

AN ASSESSMENT OF THE EVOLUTION OF THE SKID RESISTANCE OF PROPRIETARY ASPHALT SURFACINGS IN THE UK

Ignacio Artamendi¹, Paul Phillips¹, Bob Allen¹, David Woodward²

¹Research and Development Department, Aggregate Industries, Hulland Ward, UK

²School of the Built Environment, University of Ulster, Newtownabbey, Northern Ireland

ABSTRACT

This paper presents a laboratory and field study of the evolution of the skid resistance of different asphalt surfacing materials. A trial section was laid in September 2006 on a dual carriageway road located in the UK and subjected to heavy traffic conditions. Three different types of mixtures with 14, 10 and 6 mm maximum aggregate sizes and two different aggregate sources were used in the trial. In-situ measurements of skid resistance were carried out periodically using SCRIM and GripTester. Surface texture was also monitored using a laser sensor. Skid resistance values showed good material performance during the first 4 years since installation. Furthermore, surface texture values showed a decrease in texture for the relatively open 14 mm materials whereas no change in texture was practically observed for the denser 10 mm materials. Laboratory measurements of skid resistance were also carried out using the Wehner-Schulze (WS) device. This device is used to determine the friction of an aggregate or asphalt specimen after a polishing period. It was found that the WS ranked the mixtures in the same way as the in-situ methods whereas the PSV test did not. The WS was also used to predict the evolution of the skid resistance with traffic loading. Comparisons were then made between the predicted and measured skid resistance values. It was found that the WS device is a reliable tool for predicting the deterioration of friction due to traffic. Further work is, however, needed to relate laboratory measurements to in-situ methods.

Keywords: skid resistance, surface texture, friction

1. INTRODUCTION

Thin surfacing systems have been successfully used in the UK for the past 20 years. Some of the advantages of these surfacing materials can include enhanced skid resistance as well as noise and spray reduction. Most of these materials rely on good quality aggregate in terms of polishing resistance to provide adequate levels of friction. High specification aggregates, however, are relatively scarce and can be obtained only in limited areas, thus, they are sometimes transported long distances. These factors, therefore, have an effect on the overall cost as well as on the sustainability of these materials [1].

It is also known that asphalt surfacings with smaller nominal aggregate sizes can give higher skid resistance [2]. The use of smaller aggregate sizes in, for instance, densely packed mixtures can also improve durability. These types of surfacing materials with small aggregates have a closer texture and lower internal air voids which limits the ingress of water and subsequent moisture damage, i.e. stripping. Smaller aggregate sizes can, on the other hand, give lower texture depth which might affect skid resistance at high speeds. Nevertheless, by adequate selection of local smaller aggregate sizes with adequate polishing resistance, it might be possible to provide safe skid resistance levels through the life of the asphalt surfacing while reducing the cost and increasing its durability, hence enhancing the sustainability profile of the product.

To address some of these issues the UK Highways Agency (HA) commissioned a programme of collaborative research through Transport Research Laboratory (TRL). The latest phase of the research, the 2004 – 2007 Collaborative Programme “Surface requirements for asphalt roads” focussed on the skid resistance performance of modern asphalt surfacings and how they should be specified in terms of skid resistance of the aggregates and texture depth of the surface in order to provide safety performance levels [3]. In this study five trial sites covering a range of traffic conditions and aggregate sizes and polished stone values were evaluated in terms of early-life skid resistance and surface texture.

The work presented in this paper contains an evaluation of one of the trial sites reported in the previous study [3]. The trial area was provided by Aggregate Industries (AI) and was located on lane 1 of the A14 near Thrapston in Northamptonshire, UK. In this section two aggregates from different sources were used in three types of surfacing materials with maximum aggregate sizes of 14, 10 and 6 mm. The trial section was laid in September 2006. In situ measurement of skid resistance and texture depth were carried out by TRL using SCRIM. The aim was to monitor the evolution of these parameters with traffic. In addition to this, AI commissioned GripTester surveys on the same section. Laboratory measurements of skid resistance of the different aggregates and asphalt mixtures employed in the trial were carried out using the Wehner-Schulze (WS) device. The WS was also used to predict the evolution of the skid resistance of the different materials with traffic loading.

