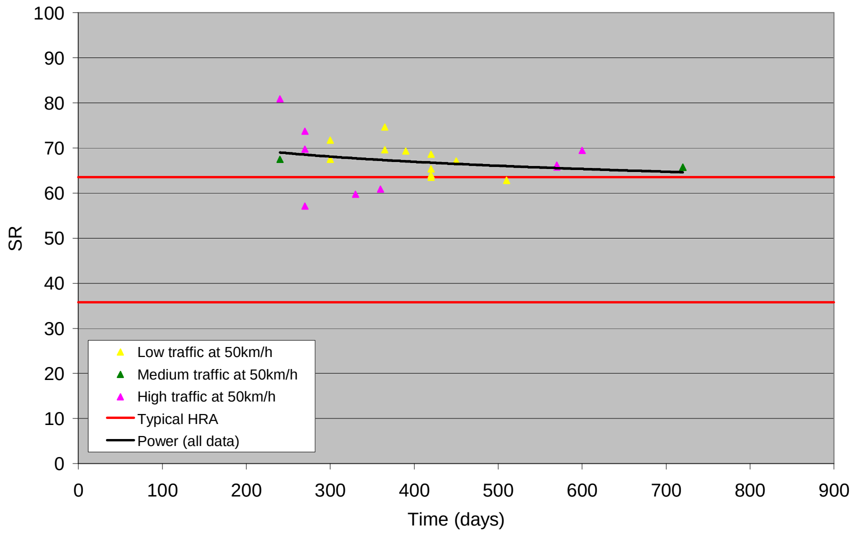


Figure 8.6 Change in low-speed wet skid resistance (SR) over time for surfacings from 6-18 months old

It can be seen from these two figures that from early in the life of the surfaces the low-speed wet skid resistance is high but in the 6-18 month period the trend is for skid resistance to decrease. Nevertheless, the low-speed wet skid resistance is high in comparison with what is commonly expected on the network.

8.3.2.2 Intermediate and higher-speeds (PFT measurements)

Equivalent graphs for the wet friction levels recorded with the PFT at two speeds, 50km/h and 80km/h, have been plotted in Figure 8.7 and Figure 8.8 respectively for the first six months and in Figure 8.9 and Figure 8.10 for surfaces from six to eighteen months.

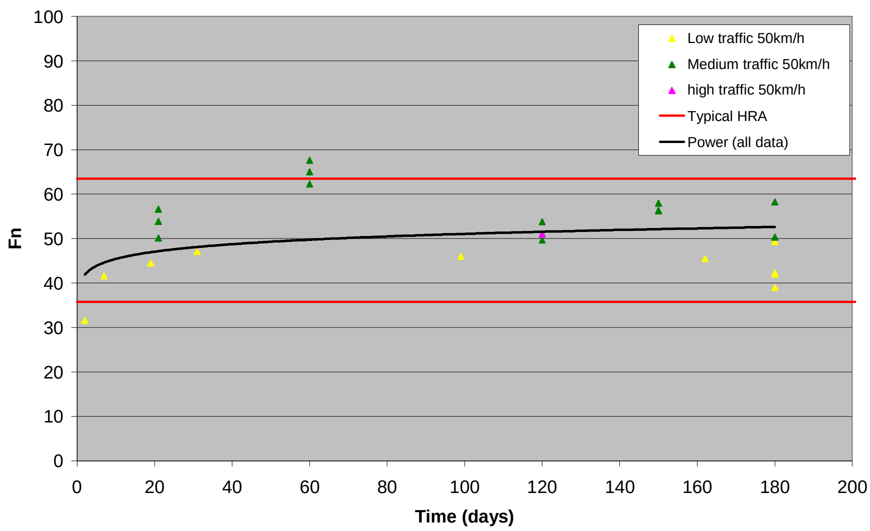


Figure 8.7 Change in wet friction at 50km/h over time for surfacings from 0-6 months old

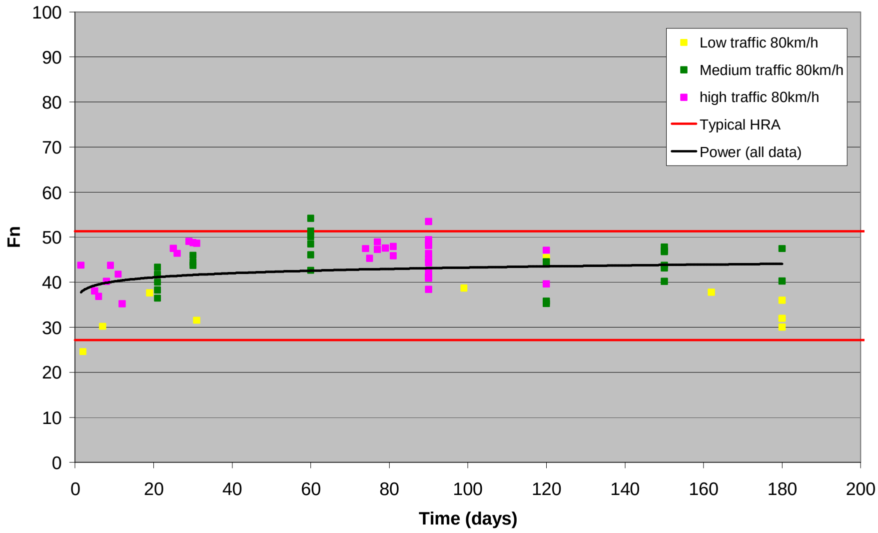


Figure 8.8 Change in wet friction at 80km/h over time for surfacings from 0-6 months old

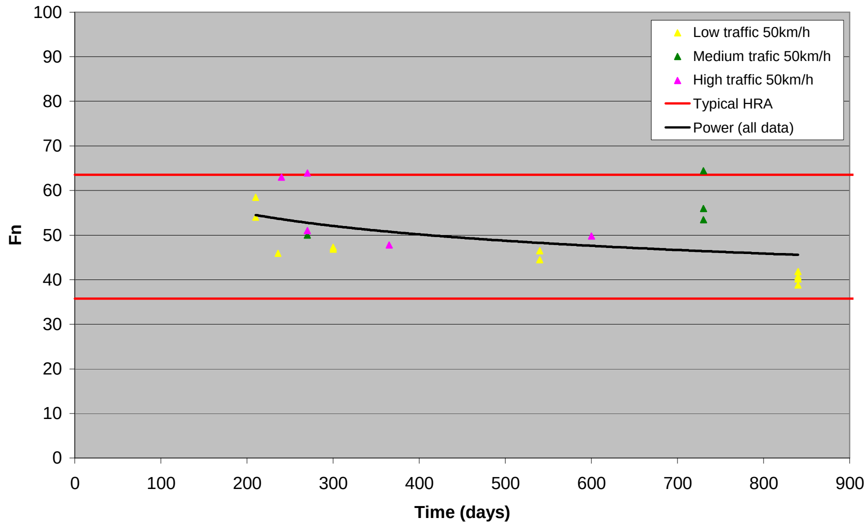


Figure 8.9 Change in wet friction at 50km/h over time for surfacings from 6-18 months old

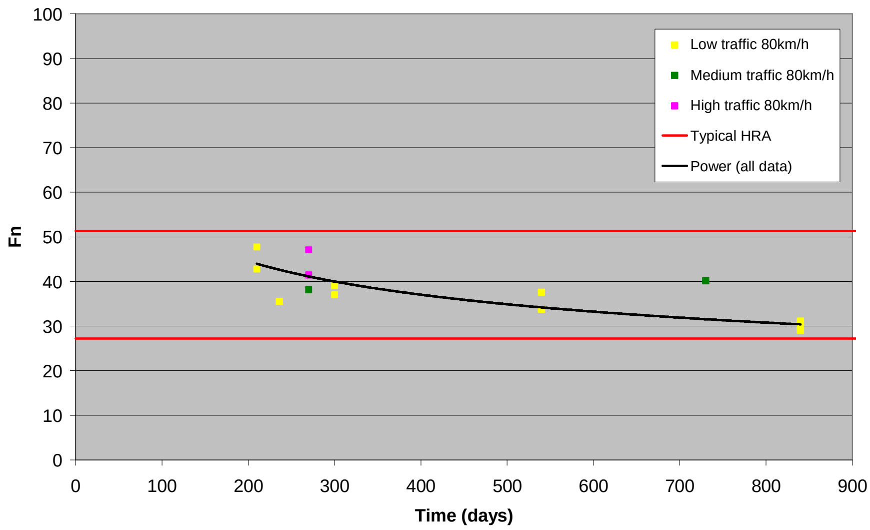


Figure 8.10 Change in wet friction at 80km/h over time for surfacings from 6-18 months old

Not surprisingly, there is some scatter in the data in these four figures but, with the exception of the very earliest measurements on low-trafficked surfaces, all the friction values fall within the typical ranges expected for trafficked HRA. This is somewhat different to the SCRIM results, where the measurements tended to be at the top of or above the expected HRA range.

The general trend during the first 6 months is for wet friction at intermediate and higher speeds to increase, most noticeably in the first two months (60 days), but to decrease over time on older surfaces. The lowest friction levels at these speeds at all ages tend to occur at the low traffic level.

The general behaviour would appear to be consistent with that which might be expected, namely that wet skid resistance is reduced by the presence of the binder film initially but that this wears (at a greater rate on more-heavily trafficked surfaces) to expose the natural aggregate surfaces, which are then polished by traffic with skid resistance eventually falling towards an equilibrium level.

However, as the surfaces age, the friction on the lightly-trafficked sites tends to fall close to the lower limit expected for “normal” HRA. This is not consistent with the above behaviour, since the HRA lower limit would typically be encountered on roads with the heaviest traffic that polishes the aggregate to a greater extent. This suggests that on the lightly trafficked sites the presence of some residual binder film may be affecting intermediate and higher-speed skid resistance for extended periods. A similar effect has been observed by other workers in low-speed measurements. Clearly, there will also be variations in behaviour as a result of different aggregates being used.

