THE EFFECT OF AGGREGATE TYPE AND SIZE ON THE PERFORMANCE OF THIN SURFACING MATERIALS

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ABSTRACT

This paper considers the prediction of skid resistance for differing types of UK thin surfacing materials in relation to mix properties such as aggregate type and size. This is based on different research projects that have been in response to meeting the needs for sustainable construction i.e. providing a safer and longer lasting pavement. The traditional UK requirement for high values of skid resistance and texture must now be viewed along with properties such as noise, fatigue, permanent deformation and rolling resistance. Using examples and case studies the paper considers the implication of combining these sometimes conflicting properties.

1. INTRODUCTION

Sustainability has become one of the most important issues in any type of construction. The last 10 years has seen tremendous change in terms of government policy, specifications, design to product development and the laying of asphalt materials.

The many definitions of sustainability from Brundtland (WCED, 1987) to the English Highways Agency (2003) address issues such as global warming, greenhouse gases, carbon emissions and the carbon footprint. In relation to highways, sustainability is about recycling, reuse and minimizing use. It is about improved stiffness and fatigue characteristics of the load bearing layers allowing reduced layer thicknesses, less aggregate and bitumen use.

More importantly, sustainable highway construction is about appreciation of the bigger picture e.g. from the inevitable future shortage of bitumen to understanding the interconnections between practises, expectations, policies, technologies, whole life costing and the limitations of the materials used.

In practical terms sustainability is about making better use of our resources whether they are aggregates or construction employees to minimize the risk in providing longer-term performance of what may be conflicting in-service property expectations. This paper draws from research and case studies in a range of areas relating skid resistance to aggregate and mix properties and the ideals of sustainable construction.

2. IMPROVING LABORATORY PREDICTION

Laboratory investigation under controlled conditions removes many of the variables that can affect on-site measurement. However, such work is limited in the ability to simulate and predict real in-situ conditions.

Woodward (1995) considered the laboratory assessment of surfacing aggregate and compared the existing BS 812 methods to the then proposed European Standard methods. It was concluded that all of the standard tests evaluated were limited in their ability to predict subsequent performance of a surfacing aggregate. Many of the methods are limited in their ability to simulate and so predict performance. For example, the assessment of single sized aggregate compared to its graded use. The test methods for strength and abrasion do not consider the fundamental effect of rainfall. Small increases in skid resistance for a particular rock type tend to achieved at the expense of most other aggregate test properties.

SKIDPREDICT (Roe and Woodward, 2004) was a collaborative project between the Transport Research Laboratory and the University of Ulster, funded by the Highways Agency, Country Surveyors Society and Quarry Products Association. It re-investigated the ability of the PSV test to assess skid resistance and developed a range of alternative versions of the test to vary in-service stressing conditions.

The EPSRC funded SKIDGRIP project (Woodward 2003) investigated the prediction of early life skid resistance of new asphalt surfacing materials. Both SKIDPREDICT and SKIDGRIP found that aggregate responds to the applied test conditions during testing in the accelerated polishing machine. The value of skid resistance obtained e.g. the standard 6 hour PSV (BSI, 2000) is simply a value of equilibrium that can be altered by changing test conditions such as loading, applied stress, climatic conditions or duration of testing.

In terms of surfacing aggregate and the development of early life skid resistance, GripTesting of sites across the UK and Ireland showed how different types of asphalt mixes behaved during their early life. If the bulk aggregate is moisture sensitive or contains particles which are moisture sensitive they will quickly loose their bitumen coatings and so facilitate the development of early or very early life skid resistance.

However, premature loss of particle edges or loss of individual particles may detrimentally affect mix durability and tyre / surface contact patch phenomena both in early and more importantly in mid life. This work, particularly the extensive measurement of skid resistance using GripTester in relation to how the surface was developing led to improved understanding of how the different types of asphalt material responded to different types of trafficking.

MacCombe (2006) considered how the very early life skid resistance of a 14mm high stone asphalt mix could be improved prior to trafficking. Most guidance recommends the application of coarse grit. Whilst this has been found to improve skid resistance, the grit can have problems such as sourcing, cleanness, method of application and tends to reduce the initial texture depth.

SKIDGRIP had found that grit sized particles embedded in the bitumen coatings of PSV test specimens gave a secondary micro-texture which caused a marked increase in skid resistance even when no aggregate was exposed. MacCombe (2006) used a modified wheel tracking apparatus to assess the effect of sand applied to high stone asphalt slabs.