2. TRIAL

2.1 Materials

Three AI proprietary surfacing materials namely, 6 mm Urbanpave, 10 mm Superflex Carriageway and 14 mm Hitex were used in the trial. Urbanpave is a gap-graded material similar to SMA that incorporates a polymer modified binder for improved performance. The material provides a uniform and even surfacing particularly important in urban areas. Superflex, on the other hand, is characterised by a continuously graded aggregate structure similar to asphalt concrete and is produced with a polymer modified binder for enhanced flexibility and cracking resistance. The material is used when durability is placed as of higher importance to high textures. Both Urbanpave and Superflex materials are practically impermeable with lower in-situ air voids than more common thin surfacing systems. Finally, Hitex is a polymer modified asphalt thin surface course designed for high speeds, high volume roads. It provides noise and spray reduction combined with good resistance to permanent deformation.

Two types of igneous rocks namely, andesite and granite, were used in the above mixtures. Polished stone values of the andesite and granite coarse aggregates were 60 and 55, respectively. Three aggregate fractions, 4/10, 2/6.3 and 0/4 mm combined in different proportions were used to produce the mixtures.

2.2 Trial section

The trial section was located on lane 1 of the A14 eastbound between junctions 15 and 16 near Thrapston in Northamptonshire, UK. It consisted of 6 different surfacing mixtures with three aggregate sizes of 14, 10 and 6 mm, from two aggregate sources. The length of each trial panel was 500 m approximately. The mixtures were laid between 21 and 23 September 2006. Traffic levels for this site are considered heavy with estimated commercial vehicles per day of 3250. A schematic diagram of the trial section is presented in Figure 1.

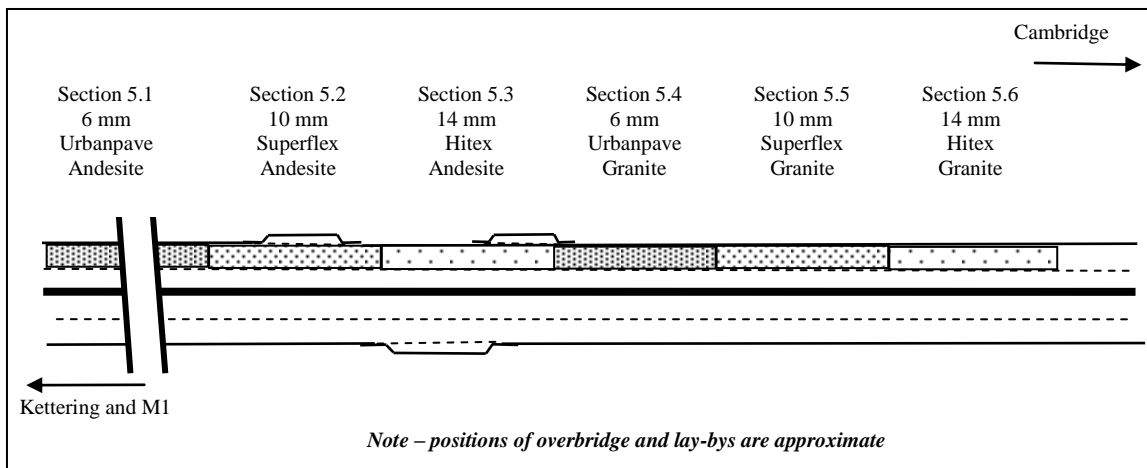


Figure 1: Schematic diagram of trial section, A14 Thrapston

3. EXPERIMENTAL

3.1 In-situ measurements

In situ measurements of low-speed skid resistance were carried out by TRL using SCRIM. Measurements of texture depth, as sensor-measured texture depth (SMTD), using the laser sensor fitted to the SCRIM machine were also performed. A single pass measuring both texture depth and sideways-force coefficient at a test speed of 50 km/h were made at each visit. A total of 9 visits from September 2006 to October of 2009 were made.