On those sites where detailed measurements were made, some variation in behaviour was observed on different parts of the sites. It is probable that local topography has an influence on the rate at which friction develops, as does natural variability in the materials laid, but it would require far more detailed study than has been possible in this project to draw definitive conclusions. In the measurements on the A621, some seasonal variation was observed on the control surface but this was not detectable in the results on the SMA at that site or the nearby A618.

8.3.3 *Very early life – the first few days*

The main focus of the present study was on the longer-term persistence of the phenomena observed, particularly at higher speeds and in dry conditions. However, there have been suggestions that wet new surfaces can be unusually slippery very early in their lives. Other studies, such as that by the CSS and, more recently, by the University of Ulster (Woodward et al, 2005) have found that wet skid resistance as measured by SCRIM or GripTester may be high immediately after laying but then decreases in the first few days after opening to traffic before recovering to a higher level. That work has tended to focus on low-speed skid resistance and on local authority roads with SMA surfacings.

The measurements made in the third stage of this project, however, (Section 7) were designed to provide some information about the very early life skid resistance at higher speeds with approved thin surfacings under heavier (motorway) traffic. Figure 8.11 plots wet Fn_{80} against time for the new surfaces on the M3 over their first month. Each point on the graph represents the average friction recorded on a section of material of a known age, laid as part of the same resurfacing programme – they are not necessarily on the same sections. (These data are incorporated into Figure 8.8 but Figure 8.11 separates them out on an expanded time axis.)

The friction values were relatively low initially (but still within typical range for trafficked HRA) and then increased. The lowest friction value was recorded after twelve hours (ie the morning after laying overnight).

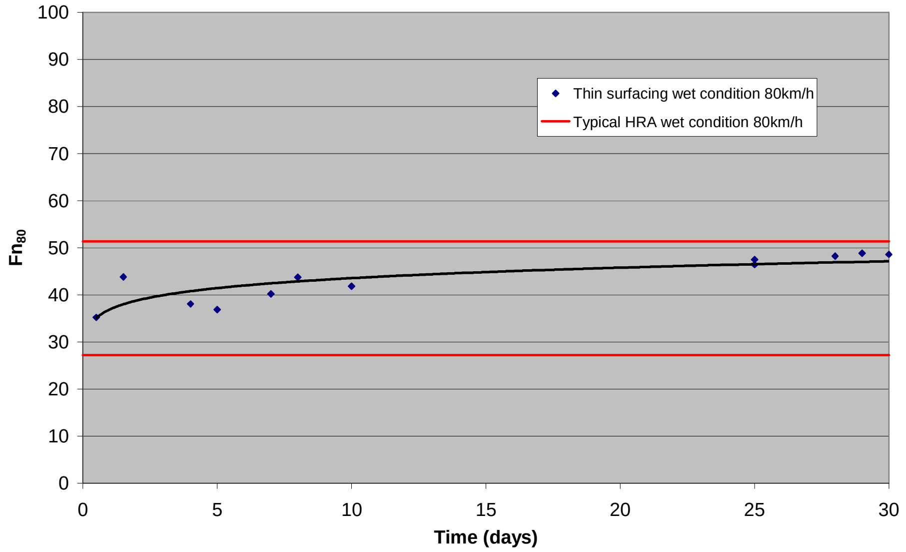


Figure 8.11 Development of higher-speed wet friction in the first month on the M3 sites

8.4 Dry friction

A major focus of this study has been on the measurement of friction in dry conditions, which has been observed to be lower than expected on "normal" roads. As with wet friction, the results have been considered in terms of the effect of speed and the influence of time and traffic.

8.4.1 Effect of speed on dry friction

The A511 site was used to study in detail the effect of speed on dry friction, initially covering a speed range from 20 to over 100km/h. Results from two days after opening are shown in Figure 8.12.

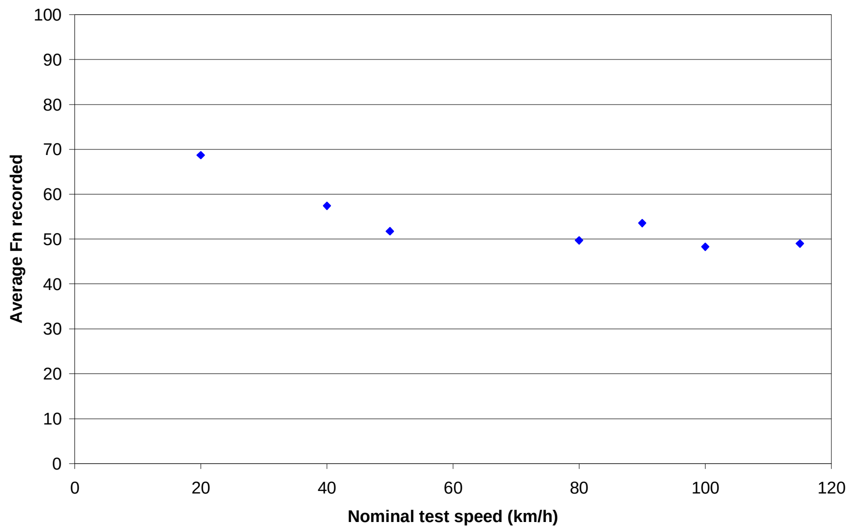


Figure 8.12 Dry friction versus speed on the A511 (western section) two days after opening

It can clearly be seen that dry friction decreases with increasing speed for speeds up to about 50km/h, after which it remains essentially constant. However, the extent to which the friction falls in this case is less and the minimum is achieved at a lower speed than on a normal wet road, which would be expected to reach a minimum value at about 100km/h (Roe, Viner and Parry, 1998). A similar pattern was observed on subsequent visits up to six months after opening to traffic.

Using a similar approach to that in section 8.3.1 above, Figure 8.13 plots the average dry Fn values measured at various speeds for all the sites studied. In the light of the results from the A511, and for practical reasons, the range of speeds at most sites was limited to one or two speeds, with speeds above 80km/h being used on only one or two sites.. For simplicity, the trend line curves have been drawn using a second-order polynomial fit to the data, as with the wet friction measurements, although a two-stage curve showing no change beyond 50km/h might equally have been used for this illustrative purpose. The results from the various control surfaces are also included on the graph for comparison.

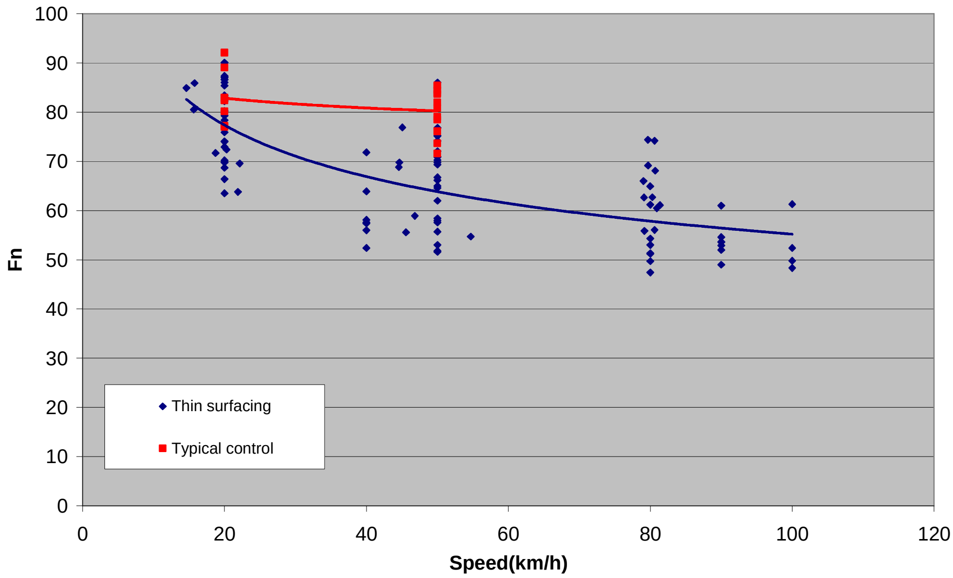


Figure 8.13 Dry friction measurements at different speeds on all sites from 1 day to 18 months old

It is generally assumed that speed has little effect on dry friction, but it can be seen in Figure 8.13 that on the control surfaces there was a small decrease in friction on average. The range of values on the control surfaces at each of the two speeds is illustrative of the fact that aggregates are polished by traffic and that the consequent loss of microtexture affects dry friction as well as wet. Nevertheless, the general dry friction levels on the control surfaces were are all high, as expected.

However, on the thin surfacings, the trend seen on the A511 for dry friction to decrease with speed (but not greatly beyond about 50km/h) was observed across the range of sites. It was found that as the materials aged, or were subjected to greater trafficking, the effect of reduced friction became less marked and this is reflected in the spread of Fn values on the thin surfacings at intermediate and higher speeds.

An important observation, however, is that the dry friction in early life is generally lower than would be expected from a normal, trafficked, dry road. At low speeds the difference is small and the friction is at a high level, but at intermediate and higher speeds, the difference is greater. Comparison with Figure 8.3 suggests that, in some circumstances, at low and intermediate speeds the dry friction may be at a comparable level with wet friction.

8.4.2 Effect of traffic levels and time on dry friction

It might be expected that, under the combined influences of time, weather and traffic, any bituminous coating on the aggregate would harden or wear away and so the effect of reduced dry friction would become less as the surfacing ages. A general assessment of the change in dry friction over time at different traffic levels was made on a similar basis to the assessment of wet friction in section 8.3.2. Thus, the change in dry friction at intermediate and higher speeds over time, at different traffic levels, is illustrated for surfaces up to six months old in Figure 8.14 and for surfaces from 6 to 18 months old in Figure 8.15. Because speed has little effect above 50km/h, both the 50km/h and 80km/h data are plotted where these were recorded. A general trend line for the thin surfacings and, for comparison, a typical minimum dry friction value that might be expected from a trafficked hot-rolled asphalt surface (Fn = 70), are also shown on each graph.