Figure 1 shows the characteristic drop in very early life skid resistance followed by a rise and subsequent decrease. This drop followed by rise was found during GripTesting of a proprietary 14mm thin surfacing. It also shows that the application of ordinary sand had a marked improvement in both very early life and subsequent development of skid resistance.

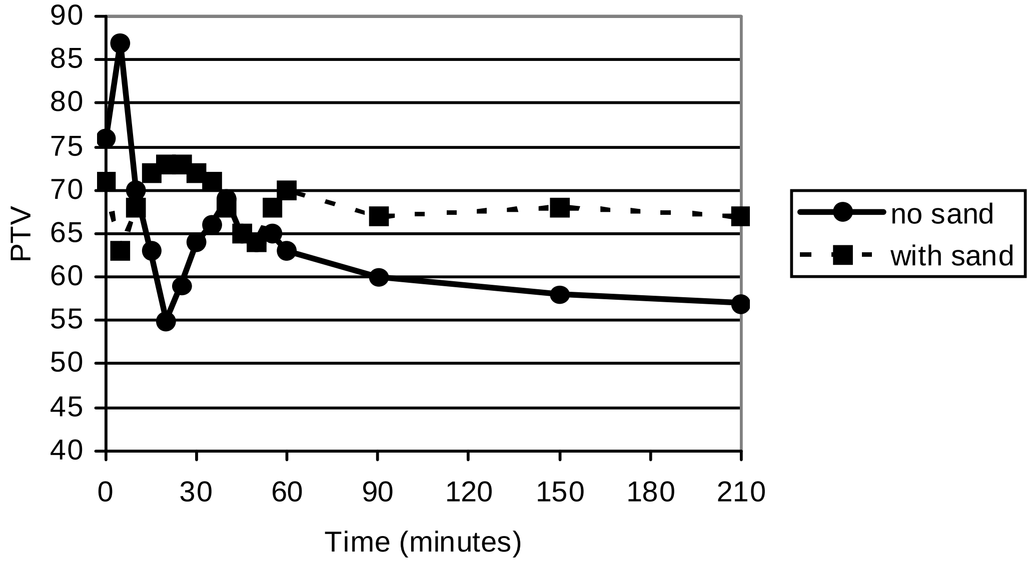

Figure 1 Application of sand on early life skid resistance of a 14mm thin surfacing

Figure 2 shows the development of early life wet skid resistance for 6mm and 14mm high stone asphalt using the Road Test Machine (RTM) located at the University of Ulster. Up to 10 asphalt slabs 305 x 305 x 50mm can be fixed to a rotating table and tracked by 2 full-scale loaded tyres.

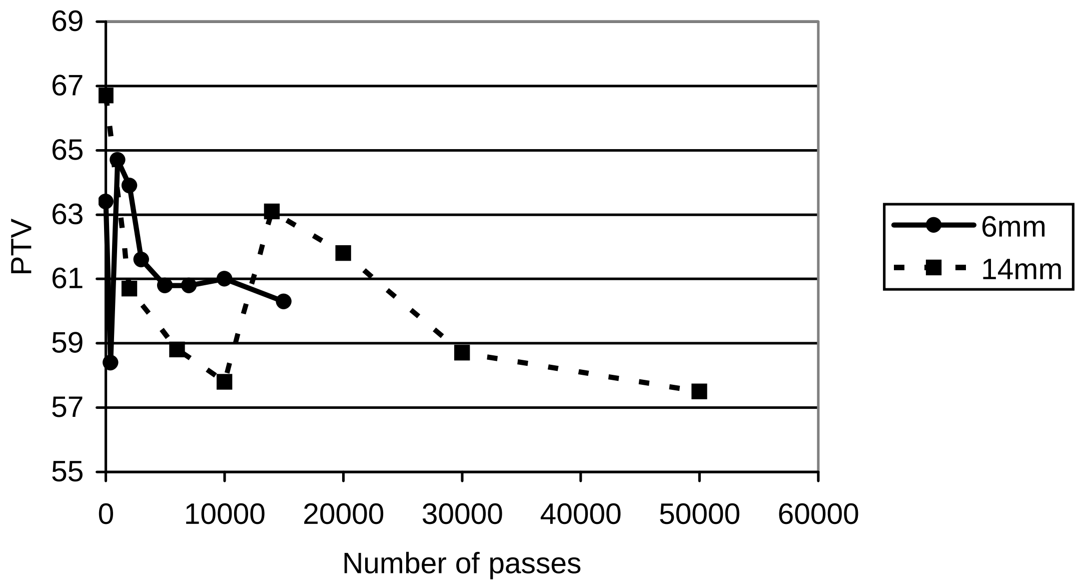

Figure 2 Development of early life wet skid resistance for 6mm and 14mm high stone asphalt using RTM