In addition to this, AI commissioned GripTester surveys on the trial section. Tests were carried out at the standard test speed of 50 km/h and water film thickness of 0.25 mm under the measuring tyre. A total of 4 visits from December 2006 to August 2010 were made.

3.2 Laboratory tests

Laboratory measurements of skid resistance were carried out using the Wehner-Schulze (WS) device [4]. The WS device was developed in Germany to assess polishing properties of aggregates and asphalt mixtures. The device is designed to carry out first accelerated polishing of aggregate or asphalt specimens and then to assess their friction characteristics. In the WS test mosaic specimens of 225 mm diameter made with uncoated aggregate particles fixed in an epoxy resin are employed. Laboratory prepared asphalt specimens or cores taken from actual roads can also be used for testing.

During the polishing stage three rubber-covered conical rollers are forced onto the test surface at a pressure equivalent to the tyre pressure of a commercial vehicle. The roller head is rotated at 500 rpm for 1 hour giving a total of 30,000 revolutions and 90,000 roller passes. The friction measuring system consists of a measuring head with three rubber sliders. The measuring head is accelerated to 3,000 rpm equivalent to a tangential velocity of the rubber sliders of 100 km/h. Water is sprayed on to the surface to give a 0.5 mm water film thickness. The test head is then lowered to make contact with the surface. The head then decelerates as a result of friction to a stop. Torque transducers mounted in the measuring head measure the reaction force which is then used to determine the friction coefficient at any instant. In the standard test, the friction at 60 km/h is used. Details of the full test can be found in [4].

In this work asphalt materials mixed at the plant were compacted to 300 x 300 x 50 mm³ slabs using a laboratory roller compactor. Cores of 225 mm diameter were then taken from the slabs. Two materials, 6 mm Urbanpave and 10 mm Superflex produced with andesite and granite aggregates were tested. Specimens were manufactured at the R&D laboratory of Aggregate Industries. Testing was carried out at the University of Berlin.

4. RESULTS AND DISCUSSIONS

4.1 Evolution of skid resistance

SCRIM coefficient (SC) values were determined by dividing the sideways force by the vertical load multiplied by 100 for a 10 m length of road. Average SC values for the test sections obtained during the site visits are presented in Figure 2. It can be seen that the initial SC values varied between 0.65 - 0.75 which indicated high low speed skid resistance of typical new asphalt materials. After two months, SC values remained practically the same. There was a marked

decrease in skid resistance from Nov 2006 to Sep 2007 as a result of both seasonal variation (lower skid resistance in the summer) and some early polishing of the aggregate. As regards seasonal variation, it has been suggested that in the winter when the roads are wet the detritus is mainly gritty and the road surface becomes harsh increasing the skid resistance. In the summer, on the other hand, the surface is generally wet for shorter times and the detritus on it is mainly dusty so that the surface becomes polished and the skid resistance decreases [5]. Thus, lower SC values are obtained in the summer season than in the winter. The length of time for the bitumen film to be removed from the aggregate to expose its microtexture depends on local conditions and traffic levels. For most materials, however, after six months the aggregate microtexture is fully exposed and polishing can take place [6]. From Sep 2007 to Nov 2007 there was again an increase in skid resistance most probably due to seasonal variation. SC values in Nov 2007 were, however, lower than those obtained a year earlier. The skid resistance decreased again from Nov 2007 to Jun/Jul 2008 as a result of further polishing of the exposed aggregate. Between July and Oct 2008 there was a slight increase in skid resistance due again to seasonal variation. From Oct 2008 to Aug 2009 there was a noticeable drop in skid resistance as a result of polishing followed by an increase in Oct 2009 due to seasonal conditions.

In order to isolate seasonal variations to evaluate the polishing effect of traffic on skid resistance, only SC values measured in the summer period have been plotted in Figure 3. Furthermore, standardised test measurements in the UK are made during the summer period 1 May – 30 September when the skid resistance is lowest [5]. A logarithmic trend line was then fitted through the data. It can be seen that the skid resistance decreased during the early life of the surfacing and then tended towards an equilibrium level. Data presented in this figure suggest that the equilibrium level has not been reached. It was also observed that for the same aggregate type, the 14 mm mixtures had worse low speed skid resistance than the 10 mm and 6 mm mixtures. Furthermore, the 10 mm mixtures performed marginally better than the 6 mm mixtures. Comparison between the materials produced with the two aggregate types indicated that the granite mixtures performed better than the andesite ones in terms of resistance to skidding. It should be noted that the granite aggregate had lower PSV (PSV = 55) than the andesite (PSV= 60).