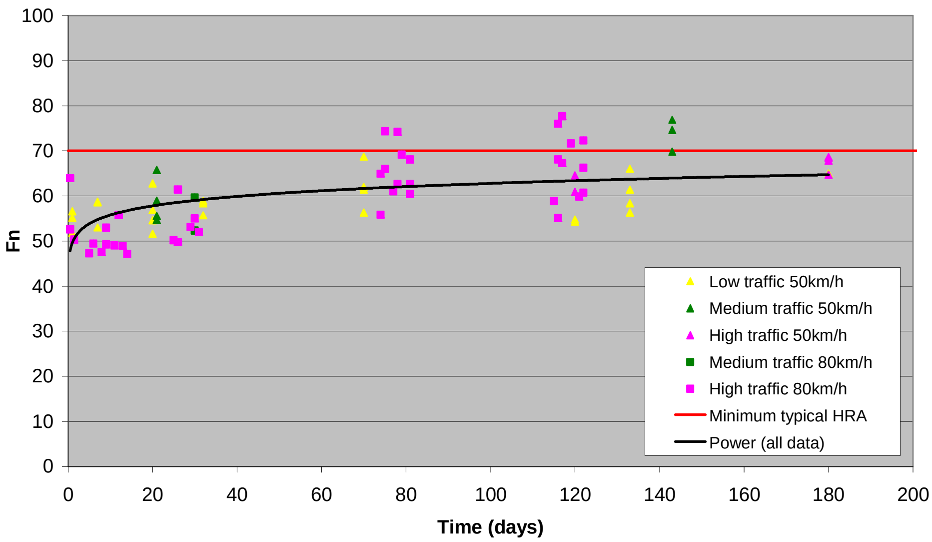


Figure 8.14 Change in dry friction at 50 or 80km/h over time for surfacings from 0 - 6 months old

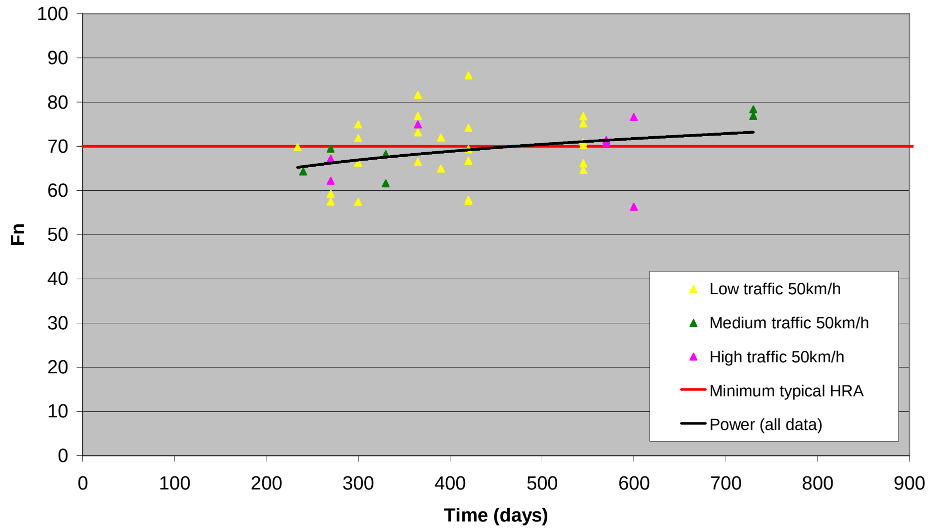


Figure 8.15 Change in dry friction at 50km/h over time for surfacings from 6-18 months old

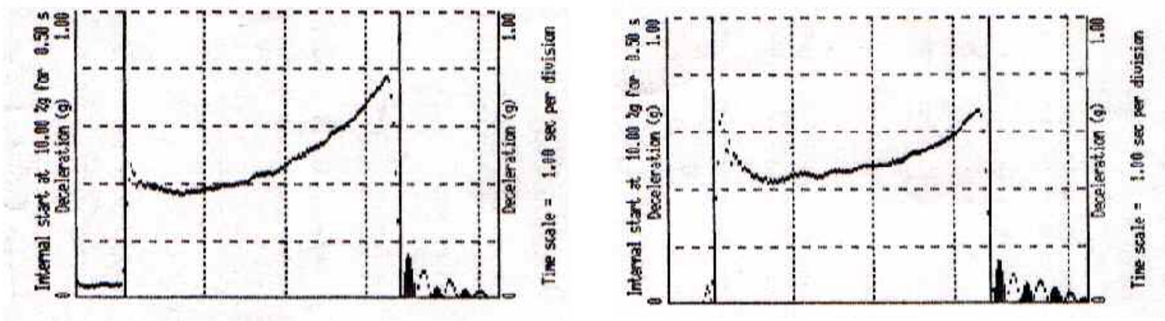
The general trend is for dry friction at intermediate speeds to increase with time, and there is an indication that the increase occurs sooner at higher traffic levels. It can be seen in Figure 8.14 that the groups of points are roughly in the 45-65 range of Fn in the 0-20 day period but by 120-150 days the heavier traffic levels (green and pink spots) have increased more than the lower traffic (yellow) sites and are mostly over 65 Fn. However, a wide range of behaviours was observed at the different sites studied. Typically, at low traffic levels, over 6 months elapses before dry friction reaches the level of a typical trafficked HRA whereas on high traffic roads the dry friction levels reached typical HRA values in about three months. There were exceptions to this general picture, with some low-traffic sites reaching higher friction levels quickly and some medium traffic sites still showing relatively lower friction levels over a year after laying.

As with the wet friction measurements, on those sites where detailed measurements were made, some variation in behaviour was observed on different parts of the sites. Again, it is probable that both local topography and variability in the laid materials influence the rate at which friction increases, but it would require far more detailed study is needed to draw definitive conclusions. An important point to note from this general overview of the results is that all the materials tested exhibited similar behaviours in the first few months of service.

8.5 Police locked-wheel braking tests

The “Skidman” measurements that were carried out in the early stages of the project provide an indication of how the measurements recorded by the police compare with the controlled tests using SCRIM and PFT. As has been stressed, the techniques are different and the results are not directly equivalent. For convenience, the Skidman results for these 2 sites have been tabulated in the Appendices together with those from the PFT and SCRIM.

The form of the results is illustrated in Figure 8.16, which shows examples of the output from the device (copied directly from the low-resolution printout) for wet and dry friction tests on one of the SMA sections on the A611 tested in September 2001. The horizontal axis in the graphs as shown represents time and the vertical axis, expressed in units of “g”, represents the deceleration and is equivalent to the average coefficient of friction (but uncorrected for any slope in the road).



(a) Wet SMA

(b) Dry SMA

Figure 8.16: Examples of “Skidman” outputs on A621

It can be seen that deceleration increases to a peak as the brakes are locked (at the first vertical line), reduces to reflect sliding friction and then *increases* as the test proceeds. This effect of increasing friction, most noticeable in the wet test (a), is a result of the decrease in speed during the test, demonstrating the same general behaviour that is observed with devices such as the PFT, i.e. friction is higher at lower sliding speeds. Interestingly, the same effect can be seen to a lesser extent in the dry test (b) and this could be postulated being due to external factors such as changes in temperature, tyre or surface. However, even if the physics behind the Skidman technique is not fully understood this is further evidence that there is a speed effect on this type and condition of surface, as observed with the PFT.

On both sites, the police obtained average dry friction values of approximately 0.55 in September 2001. These were markedly lower than they expected based on their experience of dry road surfaces, where typical values would be of the order of 0.70.

The Police also re-visited the A621 to make dry skid tests on subsequent occasions, to coincide with the TRL visits with the PFT. These follow-up tests also included the southbound lane. Figure 8.17 compares the results from the PFT and Skidman on A621 through the monitoring period. This shows that the two techniques, although giving somewhat different numerical values, as would be expected, show similar trends.

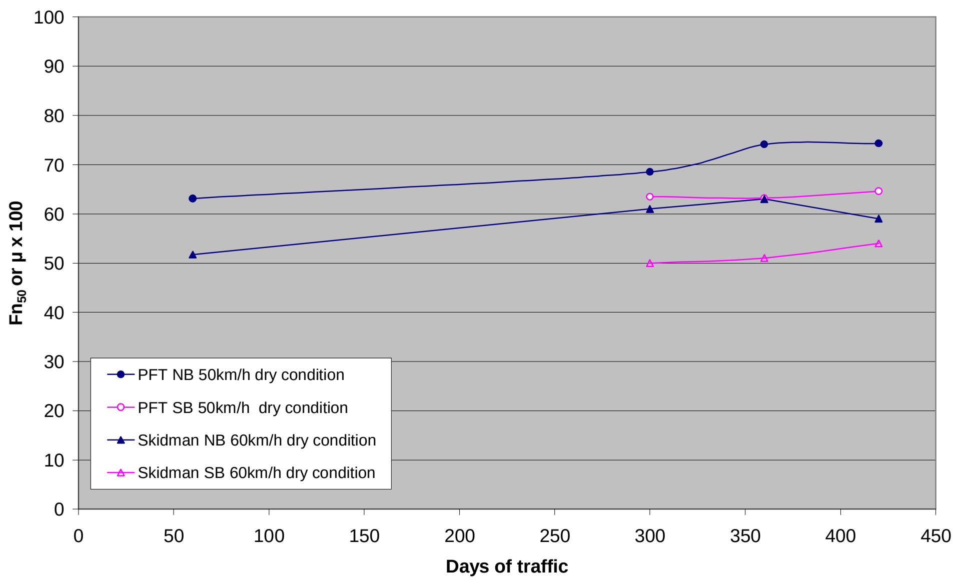


Figure 8.17 Comparison between Skidman and PFT dry friction measurements on the A621

8.5.1 Effect of tyre and PFT trailer weight

This section summarises the results of the tests on the M3 that were carried out to compare results from PFT measurements made with the standard friction test tyres and static vertical load that are normally used with measurements made at a lighter loading and with a normal patterned car tyre. The results of these measurements are summarised in Table 8.1. The table gives the mean and standard deviation (SD) of Fn_{80} from three sample measurements on each section with each tyre and test condition.