The equipment has been used to assess a range of surfacing materials. It is accredited by the BBA to assess the wear characteristics (Nicholls, 1997) of high friction anti-skid surfacing materials.

The two plots in Figure 2 represent the average change in skid resistance for the same grading high stone content grading made with 12 different types of 6mm and 14mm nominal sized aggregate. Skid resistance was measured using the Pendulum Tester and wide slider.

This figure again shows the characteristic initial decrease in skid resistance, followed by increase and subsequent decrease in skid resistance until equilibrium is reached.

The data also shows a noticeable difference in time line with this typical sequence of events happening much quicker for the 6mm mixes. This may reflect the greater number of contact points within the contact patch for the smaller nominal sized aggregate mix.

Again, this assessment mirrors what was found when assessing a wide selection of thin surfacing mix types made with differing aggregate with a GripTester.

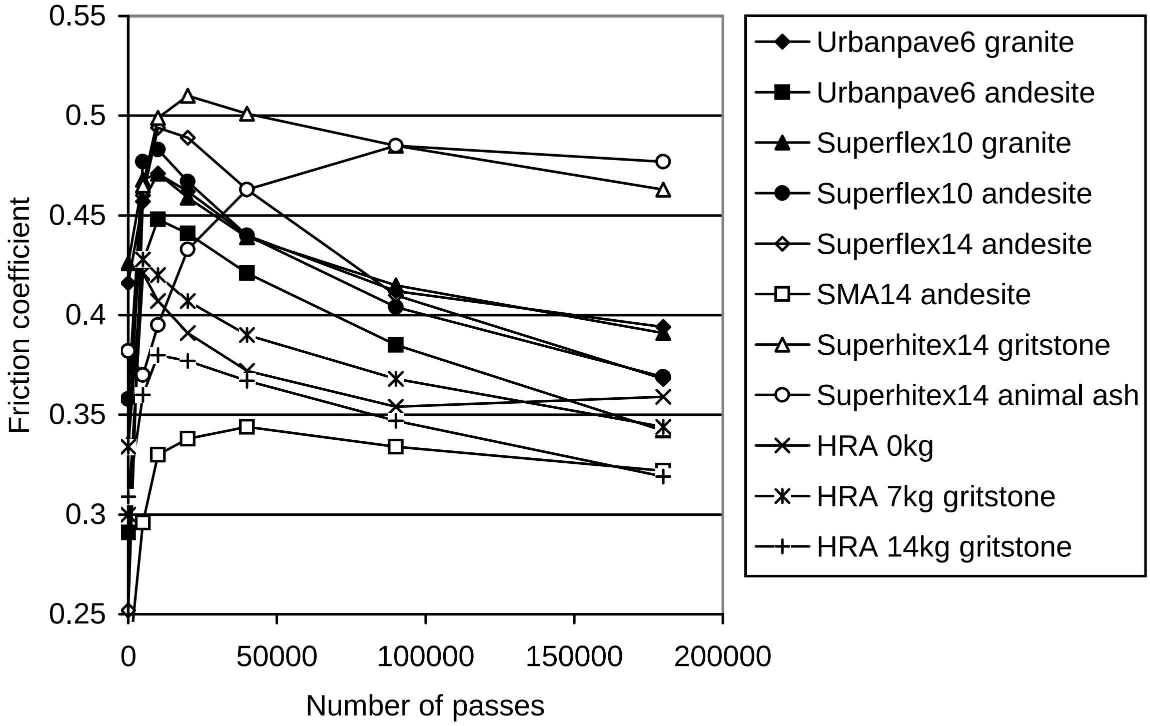

Figure 3 Average WS friction coefficient

Figure 3 plots the development of skid resistance for 11 different types of UK surfacing asphalt using the German Wehner Schulze test. The materials were either sampled at the mixing plant or prepared in the lab. Each was reheated and used to prepare 305 x 305 x 50mm slabs using a roller compactor. These were cored and assessed using the Wehner Schulze at Berlin Technical University.