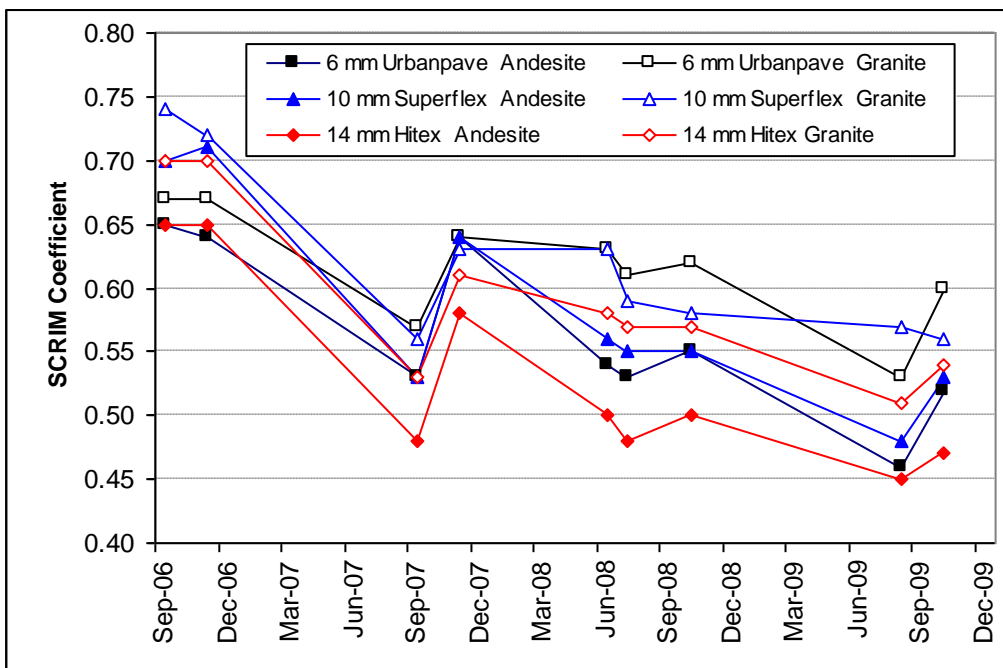


Figure 2: SCRIM coefficient values

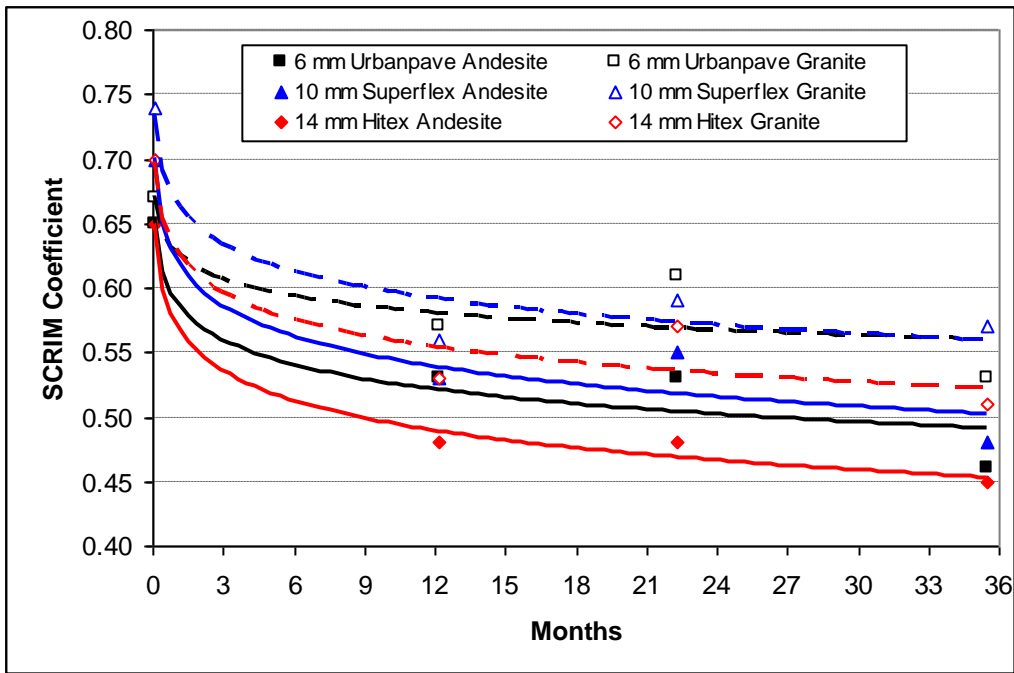


Figure 3: Evolution of skid resistance with time (SCRIM – summer values)

GripNumber (GN) values for all sections are presented in Table 1. It can be seen that the initial GN values varied between 0.75 - 0.80. GN then decreased to between 0.55 – 0.65 after more than 3 ½ years of trafficking. GN values were converted to SC values using the following expression [7],

$$SC = 0.89 \times GN \quad (1)$$

SC values determined using Equation 1 are presented in Figure 4. A logarithmic regression curve was then fitted through the data. It can be seen that the skid resistance decreased with traffic due to polishing of the aggregates. It can be also observed that, for the same aggregate type, the 10 mm materials had higher SC values than the 6 mm and 14 mm materials. As regards the type of aggregate, surfacing materials produced with the granite aggregate (PSV = 55) showed higher SC values than those produced with andesite (PSV = 60). The same was observed from SCRIM measurements. This indicates that the PSV under predicts the performance of the granite aggregate in terms of friction. Furthermore, better friction of the granite aggregate might be attributed to its mineralogy and mineral grain shape and hardness. Comparison between SC from SCRIM and from GripTester indicated that the latter were somehow higher than the former (see Figures 3 and 4).

Table 1: GripNumber

| Material | Aggregate | Date | | | |
|-----------------|-----------|----------|----------|----------|----------|
| | | Dec 2006 | Sep 2007 | Sep 2008 | Aug 2010 |
| 6 mm Urbanpave | Andesite | 0.77 | 0.63 | 0.60 | 0.55 |
| 10 mm Superflex | Andesite | 0.75 | 0.63 | 0.61 | 0.59 |
| 14 mm Hitex | Andesite | 0.77 | 0.61 | 0.61 | 0.56 |
| 6 mm Urbanpave | Granite | 0.79 | 0.63 | 0.69 | 0.65 |
| 10 mm Superflex | Granite | 0.77 | 0.69 | 0.72 | 0.66 |
| 14 mm Hitex | Granite | 0.80 | 0.65 | 0.68 | 0.65 |