Table 8.1 Comparison between different tyres and weights in wet and dry condition

Section reference		Friction measurements (80km/h)					
		Tyre load 300kg				Tyre load 500kg	
		Dry		Wet		Dry	Wet
		ASTM smooth tyre	patterned car tyre	ASTM smooth tyre	patterned car tyre	ASTM Smooth tyre	ASTM Smooth tyre
S1	Mean Fn	50.5	50.1	40.7	40.3	47.2	38.1
	SD	3.4	2.2	2.8	2.4	1.4	2.8
S2	Mean Fn	52.4	54.9	41.5	41.4	49.5	36.9
	SD	2.3	3.6	2.1	2.4	1.8	3.1
S3	Mean Fn	55.0	53.2	49.2	50.3	49.3	43.7
	SD	3.3	1.7	3.3	3.3	0.4	4.5
S4	Mean Fn	53.8	52.7	46.2	47.7	48.6	41.8
	SD	2.3	1.2	2.2	4.6	2.7	3.8
S5	Mean Fn	54.4	53.3	43.9	46.6	49.0	40.2
	SD	3.1	1.5	1.6	2.2	1.7	3.8

In every case, the dry Fn_{80} was higher than the equivalent wet measurement. Under the 300kg loading, the patterned tyre Fn_{80} values were generally similar to the smooth ASTM tyre in both wet and dry conditions. However, the measurements obtained for the smooth tyre were higher with the 300kg load than with the 500kg load.

The similarity between patterned and smooth tyres in the wet is not surprising: previous work has suggested that, in effect, on well-textured surfaces the tyre tread pattern simply adds to the surface texture without a marked effect on higher-speed skid resistance. On the dry surface, the tyres are sliding on the bitumen-rich surface and there is no reason to expect a marked difference. Regarding the differences at the different load levels, past experience at TRL and elsewhere suggests that lower tyre loads result in greater friction being measured.

This exercise demonstrated that the phenomena observed using the standard tyres and conditions on the PFT are indicative of what might be expected from “real” tyres. It was found that in some cases the police skid tests recorded lower dry friction values than TRL but this may have been be due to the number of additional variables involved with the police tests, including the fact that the police technique involves the average of four tyres sliding to a stop rather than a single locked wheel sliding at a constant speed.

9 Discussion (1) – the physical effects

9.1 "Normal" behaviour

Before discussing the aspects of early life behaviour, it is important to review what friction conditions might be regarded as "normal" for an in-service road and what would be regarded as a "normal" surface. For the purpose of this discussion, a "normal" surface is one which has been open to traffic for some time and, in the case of an asphalt material, on which the aggregate at the surface is fully exposed to traffic. There is a basic assumption that skid resistance (or surface friction) on dry, uncontaminated, surfaces is usually high, typically in the range 0.65-0.75 depending on the type of surfacing and the microtexture condition of the surfacing aggregate. This assumption has been borne out by the measurements on dry, well-trafficked surfaces in this study.

In wet conditions, skid resistance can be much reduced in relation to dry conditions, again depending upon the condition of the aggregate microtexture. The general effect of skidding resistance reducing with increasing speed in wet conditions, together with the importance of texture depth has been recognised for many years.

The 1990s study by Roe, Parry and Viner reported in TRL367 investigated the effect on skidding resistance of speed combined with texture in wet conditions on a wide range of surfacings. The results of that study demonstrated that texture had little effect on friction at low speeds. However, the effect of decreasing friction with increasing speed was observed at all levels of surface texture and there was a greater loss of friction at high speeds with low texture depth. At textures below about 0.8mm SMTD there was a noticeable increase in the rate of loss of friction as texture decreased.

Thus, a surfacing could have good skidding resistance at low speed but, as a result of low texture, have much lower skidding resistance at higher speeds than another surfacing with better texture, even though that had lower skid resistance at low speed. It was found that the lowest level of wet skidding resistance was typically reached at around 100km/h and, importantly, skidding resistance had reduced markedly at intermediate speeds.

Figure 9.1 is based on data taken from the TRL 367 work. It compares the wet friction versus speed relationship on two different surfacings with contrasting characteristics. One surfacing (Site 1 in the figure) was an HRA, with high texture depth and high low-speed skid resistance, represented by the values of SR and SMTD (sensor-measured texture depth) shown; the other (Site 2) was a worn brushed concrete with lower, but still acceptable, SR and very low SMTD.

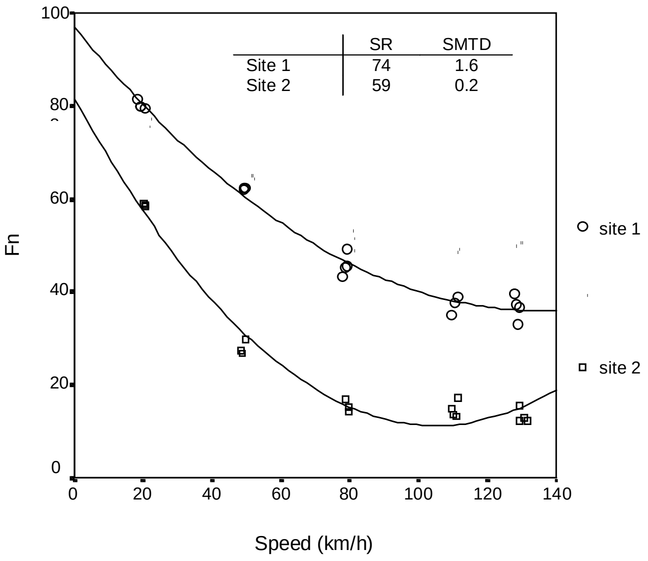


Figure 9.1: Wet friction versus speed two different "normal" surfaces

On the higher-textured surface, Fn decreases by about 25 percent between 20 and 50 km/h and by about 40 percent between 20 and 80 km/h. On the very low-textured surface, however, the change is much more rapid, with a decrease of over 50 percent between 20 and 50km/h, while over the 20 to 80 km/h range the decrease is about 70 percent.

These examples represent typically the range of levels of wet skid resistance that may exist on the network and that are usually regarded as acceptable. However, the example of brushed concrete shown here has unusually low texture depth and current requirements on trunk roads would require that the investigatory level for low-speed skid resistance should be assessed and, if necessary, increased to offset this.

9.2 The UK trunk road skid resistance standards

Another important aspect to bear in mind when considering the early life characteristics of new surfacings is how the measured friction values relate to standards for skidding resistance against which roads are normally assessed.

The model for this is the Highways Agency requirements set out in HD28/04, in Volume 7 of the Design Manual for Roads and Bridges. This document, however, refers to wet skidding resistance as measured by SCRIM and so some interpretation is required to relate the results from the present study to the HA standards. (Some local authorities may have their own standards, but they are often modelled on the HA version.)

Dry friction is assumed always to be adequate and so the standards in HD28/04 are based upon the principle of equalising risk of wet skidding, recognising that this risk can never be completely eliminated. The low-speed skid resistance of the network is monitored (with SCRIM) and the results for a particular site are compared with an "investigatory level" appropriate to that type of site and the accident risk in its local circumstances. Investigatory levels are set in terms of Characteristic SCRIM Coefficient (CSC), which represents the underlying skid resistance of the road. It is determined from SCRIM measurements over a period of three years, adjusted to take account of seasonal variation, and also includes a factor to relate present-day measured values to historic research.

Because the objective of the standards is to "manage the risk of skidding accidents in wet conditions so that the risk is broadly equalised across the trunk road network", rather than set absolute levels for skid resistance, different levels of skid resistance apply around the network. The lowest investigatory levels are given to the lowest-risk sites (from the point of view of wet skidding) such as motorways and well-designed dual carriageways. Higher investigatory levels are applied to sites with higher risk, such as single-carriageway roads, bends, junctions and hazards like pedestrian crossings.

It is not practical to make direct measurements of friction at high speed on a network-wide routine basis, so skidding resistance at higher speeds is currently taken into account indirectly by requiring a minimum texture depth when the surfacing is first laid. This level is currently 1.5mm as measured by the sand patch technique. (There is no direct correlation between sand patch and SMTD for thin surfacings or generic SMAs, but work over past years has indicated that SMTD values over 1mm are likely to exceed the requirement). In the UK, there are no requirements for texture depth directly linked to skid resistance on in-service roads. However, the importance of the property in the development of skid resistance is recognised and HD28/04 requires engineers to consider this factor either when setting or reviewing the investigatory level or when investigating sites that have measured skid resistance below the investigatory level.

9.3 The main phenomena observed

9.3.1 Wet friction behaviour

The low-speed friction behaviour of the surfacings is represented by SCRIM measurements where made or Fn_{20} measurements with the PFT. The sites on which measurements were possible all showed the same basic characteristics: early-life wet, low-speed friction was high. The values recorded were often higher than would be expected from a new surfacing with no bitumen on the aggregate and sometimes were higher than expected for a dry surface.

Other workers have reported relatively low values for low-speed wet skid resistance in the first few days after laying the surfacing. The values obtained were such that the skid resistance may have been below investigatory level for a short time for intermediate or higher-risk sites. However, no such observations were noted in the TRL measurements. This does not mean that such circumstances do not occur: rather, it suggests that the effect is short-lived and the timing of the visits to the sites or the range of measurements that could be made simply did not detect the phenomenon. Measurements of low-speed wet friction were made on only one site during the very early period and on that site the surfacing had been open to the elements for a week or so before opening to traffic and before the TRL measurements were made.