The results show that the Wehner Schulze test discriminated between materials. The found ranking using Wehner Schulze agreed with the findings of full-scale trials that suggested that aggregates with lower PSV e.g. granite could perform as good if not better than aggregates with higher PSV e.g. andesite.

The simple examples illustrated in Figures 1, 2 and 3 show that all of these differing types of simulation test show variation in skid resistance during the early life of the differing asphalt materials being assessed. Thereafter each of the materials reaches a level of equilibrium in relation to the specific test conditions.

For example, if the speed of rotation during RTM testing is then increased from the standard 10rpm to 15rpm the additional stressing imposed will result in a further drop of skid resistance to a new lower level of equilibrium.

The three methods discussed allow different aspects of skid resistance to be assessed. No one method is better than the other. However, one method may be better at predicting a particular aspect than another.

Whilst the modified wheel–tracking approach measures at slow speed the equipment allows cores to be assessed at a range of higher temperatures than would normally be used in testing in the laboratory. This aspect was used by Yacoob (2006) to study the effect of higher road temperatures on texture change of surface dressing.

This found that increases in test temperatures caused greater embedment and as the texture changed so did skid resistance. Using methods developed at Ulster, subsequent evaluation of the tracked cores found that noise and rolling resistance characteristics also changed with simulated trafficking.

In terms of sustainability i.e. understanding the bigger picture, this ability to relate changes of skid resistance with changes in noise and rolling resistance is just as important as ensuring that the surface maintains an adequate level of skid resistance throughout its design life.

The RTM has the advantage of using a two full size loaded van tyres. The larger 305 x 305mm sample can be easily prepared in a roller compactor and not only allows change in skid resistance to be evaluated, but also texture depth and ultimately ravelling as the aggregate / binder bond is distressed and the mix integrity fails. Image analysis can show how these develop with time.

Typical testing on the RTM is done in a dry condition. But the test specimens can be easily conditioned by soaking in water or other substances such as diesel. This can be used to assess how asphalt mixes react to trafficking in differing types of climate or to localised cases such as a diesel spillage on a busy motorway.

This is a very important attribute of simulated trafficking of asphalt mixes that cannot be determined by the standard PSV test. By aggressively trafficking the asphalt mix many additional issues can be quickly and inexpensively determined. This includes issues such as moisture sensitivity of the aggregate / bitumen combination, excessive wear and / or rounding with the use of higher PSV aggregates and differential wear of different aggregate blends.

These three types of simulation assess the asphalt mix and shown that its skid resistance may be different from that suggested by the PSV test. For a given aggregate, greater skid resistance could be achieved by reducing the nominal stone size and / or by modifying the void content.

This reduction in stone size relates to a range of subsequent issues. For example, the layer could be made thinner. It also means that the resulting texture of the material will probably be less unless specifically addressed in the design. This is important in the UK where a minimum texture depth of 1.5mm has been the requirement for many years.

However, just as there are different types of rubber compound and tyre tread patterns then it is possible to get better grip with less texture if the water has a means of escaping from under the tyre. A greater number of contact points can cut through the film of water with excess water either escaping along the surface, within the mix or using the tyre tread pattern and depth.

In terms of sustainability it is very important that the role of each factor be properly understood. How a road surface and tyre interact with water both during and after a rainfall event is currently being researched by Nursetiawan (2008). Using a rainfall simulator, large slabs of asphalt 1400mm x 600mm x 50mm are being evaluated at different crossfall and rainfall intensities.

Figure 4 shows an example of the data being produced relating texture depth of the slab to Tft at rainfall intensities of 31, 54 and 78mm/hr and a 2% crossfall. TfT is termed the Time for Transition Flow and relates to the time it takes for the surface texture to be infilled by water and surface flow of water to start i.e. a basic performance characteristic of a road surface material.

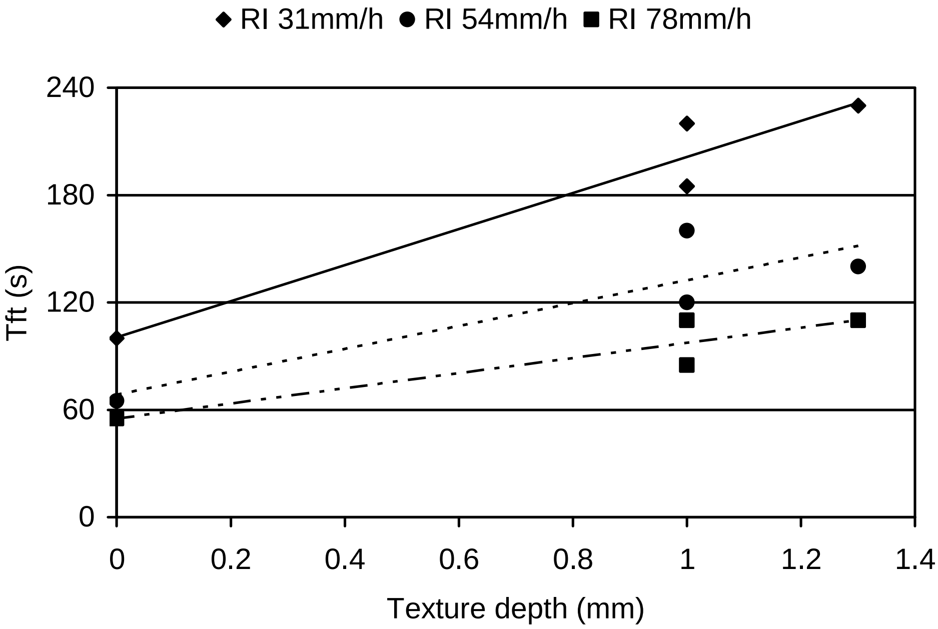

Figure 4 Effect of texture depth on Time Concentration for Slope 2%

Figure 4 shows a good relationship between these two simple variables. The research is also considering the relationship between surface water flow with flow within the interconnected void structure of the asphalt mix. The research is also considering simple issues such as how long does a particular asphalt mix stay wet after a rainfall event.

This has obvious issues relating to moisture sensitivity and ravelling. It also has implications on wet skid resistance as water held within the void structure for quite long periods of time could be sucked back up to the surface by trafficking so retaining lower skid resistance conditions for longer periods of time.

These properties of water flow relate to mix type, aggregate size, shape and the type of void structure within the mix. These factors are closely related to other important sustainability issues such as the generation of road surface / tyre noise and its subsequent reflection or absorption by the surface layer.

In the UK noise is the second most important property after skid resistance. Anderson (2000) considered the generation of road / tyre noise in relation to porous asphalt mixes and concluded that aggregate size and shape was important together with mix tortusoity i.e. how the voids were interconnected.

Yacoob (2006) considered the use of smaller sized types of surface dressing as a sustainable option to re-surfacing high stone mixes or concrete surfaces. The research concentrated on assessing the role of texture in the generation of noise.

A methodology was developed to take road surface latex castes and produce specimens for testing using a rotating drum. This method removed many of the variables that cause problems with this type of work and concentrated simply on the influence of surface / tyre interaction i.e. the size, shape and orientation of the aggregate particles in contact with the tyre.

Test conditions of speed, load and tyre type were varied and noise measurements used to develop a simple noise index (Woodward et. al. 2005).

Whereas Anderson (2000) had found that a smooth road surface and negative texture with interconnected voids was beneficial for a hot mix, Yaccob (2006) found that reducing the texture depth of positive textured surface dressing resulted in significant reductions in road/ tyre noise.

McErlean (2006) developed a simple coast-down technique and using this type of casting technique concluded that surface texture appeared to be the main surfacing property that needed to be considered when developing more fuel-efficient surfacing materials.

Figure 5 plots Yacoobs noise index (negative value is quieter) and McErleans rolling resistance index (positive number is better) with texture depth. Comparison of noise and rolling resistance characteristics show a clear relationship between the two factors concluding that significant sustainability improvements could be gained by moving toward smaller nominal size materials and textures.