All sites showed a decrease in wet friction with increasing speed on all surfaces, as would be expected. Table 9.1 gives the average relative decrease in Fn between 20 and 50 km/h and between 20 and 80km/h for one of the visits to A621, A618 and A511 sites. It is of interest to note that the reduction in skid resistance on the proprietary thin surfacing, on which the aggregate was fully exposed, was much less than on the SMA surfaces.

Table 9.1 Relative change in wet friction with speed in July 2002 for the first 3 sites investigated

Site	Surfacing	% decrease in wet Fn with increasing speed	
		20 to 50km/h	20 to 80 km/h
A621	SMA northbound	33	48
	SMA southbound	38	48
	Trafficked thin surfacing	17	29
A618	SMA northbound	38	-
	SMA southbound	34	44
A511	SMA eastern section	32	-
	SMA western section	40	49

Comparing these results with Figure 9.1 it can be seen that, although texture depth is high, the friction/speed effects on the wet SMA surface are much more akin to the low-textured site in that diagram. For surfacings with texture depth at 1mm SMTD or above (which all those studied were), it would be expected that the decrease would be less marked than was generally observed, more in line with that observed on the well-trafficked surface.

These examples were recorded in July 2002; at that date, the SMA surfacing on the A621 was 12 months old, that on the A618 was 15 months old and that on A511 was a little over three months old. Low-speed measurements were not made on every site and so this comparison can not be made directly for them all, but on those sites where a significant binder film remained, whatever the material type, the higher-speed skid resistance showed behaviour consistent with this finding.

A similar result had been obtained during the work for TRL367, when a new thin surfacing was tested with the PFT just after laying and before trafficking.

It should be noted that similar low levels of friction at high speed could also result from a road with reasonable texture but with highly polished aggregate, but such a road would also have lower friction at low speed.

Therefore, three key effects appear to be observable in relation to wet friction on newly laid surfaces:

- Low-speed wet skid resistance is generally high, often higher than for a dry surface, even though there is a binder film covering the aggregate microtexture.

- There is some suggestion from other workers that there may be a short period soon after laying when wet low-speed skid resistance is lower than expected.

- As speed increases, wet skid resistance falls more rapidly, and to lower levels, than would be expected for a well-textured surface with high skid resistance at low speeds.

9.3.2 Dry friction behaviour

As has been mentioned earlier, dry friction on "normal" surfaces is expected to be high and not to be markedly affected by speed. Measurements made on such surfaces during the course of this research have been consistent with that expectation.

However, on the new asphalt surfaces, the dry friction measured was affected by speed, decreasing to a minimum level at 50km/h sliding speeds. For example, on the A511 the SMA surfacing gave average Fn_{50} in the range 52-62 over the first six months of the surfacing's life compared with 72-85 on the HRA section. Similar levels were observed on all of those surfacings studied on which there was a significant film of bitumen-rich material covering the aggregate. Typically, low-speed, dry friction can be about 20 percent lower than "normal" levels. At intermediate and higher speeds, dry friction can be markedly reduced, by about 30-40 percent, from normal levels.

The dry friction behaviour on new asphalt observed in this study can be summarised thus:

- At low and intermediate speeds, dry friction during the early life period is lower than for normal surfaces and is generally at a similar level to wet friction.

- At the lowest speeds, when the surface is very new, wet friction may be higher than dry friction.

- At high speeds, dry friction is markedly lower than normally found on dry roads. However, it is generally higher than wet friction would be on older trafficked surfacings.

9.3.3 Relevance of the observations to other asphalt materials

The new surfacings studied in this work were all modern "thin surfacings" or generic SMA materials. A question that is often asked is whether the effects observed are unique to these newer types of surfacing, or whether they apply to other, traditional, materials.

In principle, there is no reason to suppose that the effects seen here would not be exhibited to a greater or lesser extent by chipped hot-rolled asphalt or dense bitumen macadam (DBM) materials that have an initial coating of bitumen on the surface. The police report on the M4 crash in the 1980s postulated the existence of reduced dry friction while SCRIM measurements at the time suggested that wet friction was relatively high, implying that perhaps the effects may have been present on that very new HRA. However, there is no documented evidence from current practice as to this. It has not been possible to assess new HRA or DBM in this study because these materials have not been used on trunk roads for several years and are used much less on local authority roads than in the past.

Some surface dressing systems (widely used on local authority routes but not on trunk roads at the present time because of their relatively greater noise levels) utilise a very thin coating of bitumen on the aggregate to assist initial adhesion to the bitumen sprayed on the road. It is considered unlikely that the "early life" effects would apply to such surfacings, particularly in association with the aggressive "positive" texture on new surface dressings but they have not been specifically studied. No studies have been made of new micro-surfacings.

9.4 Mechanisms involved

It has been suggested that the reason for the unusual friction behaviour observed on asphalt surfaces early in their lives can be attributed to the presence of the bitumen film. In wet conditions this might be expected to "blind" the microtexture and therefore prevent the tyre from making proper contact with the aggregate to develop friction. In dry conditions, the binder film might melt as a result of the shear forces and heat generated in a skid to provide a film on which the tyre can slide. Both of these suggestions are borne out by observations in this work, as explained further below.

9.4.1 Wet conditions

The unexpectedly low levels of high-speed friction for a surfacing with high texture depth are probably best explained by the "blinded microtexture" hypothesis. The very smooth surface created by the binder film is akin to an aggregate that has been highly polished by traffic, and so there are few asperities to break through the water film and make adhesive contact with the tyre. Therefore, a lower level of friction is to be expected.

However, there is another phenomenon that requires further explanation, namely the very high levels of wet friction observed at low speeds, especially on very new surfaces. In this case a different mechanism must be involved since there is little microtexture to generate such high levels of friction. The effect is possibly due to adhesive properties of the binder itself while it is still relatively fresh. As it weathers, its "sticky" properties would be expected to decrease, as the binder oxidises and dust and detritus are forced into the bitumen by traffic. This idea would be consistent with the lower values of Fn recorded here after a period of trafficking.

Another possibility is that, especially on very new surfaces, as a result of surface tension (in an effect akin to water on recently-applied gloss paint or a freshly-polished car), the water from the friction measuring device may not have time, or be able, to wet the surface fully and is therefore more easily displaced from the interface between the tyre and the road, leading to almost dry contact. Observation from the roadside of SCRIM measurements on very new surfacings has shown that the machine can leave a distinct tyre mark that remains visible after the surface has dried, implying that the binder has been "smeared" in some way, suggesting that this kind of mechanism may be involved.

During this work, the low values of wet skid resistance in the first few days reported by others were not observed. It has been suggested (for example, Woodward et al, 2005) that the surface of the bitumen is initially "polished" by traffic, effectively spread to a smooth surface covering the aggregate. Another explanation might be the short-term presence of contaminants on the surface that could affect the wet friction adversely which result from the paving process. However, the emergence of oils or other materials from newly-laid road grade bitumen is not a recognised phenomenon.

Eventually, any deposits on the surface will be washed or worn away and grit and dust from the environment, combined with exposure of the fines in the asphalt mix provide some microtexture until the aggregate becomes exposed.

However, the physics behind these various tyre/road interactions has not been studied and at present they remain plausible, but theoretical.

9.4.2 Dry conditions

Generally, bitumen is a very viscous material that becomes harder at low temperatures or high shear rates and softer at higher temperatures or low shear rates. This is why some asphalt materials are generally strong (resisting the frequent impact of heavy blows from passing traffic) but can deform in situations where relatively high road temperatures are combined with slow-moving heavy traffic. At much higher temperatures, however, the bitumen "melts" and becomes liquid. The idea of the binder "melting" during a dry skid was suggested following the M4 crash in 1988. Observations of the road surface and the test equipment during this study strongly support this idea.

Where safe to do so, during each test visit, the skid marks from the PFT were inspected. At the higher-speed skid locations, the binder on the surface of the road in the main line of the skid was obviously “blurred” and patches were visible at the end of each skid mark (Figure 9.2). This suggested that during the skid, hot binder builds up at the leading edge of the contact patch of the skidding tyre that is then carried over and re-deposited on the road surface when the brake is released and the wheel is allowed to rotate back up to speed.

Inspection of the PFT following dry skid tests revealed residual binder on the tyre from just such a build-up. Further, the inside of the mudguard over the test wheel had been repeatedly sprayed with droplets of binder, an effect not seen in normal wet testing or occasional dry tests on older roads. Also, an observer at the roadside noted that during a dry skid the sound made by the tyre was unusual, markedly different from the squeal of a normal dry skid or the gentle hissing noise made on a wet road, suggesting that it was sliding on the surface.

It may be that the deposited material is not just binder (bitumen plus additives such as cellulose), but a combination of those components and the tyre tread polymer. No attempt has been made to analyse the material, however suffice it to say that the tyre appeared to be sliding on a material that has melted.

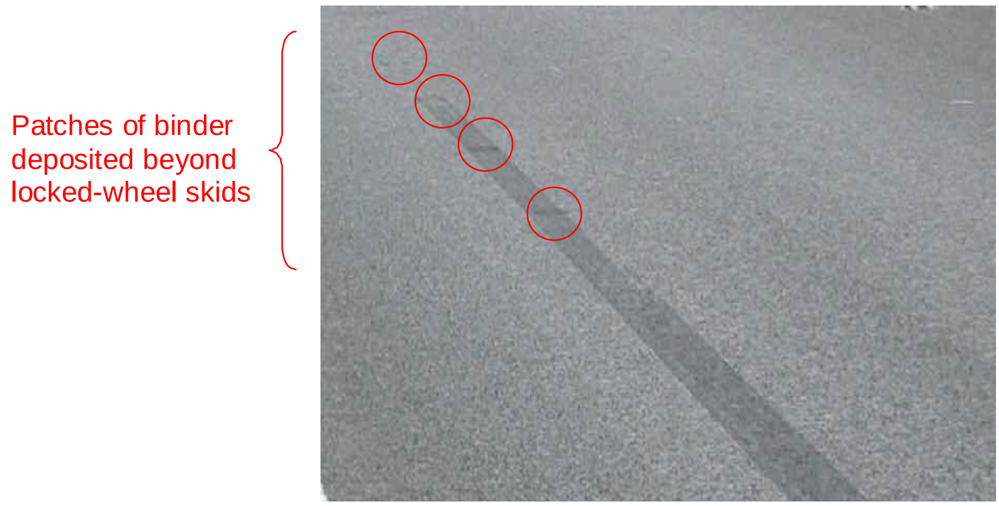


Figure 9.2: patches of transferred binder visible at the end of a skid mark

Further evidence for the blurring of the surface and the binder film being carried along the skid comes from closer examination of the main skid marks. It was noted that fine aggregate in the asphalt mix, clearly visible at the surface outside the area of a skid mark was less visible within it, either as a result of it being covered by bitumen or by being moved away in the process. It was also clear, especially as the surfacing aged, that the sharper edges of the coarse aggregate were gradually exposed, although the flatter faces retained a noticeable binder film. These effects are illustrated in Figure 9.3 (approximately actual size when printed on A4 paper).