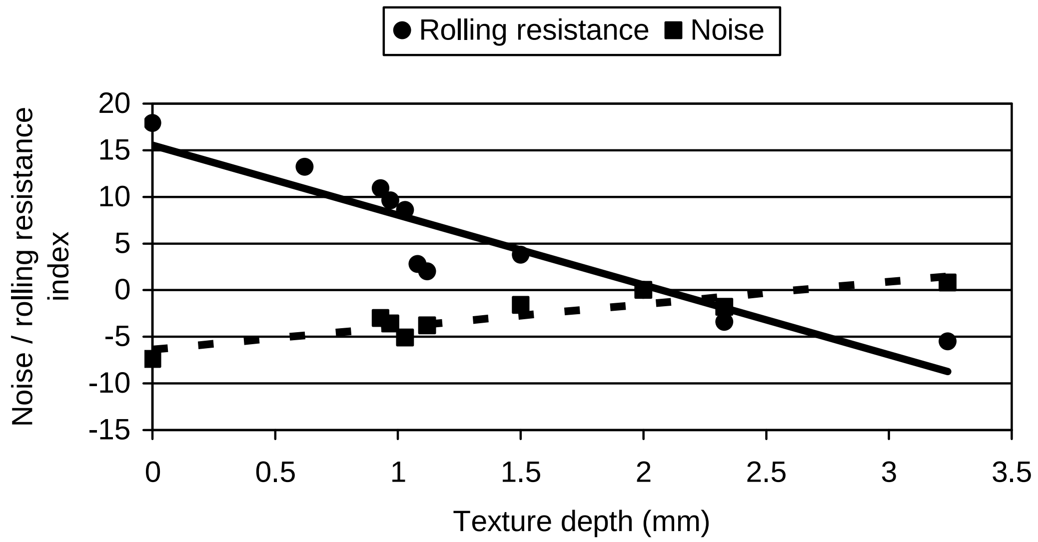

Figure 5 Plot of Yacoobs noise index and McErleans rolling resistance index with texture depth

3. IMPROVING FIELD OBSERVATIONS

During SKIDGRIP, trial sections were constructed using the 12 aggregates evaluated in the laboratory. Friction surveys were carried out after installation using GripTester to determine how skid resistance and other surfacing properties changed with trafficking e.g. aggregate exposure with time, changes in texture and physical form of aggregate particles.

Figure 6 shows the variation in skid resistance over the first 330 days for a 14mm high stone asphalt. This illustrates the issue of specifying initial skid resistance as a specification requirement i.e. when it is measured?

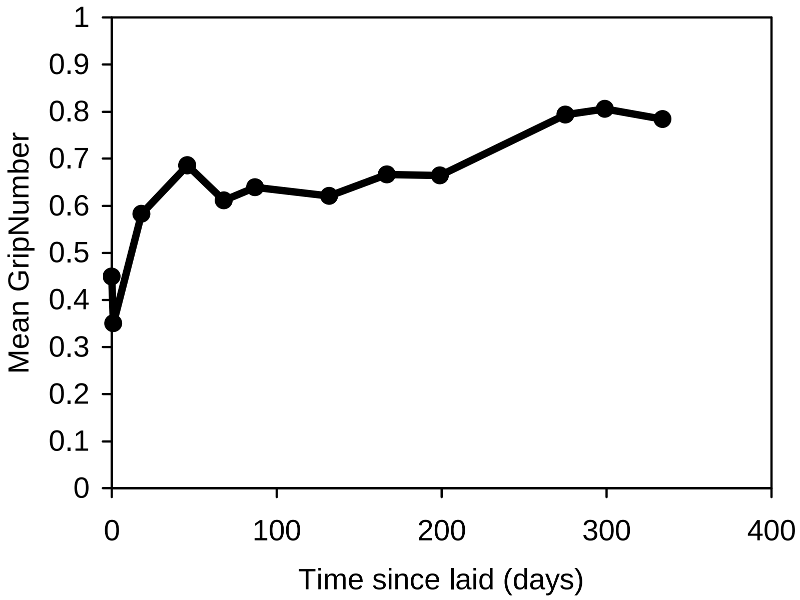

Figure 6 Early life skid resistance time line for a 14mm thin surfacing

The onsite data agrees with different laboratory assessments to show that initial skid resistance prior to trafficking reduced when trafficked and then increased. Field and laboratory observation found that the bitumen coatings quickly became smoothed explaining the low very early life values.

A secondary texture started to develop on the surface of the bitumen coated aggregate particles as fine aggregate trapped within the mastic coating becomes exposed due to this smoothing. The contact surface area of the coarse aggregate particles increased as the bitumen / mastic coating the aggregate particles smeared laterally. With increased traffic, increasing exposure of the aggregate micro-texture contributed to this secondary texture and growth in contact patch area.

Figure 7 plots the change in very early life skid resistance of three asphalt materials over a period of approximately 60 hours from when they were laid. It was found that each material had approximately the same wet GripNumber of 0.4 to 0.45 when laid and trafficked for a few hours. Thereafter, each material behaved differently.

The 20mm dense bituminous macadam (DBM) made with a low PSV limestone and 200pen bitumen quickly lost skid resistance but then showed a significant increase. The hot rolled asphalt (HRA) surfaced with high PSV greywacke 20mm chippings showed a steady increase whilst the high PSV greywacke 14mm high stone mix made with modified bitumen showed relatively little change.

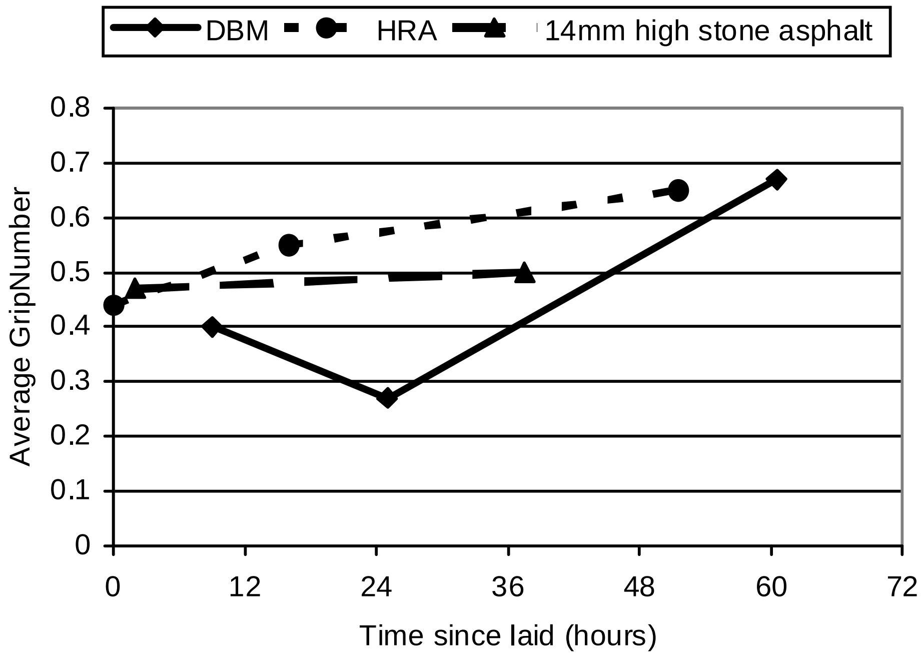

Figure 7 Very early life timelines for three asphalt materials at the same site

The data suggests that skid resistance of the aggregate may not be a significant factor during this very early life period as the 20mm DBM containing low PSV limestone aggregate was comparable to the high PSV greywacke aggregate used for the HRA and thin surfacing materials.

Rather, the data suggests that the development of very early life skid resistance is related to the type of bitumen used, the bitumen coating thickness on the aggregate particles, trafficking and environmental conditions i.e. the factors identified in the laboratory studies.

The final case study considers the findings of an investigation into the skid resistance of micro-asphalt (Ellis, 2007). In terms of sustainability this was an interesting study as it addressed important issues ranging from the low energy required during manufacture and installation to the use of a nominal 6mm mix.

The UK specification of skid resistance has been historically influenced by data obtained from hot rolled asphalt and 20mm chips and the laboratory assessment of PSV using 10mm sized aggregate. With the exception of high friction surfacing there is relatively little available research into the use of sub 10mm or 6mm sized aggregate or asphalt mixes.

One of aims of the investigation was to determine whether acceptable levels of wet skid resistance could be provided by the use of these smaller sized aggregates. Blends of mid PSV natural aggregate and very high PSV calcined bauxite were evaluated in the laboratory and at a full-scale road trial to determine whether smaller sized, lower PSV mixes could provide acceptable levels of skid resistance by providing more tyre point contacts within the contact patch.

The skid resistance characteristics for each of the aggregate was assessed using the standard 6.3/10mm aggregate size. Modified testing assessed the characteristics of the non-standard 4/6.3mm, 2.36/4mm and 1.18/2.36mm sizes for each aggregate.

Each of the blended aggregate gradings was also assessed using the accelerated polishing machine.

Five micro-asphalt mixes were subsequently laid as a full-scale road trial on the A26 in SE England. Samples of the trail mixes were assessed using the RTM apparatus with development of early life wet skid resistance measured on-site using GripTester over a 2 year period.