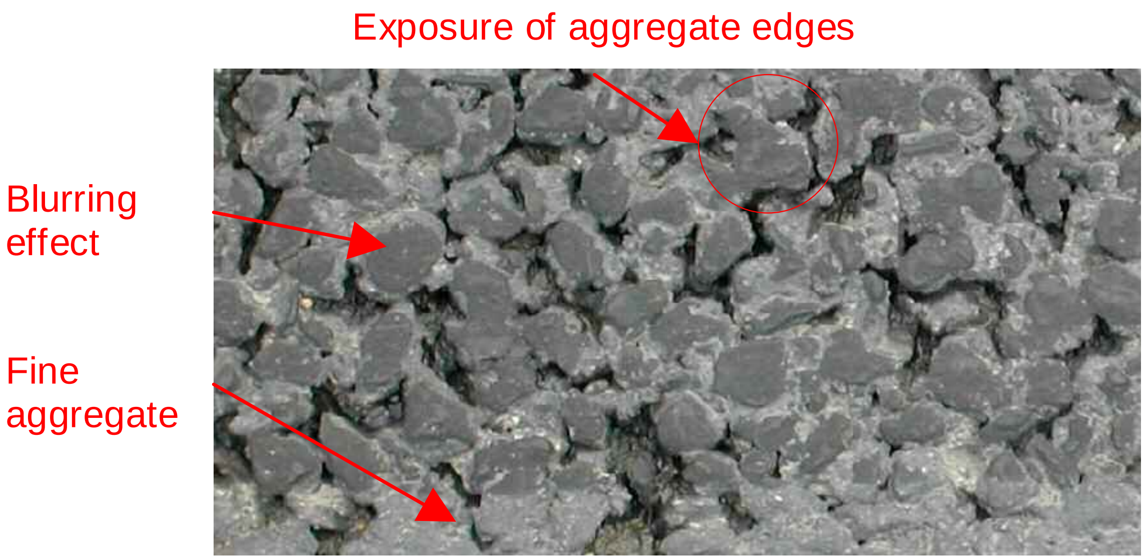


Figure 9.3: Close-up of part of a dry skid mark

These observations are supported by comments by police accident investigators who often describe a "hissing" effect as the vehicle skids to a halt. Bullas (2005) has used a thermal imaging technique to assess the temperature of the surface in the path of tyres of a car carrying out a skid test. This demonstrated that temperatures can be reached during locked-wheel skids that are high enough for the bitumen to liquefy.

9.5 The persistence of the observed effects

All of the types of surfacing studied (both generic SMA and HAPAS approved thin surfacings) showed all of these effects. However, the time for which they persist can be expected to vary widely. It is likely that the persistence will be affected by combinations of factors, including:

- The thickness of the initial binder film.
- The presence of additives in the binder: many surfacings use fibres or polymer modifiers and work at University of Ulster (Woodward et al, 2005) suggests that polymer-modified binders may take longer to wear away.
- The type of aggregate, which can affect how easily the binder adheres to the surface.
- The topography of the site and prevailing weather conditions.
- Traffic levels and type.

The results on the A621 showed that after 15 months of trafficking the SMA on this site had started to behave similarly to the control section in dry conditions. However, the effects in wet conditions of high friction at low speeds with a rapid fall in friction with increasing speed were still evident. The results from later visits suggested that, at that time, the surfacing was in a transition stage, moving towards the normal processes of traffic action on the exposed aggregate.

The A618, after 18 months of traffic, was showing similar behaviour to the A621. It is likely that this site was also in a transition stage, although the surfacing was some three months older. It is possible that on the A618 the local climatic and traffic conditions were such that the changes in the surfacing were taking longer to occur.

The A511 had only shown small changes in the six months between opening to traffic and the most recent measurement in this study. There had been a reduction in low-speed wet friction (which nevertheless remained high) and a small increase in wet friction at intermediate speeds, although relatively lower than might have been expected. In effect, the SMA on the A511 at six months old was behaving similarly to A621 and A618 when the study began, when they were at a similar age.

The sites located on the M3, on which the material was an SMA-derived thin surfacing, showed that after 3 months of heavy traffic the surfacing skid resistance was behaving in a similar way to a typical HRA road. The results also suggested that weathering of the material was occurring differently in patches along the surfacing sections, possibly reflecting variability in the original material as laid.

On the A339, the measurements were carried out when the surfacing was 3 months old. The wet measurements appeared to be similar to typical traditional surfaces but the lowered dry friction effects were still observed.

On the A259, a week after surfacing, the wet friction behaviour of these experimental materials was similar to typical HRA. However, the reduced dry friction effect was present. After five months of medium trafficking, the effect had disappeared.

The sites in the north of England were mostly older but some were lightly trafficked by trunk road standards. Nevertheless, the indications were that after 6 months of trafficking most of the dry friction effects had disappeared.

It can be concluded, therefore, that in most circumstances the potentially adverse effects observed on new surfacings can be expected to have disappeared naturally after about six months. On more heavily-trafficked sites this may happen in three months or less. However, on lightly trafficked roads, with some materials, especially those that have thicker binder films or that incorporate polymer-modified binders, it may take eighteen months or more for all the possible effects to disappear.

However, the potential occurrence of these effects does not necessarily mean that there is a problem in a particular situation: this aspect is discussed further in section 10.

10 Discussion (2) - implications for accident risk

A number of effects relating to skid resistance in the early life period of a new surfacing have been identified that have the potential to have an adverse effect on road users. Some authors have even described such surfaces, somewhat emotively, as being "dangerous" but without due consideration of what this implies. The purpose of this section of the report is to discuss the issues of potential accident risk in relation to the effects observed.

It should be recognised at the outset that, as discussed in 9.1 and 9.2, some risk of skidding always exists and that it varies from site to site. The trunk road skidding standards recognise this fact and take it into account by means of investigatory levels that have been derived on the basis of studies of accident risk in relation to skid resistance.

10.1 Circumstances when problems might arise

It is important to recognise that lack of friction is not usually a causative factor in crashes. A combination of several other factors will come into play that results in circumstances in which the friction is inadequate. It is then that surface friction becomes a "contributory" factor. In many cases, although a theoretical contributory factor, the circumstances will be such that even the greatest level of tyre/road friction that can practically be achieved would not prevent the accident occurring. Indeed, situations may occur (such as excessively fast cornering) when high friction levels could make matters worse, with a vehicle rolling over instead of skidding sideways.

In normal driving, on surfaces in an acceptable condition, drivers do not usually demand greater friction than the road can provide. Even in wet conditions, there should be sufficient friction available for the manoeuvre to be made.

These ideas are reflected in the fact that, in recent studies to establish the investigatory levels for the road network (Parry and Viner, 2005), there was no relationship between accident risk and skid resistance on motorways and a statistically significant, but only weak, relationship non-event dual carriageways. These types of road are generally at low risk of accidents given the amount of traffic that they carry but, when unusual circumstances or driver errors do occur, combinations of high speeds and heavy traffic may mean that a crash is inevitable.

On other roads, the risk of skidding is more clearly linked to skid resistance but, even so, most drivers complete their journeys safely. In considering these "early life" effects, therefore, it must be borne in mind that the circumstances in which they become significant are likely to be unusual.

The circumstances in which reduced friction is likely to be important are:

(i) When cornering or negotiating a bend:

- High wet friction at low speed means that the "critical speed" (the maximum speed at which the particular curve can be negotiated for a given level of friction) would be increased, thus making the curve nominally safer, but there is also the potential to travel through a curve faster. In the latter situation, if the peak friction is overcome, the high-speed wet sliding friction will be reduced, thus making the risk of loss of control greater than on a normal wet road.

- The dry friction effects could mean that, when a vehicle that is being driven close to the critical speed in dry conditions, if it begins to slip sideways, the "melting binder" effect might occur, with a resultant decrease in the available friction, possibly leading to loss of control.

(ii) When braking hard or in an emergency, such as

- In an urban situation when, for example, a pedestrian unexpectedly steps into the road.

- On a fast rural road when, for example, a vehicle emerges suddenly from a side turn or an animal unexpectedly runs into the road.

10.1.1 Stopping distances

The effect of reduced friction in a straight-line locked-wheel skid is that the stopping distance is likely to be increased. In wet conditions, except possibly in the very early life, the friction levels in the early life period are generally likely to be no worse than on any other road with an acceptable surfacing and drivers should be able to cope as they normally would. In dry conditions, however, the extended stopping distance may be unexpected.

The actual stopping distance will be unique to a particular situation, with due allowance being made for driver reaction times, but to provide some comparisons, Table 10.1 gives theoretical stopping distances in a locked-wheel skid from different initial speeds for different levels of friction once the wheels have locked. These are derived from calculations based on Newton's laws of motion and assuming an average friction level throughout the skid.