The field trial site was used to validate whether the 2004 correlation of SCRIM and GripTester was applicable to a type of thin asphalt mix that was not assessed during the correlation study (Jacobs Babtie, 2004). This found that the 2004 correlation of SCRIM = 0.85 x GripNumber was slightly modified to SCRIM = 0.83 x GripNumber, $R^2 = 0.95$ with the addition of the micro-asphalt data from the different trial mixes.

It was concluded that all of the micro asphalt mixes in the road trial had SCRIM values that exceeded the Intervention Levels in HD 28/04. As expected the levels of skid resistance varied over time. However, it was found that the mixes incorporating the high PSV calcined bauxite did not have significantly increased levels of wet skid resistance.

It was found that the lower PSV aggregates were able to provide acceptable levels of wet skid resistance in this nominal 6mm graded size. Overall, the differences between the 5 mixes in the road trial were relatively small suggesting that the way in which the aggregate is used is an important aspect in terms of improving the sustainability of surfacing materials.

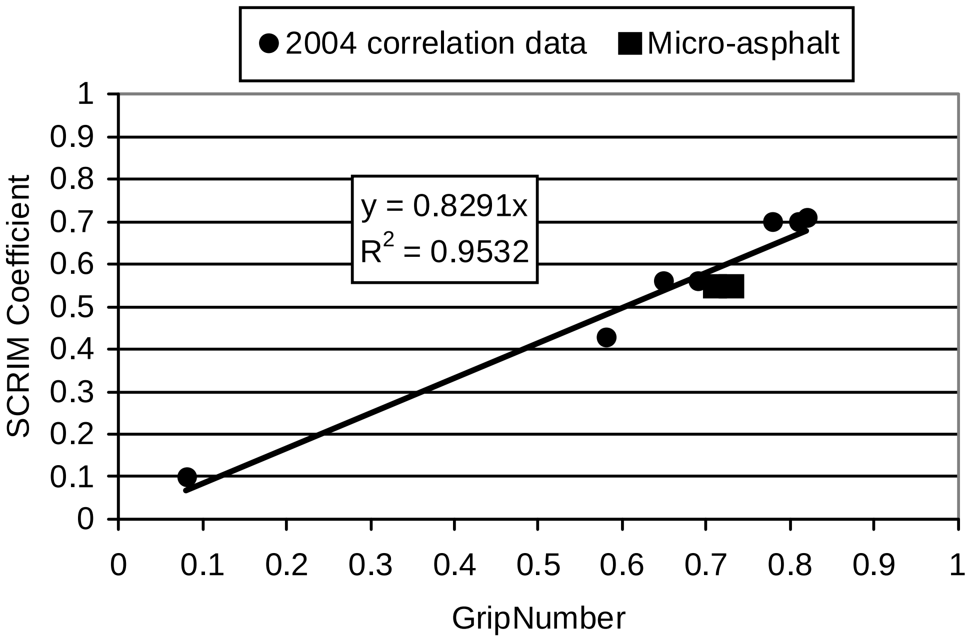

Figure 9 Data taken from 2004 SCRIM / GripTester correlation report with addition of A26 micro-asphalt test data

4. CONCLUSIONS

This paper has considered the effect of factors such as aggregate type and size on the performance characteristics of thin surfacing materials.

However, in terms of sustainability road surface performance is not simply about skid resistance.

Sustainability implies understanding performance in relation to every other property of the asphalt surfacing mix, the materials used in their construction, to the type of trafficking and environmental conditions likely during their design and subsequent performing life i.e. everything from how aggregate performance relates to its geology to the effects of global climate change.

This paper has brought together some simple examples and case studies from laboratory and on-site investigations to show the complicated inter-relationships that must be properly understood or at least recognised. Although the performance of an asphalt mix is fundamentally dependant on the aggregate and bitumen used in its construction there arte so many other factors that need considered. Research does not have all the answers yet but the means of improved understanding and prediction are becoming available.

Finally, it may be that with advances in vehicle traction systems and trye technology the inevitable sustainable solution in terms of performance is to concentrate mix development on smoother, finer textured semi porous roads constructed with harder wearing aggregates. Such surfaces will be longer lasting, quieter and more fuel efficient.

Dry skid resistance is typically not an issue with any asphalt mix. Rather, the future sustainable provision of a safer wet weather driving may lie with vehicle and tyre technology rather than skid resistance of the road surface.

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