Table 10.1 Theoretical stopping distances (from point where wheels lock) in a locked-wheel skid at different speeds and friction levels

Initial Speed (km/h)	average coefficient of friction between tyres and road throughout the skid									
	0.10	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**	**1.00**
10	3.9	2.0	1.3	1.0	0.8	0.7	0.6	0.5	0.4	0.4
20	15.7	7.9	5.2	3.9	3.1	2.6	2.2	2.0	1.7	1.6
30	35.4	17.7	11.8	8.9	7.1	5.9	5.1	4.4	3.9	3.5
40	62.9	31.5	21.0	15.7	12.6	10.5	9.0	7.9	7.0	6.3
50	98.4	49.2	32.8	24.6	19.7	16.4	14.1	12.3	10.9	9.8
60	141.6	70.8	47.2	35.4	28.3	23.6	20.2	17.7	15.7	14.2
70	192.8	96.4	64.3	48.2	38.6	32.1	27.5	24.1	21.4	19.3
80	251.8	125.9	83.9	62.9	50.4	42.0	36.0	31.5	28.0	25.2
90	318.7	159.3	106.2	79.7	63.7	53.1	45.5	39.8	35.4	31.9
100	393.4	196.7	131.1	98.4	78.7	65.6	56.2	49.2	43.7	39.3
110	476.0	238.0	158.7	119.0	95.2	79.3	68.0	59.5	52.9	47.6
120	566.5	283.3	188.8	141.6	113.3	94.4	80.9	70.8	62.9	56.7

As a comparison with what drivers might expect, the Highway Code includes advice regarding "typical" stopping distances. In section 105, typical stopping distance is broken down into "thinking distance" and "braking distance". Typical braking distances are shown as 14m for 30mph (approximately 50km/h) and 55m for 60mph (approximately 96km/h), similar to equivalent values in Table 10.1 for an average friction coefficient of 0.70. As a rule of thumb, the Code also states that drivers should *"...allow at least a two-second gap between you and the vehicle in front on roads carrying fast traffic."* A two-second gap is a distance of 54metres at 60mph and 63 metres at 70mph (112km/h). The same paragraph goes on to say *"The gap should be at least doubled on wet roads..."*

In the context of reduced friction on a dry new surfacing, two aspects are important:

- How much further will the vehicle travel before it stops? (i.e., will the vehicle strike the obstruction?)
- How fast will the vehicle be travelling at impact?

It can be seen from Table 10.1 that, in the dry skidding situation, a reduction in friction from the normal 0.70 to 0.50 typically found in this work, braking distance might be extended from 14 metres to 20 metres at 50km/h and from 56 metres to 79 metres at 100km/h. In the first of these situations, the speed after 14 metres at the lower friction level would be below 20km/h, while in the second case, after 56 metres the speed would still be 38km/h. Thus, it can be seen that, not surprisingly, the practical implications of extended stopping distances in terms of potential risk for injury or damage are noticeably less at lower speeds.

A further element of risk associated with dry emergency braking with locked wheels is that, if the skid is established with factors such as the reduced friction in effect, other influences such as driver steering inputs and cross-fall may induce yaw in the vehicle that could, in turn, lead to the driver losing control. However, this situation could also occur on a wet road that is in an acceptable condition.

10.1.2 Likelihood of circumstances occurring

Having identified the circumstances in which the early-life effects may contribute to an increased risk of an accident, the likelihood of these circumstances occurring should be considered.

The results from this study suggest that the measured low-speed wet skidding resistance is usually good, even on a brand new surface. The lowest value of Fn_{20} recorded on any of the sites during any visit was 62 and most values were much higher than this. Similarly, the lowest average SR value recorded was 53; most were at least 10 units higher. Investigatory levels are set in terms of Characteristic SCRIM Coefficient (CSC), which includes measurements over three years to take into account seasonal variation, whereas the measurements in this study were snapshot single values. However, as a guide, an SR of 53 is equivalent to a SCRIM Coefficient (SC) of 0.41 and an SR of 63 is equivalent to an SC of 0.49.

On this basis, it can be said that:

- Low speed wet skidding resistance on newly laid asphalt surfaces is likely to be above the investigatory level for most sites except those with the highest levels of risk.
- However, the measurements also suggest that occasionally the value may be close to or below investigatory level on intermediate risk sites (IL = 0.45).

The latter point is important where surfacings of this type are used to resurface a road in an intermediate (or higher) risk category, as a result of a skidding resistance problem. It raises the possibility that, although in most cases low speed skidding resistance on the new surfacing should now exceed the IL, for a time after the treatment it may not necessarily be safe to assume that all of it will. Also, the situation could be envisaged where a new surfacing has been laid as part of other work where no skidding problem had been identified (the previous surfacing was above the IL); the new one may temporarily increase the risk

In general, however, on any road, the circumstances which might lead to an accident should be the same regardless of the surfacing. It is important to recognise that some accidents that may occur on new surfacings would have occurred anyway. The issue, therefore, is one of consequence when such circumstances arise. These will be different in different situations.

- On low-risk high-speed routes such as motorways, accident risk generally is low although the consequences of an incident may be considerable. However, on these routes, skid resistance is only weakly linked to accident risk and therefore the surfacing condition is unlikely to increase any risk. Even in dry high-speed skids, the friction is likely to be higher than would be found in the wet.
- On urban speed-restricted roads, in the dry-skid situation, the friction at low speeds will be higher than in wet conditions and in the theoretical situation of a vehicle braking in dry conditions at the same place on successive days with an old and new surface in place, the extension of braking distance and relative increase in speed at impact are small. In any case, the friction conditions will probably be better than what is already acceptable when the road is wet.

- Vehicles with anti-lock braking are unlikely to suffer from significant extended braking distances in dry conditions because the wheels do not stay locked long enough for the "melting binder" effect to become established.

Another factor which may be occurring, but has not been properly assessed, is that driver behaviour may be modified on new surfacings in a way that potentially increases accident risk. For example, on a new, smooth, quieter surface, drivers may increase speed in comparison with their previous practice at a particular location, making them more vulnerable when a potential accident situation occurs.

Clearly, a quantified investigation of the effects of new surfacings on accident risk is needed and this is the subject of further research for Highways Agency now in hand.

10.2 Amelioration of risk

Since accidents result from the combination of a number of often random factors, removal of one or more of these would make the accident less likely or its consequences less severe. The principal situations in which risk is likely to be increased on new surfacings compared with existing acceptable surfaces are:

- Existing high-risk sites where higher wet friction is already required, in which case reduced dry friction may be a problem.
- Medium-risk, high-speed single carriageway sites where the dry friction might present a problem on bends or reduced wet friction at higher speeds may be an issue.

Actions to ameliorate the risk from the new surfacings in such situations could be:

- Erect warning signs to alert the driver to an increased hazard.
- Take positive action to reduce vehicle speeds, such as a temporary speed limit.
- Treat the surfacing to alter its characteristics.

Erecting warning signs is a practice that is already used, but there are difficulties with this approach. Apart from knowing whether driver behaviour is significantly altered, the type of warning sign permitted may not provide the best information. "Slippery road" signs are often used but in this context the message is ambiguous without a suitable warning plate. The "Exclamation mark" hazard warning sign might be a better choice, but again with a suitable warning plate. It is suggested that further consideration should be given to what signs and plates may be used: it may be necessary to make provision in legislation for changes to permitted signs in order to cover this kind of situation.

With either of the first two approaches, a decision must be made as to how long the warning or speed limit signs should remain in place. As has been seen, the persistence of effects will vary from site to site but in most cases, apart from SMAs on low-traffic, they will probably have reduced or disappeared in about six months, and faster than this on heavily-trafficked sites.

Various techniques for treating the new surfaces have been proposed and are used by some authorities, especially on SMAs with thicker binder films. These include mechanical re-texturing and gritting. The former attempts to remove some of the binder film using impact or water-jetting techniques, but if aggressively applied may damage or weaken the surface in the longer term. Some authorities routinely roll grit into the new surface to provide additional initial wet grip and to accelerate the process of breaking up the binder film. There are conflicting views as to the efficacy of such treatments, one potential disadvantage being that the grit may not stay on the surface or may fill the texture, reducing high-speed skid resistance performance in the longer term.

A further approach that might be considered would be to improve driver education regarding the issues to make drivers more aware of the potential risks, particularly in relation to increased speed while the surface is new.

11 Conclusions and recommendations

This study has assessed the skid resistance of new asphalt surfacings. Measurements of wet and dry friction have been made using standard road-testing equipment to measure low-speed wet skid resistance and locked-wheel friction at different speeds in both wet and dry conditions. Some 25 sites covering a range of modern surfacings, including generic Stone Mastic Asphalt and a number of proprietary thin surfacings of different ages up to two years old, together with older, well-trafficked materials have been included.

The measurements made as part of this project have demonstrated that:

- Low-speed wet friction is high, even though a binder film covers the microtexture on the aggregate.
- Wet skid resistance decreases with increasing speed, as would be expected. The new surfaces have lower skid resistance at higher speeds than would be expected for surfacings for which the aggregate is unpolished and the texture depth is good but the levels are similar to many materials after some time in service.
- Dry friction reduces with speed but does not follow the same pattern as for wet roads: the minimum level is reached at about 50km/h and does not decrease further at higher speeds.
- Compared with the high levels generally obtained on older surfaces from which the binder film has worn off, dry friction on new asphalt can be lower, by up to about 20 percent at low speeds and by about 30-40 percent at intermediate and higher speeds.
- At low and intermediate speeds, dry friction is similar to wet friction. At very low speeds, the high level of wet friction can exceed the dry friction.
- Although friction levels at high speed on binder-coated surfaces are lower than that found on dry roads with aggregate exposed, they are nonetheless much higher than wet friction.
- The effects can be observed on any new surfacing, but the length of time for which they persist will vary depending upon local conditions and traffic levels. Typically, most effects have disappeared after six months but they may persist longer and have been observed for up to 18 months on surfaces with light traffic and thicker binder films.

The measurements in this project have indicated that low-speed wet skid resistance on new surfaces is high, and can be very high in the very early life. However, other workers have observed reductions during the first few days that later recover. The levels observed in these other studies were such that the wet skid resistance may be below investigatory levels for higher-risk sites for a short time.

The work has also suggested that these “early life” phenomena can be attributed to the presence of a film of binder (comprising a mixture of bitumen, possibly with additives such as cellulose or polymer modifiers) that can adhere to the surface of the aggregate for a significant period of time. The binder film appears to have three main effects:

(i) It prevents the microtexture on the aggregate particles making contact with the tyre, resulting in lower wet friction at higher speeds than would normally be expected.

(ii) It appears to provide a different adhesive mechanism to provide high friction at low speeds even though the microtexture is obscured.

(iii) In a dry skid, the bitumen can “melt” as a result of the heat generated in the tyre contact area, markedly reducing the friction compared to a normal well-trafficked dry surface.

On the basis of the information available at present, it is concluded that in most circumstances, on most roads, the increased risk of accidents associated with these effects on new surfacings is likely to be small. However, in some circumstances these effects may lead to an increased accident risk. It is concluded that the interim advice provided by Highways Agency in IAN49, first promulgated in March 2003, remains the best advice regarding the management of new surfacings that can be provided at present. This advice provides for the erection of “slippery road” warning signs for a period of up to six months in defined circumstances, primarily at high-risk sites.

However, in the light of this research, the following further recommendations are made:

1. Specific research into any link between new surfacings and accident risk should be carried out: such work is already in hand at TRL.
2. Consideration should be given to alternative methods of ameliorating the residual risk in those locations where the properties of new surfacings may have a significant adverse effect. In particular, a review should be made of appropriate warning signs that will better inform drivers as to the nature of the risk.
3. Consideration should be given to improved education regarding new surfacings so that drivers are better informed. This might include additional advice in the Highway Code regarding driving on new surfaces.
4. Other workers have suggested that modern new surfacings may be unusually slippery in the first few hours or days after they are laid. This effect has not been observed in this study but further research to assess this aspect more thoroughly should be considered.

Acknowledgements.

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Annex A: Schematic plans of sites investigated in detail

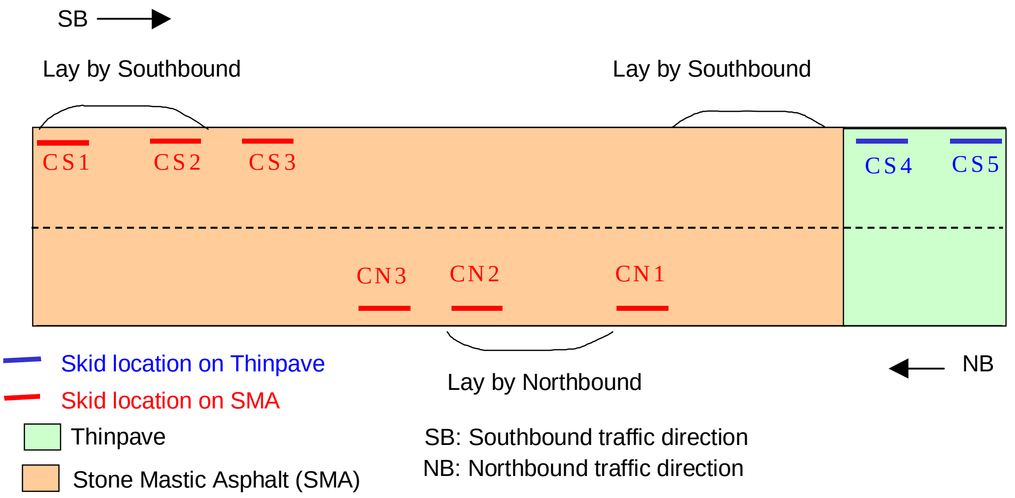

Figure A3: Schematic plan A621

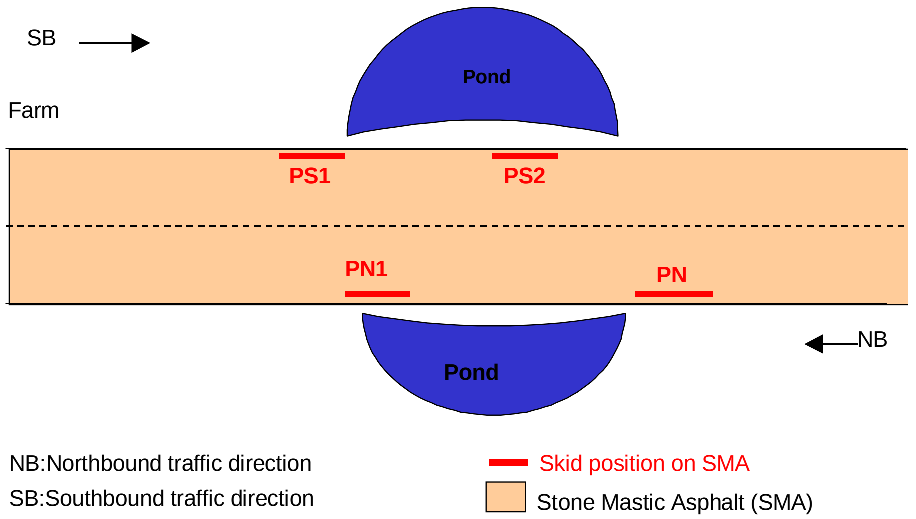

Figure A4: Schematic plan A618

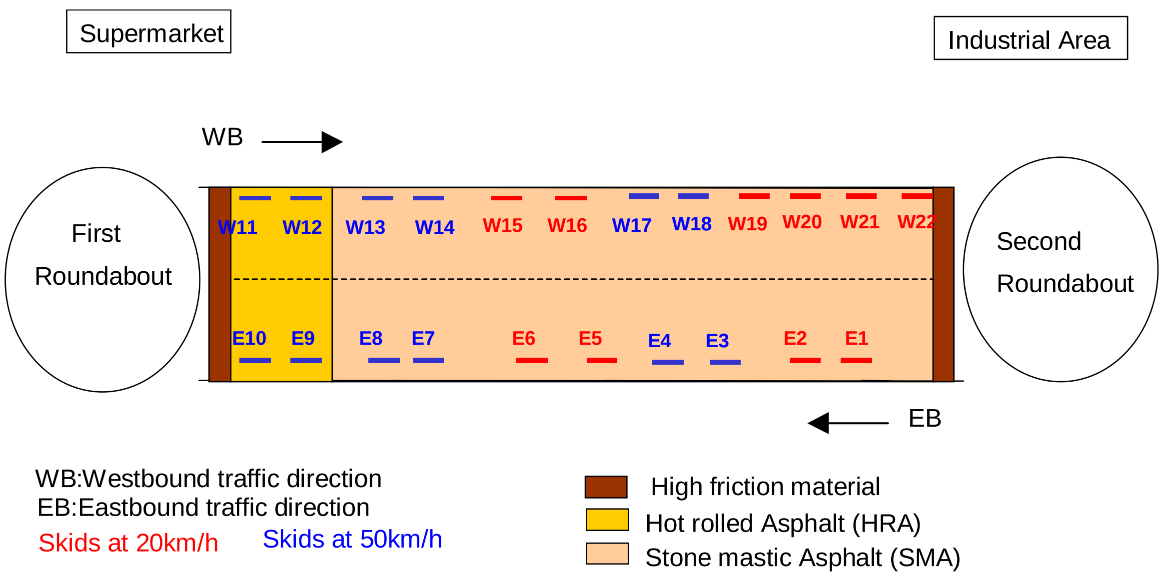

Figure A1: Schematic plan, eastern section, A511

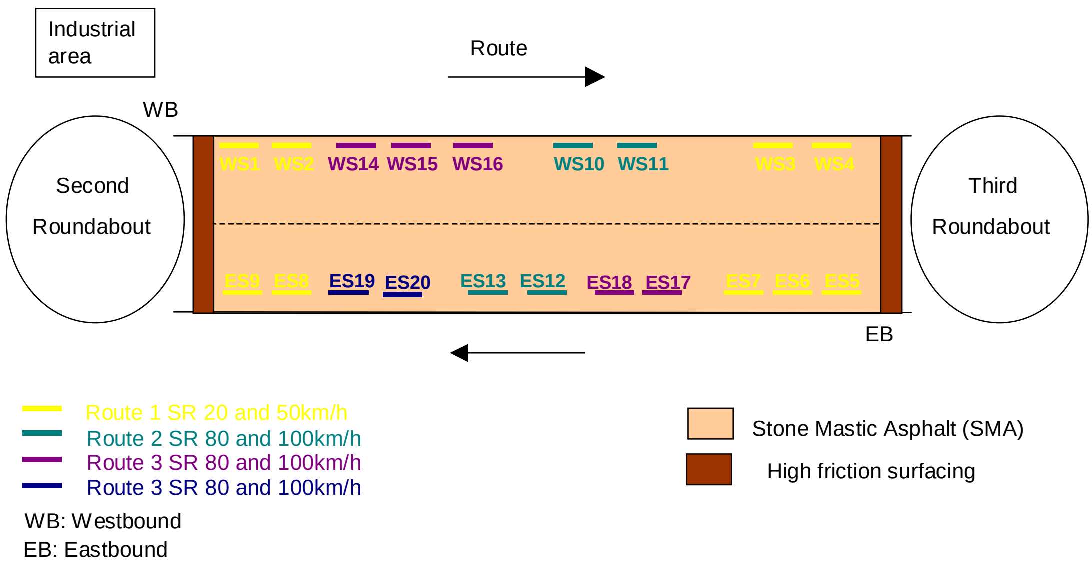

Figure A2: Schematic plan, western section, A511

The colours in Figures A1 and A2 correspond to the sequences used to cover the skid positions so that measurements at different speeds could be made as efficiently as possible.