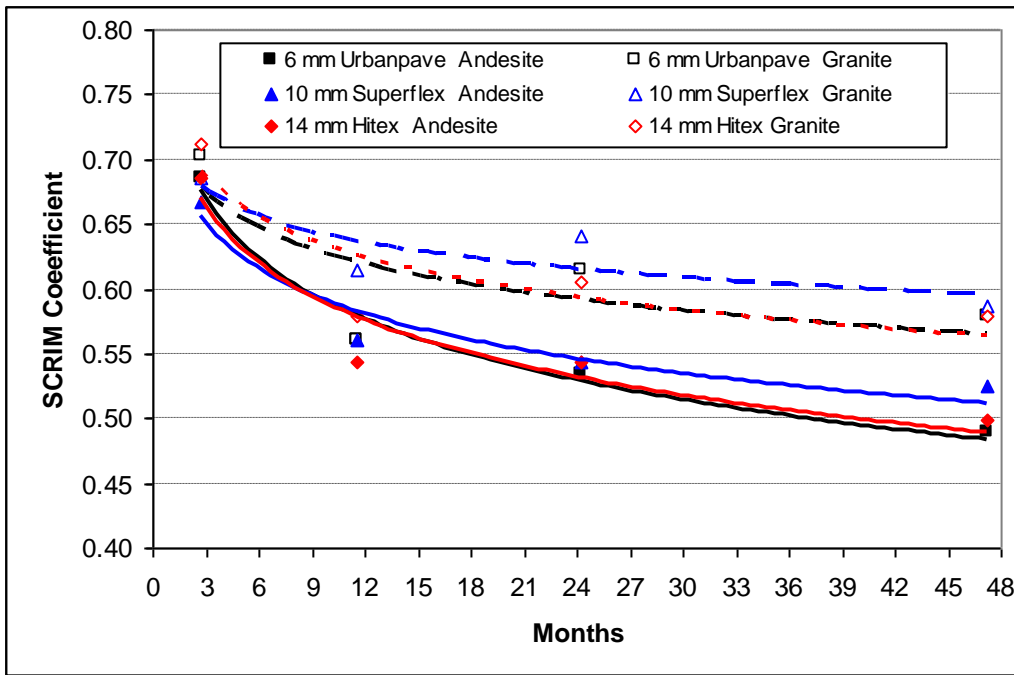


Figure 4: Evolution of skid resistance with time (GripTester)

4.2 Evolution of texture depth

The sand patch test method was used to measure texture depth (TD) just after installation. Texture was also measured using a laser sensor fitted to the SCRIM machine to give the sensor measured texture depth (SMTD). Sand patch and sensor measured texture depth values before trafficking are presented in Table 2. It can be seen that 14 mm Hitex had the highest texture followed by 6 mm Urbanpave and 10 mm Superflex. It can also be seen in Table 2 that SMTD values are markedly lower than those obtained using the sand patch method.

A power law relationship was found between the texture depth values obtained using the sand patch method and the laser sensor method as follows,

$$TD_{SMTD} = 1.67 \times SMTD^{0.84} \quad (R^2 = 0.93) \quad (2)$$

Values of the texture depth using Equation 2 are presented in Table 2. The Mean Profile Depth (MPD) which represents the average depth below the peaks of the aggregate particles in the line followed by the laser spot and is therefore analogous to the volumetric or sand patch method [3], was determined using the following relationship [8],

$$MPD_{SMTD} = 1.42 \times SMTD^{0.84} \quad (3)$$

Values of the texture depth using Equation 3 are also presented in Table 2. It can be seen that texture depth values using Equations 2 and 3 are similar and close to the actual texture depth determined using the sand patch method.

Table 2: Initial texture depth values

| Material | Aggregate | TD | SMTD | TD _{SMTD} | MPD _{SMTD} |
|-----------------|-----------|------|------|--------------------|---------------------|
| | | mm | mm | mm | mm |
| 6 mm Urbanpave | Andesite | 1.10 | 0.50 | 0.94 | 0.79 |
| 10 mm Superflex | Andesite | 0.80 | 0.46 | 0.88 | 0.74 |
| 14 mm Hitex | Andesite | 1.90 | 1.05 | 1.74 | 1.48 |
| 6 mm Urbanpave | Granite | 1.20 | 0.69 | 1.23 | 1.04 |
| 10 mm Superflex | Granite | 0.80 | 0.44 | 0.84 | 0.71 |
| 14 mm Hitex | Granite | 1.80 | 1.20 | 1.95 | 1.66 |

The evolution of the texture depth with time is presented in Figure 5. It should be noted that these values were obtained by converting SMTD values determined during the monitoring campaign to TD values using Equation 2. The figure showed that the texture decreased with time towards an equilibrium level. Furthermore, the change in texture with time was more noticeable for the mixtures with higher initial texture. Also, the texture depth of the material with the lowest initial texture, i.e. 10 mm Superflex, did practically not change during the first 3 years in service. This suggests less wear of low texture surfaces as shear and normal loads applied by the tyre are distributed over a larger contact area. Data presented in Figure 5 also shows greater variability of the texture depth measurements for the relatively open mixtures with higher initial texture. In the UK, texture requirements are specified by the initial texture plus the minimum texture retained at two years, both measured using the volumetric sand patch method [9]. This minimum value, however, is not an absolute minimum specified over the life time of the surfacing material.

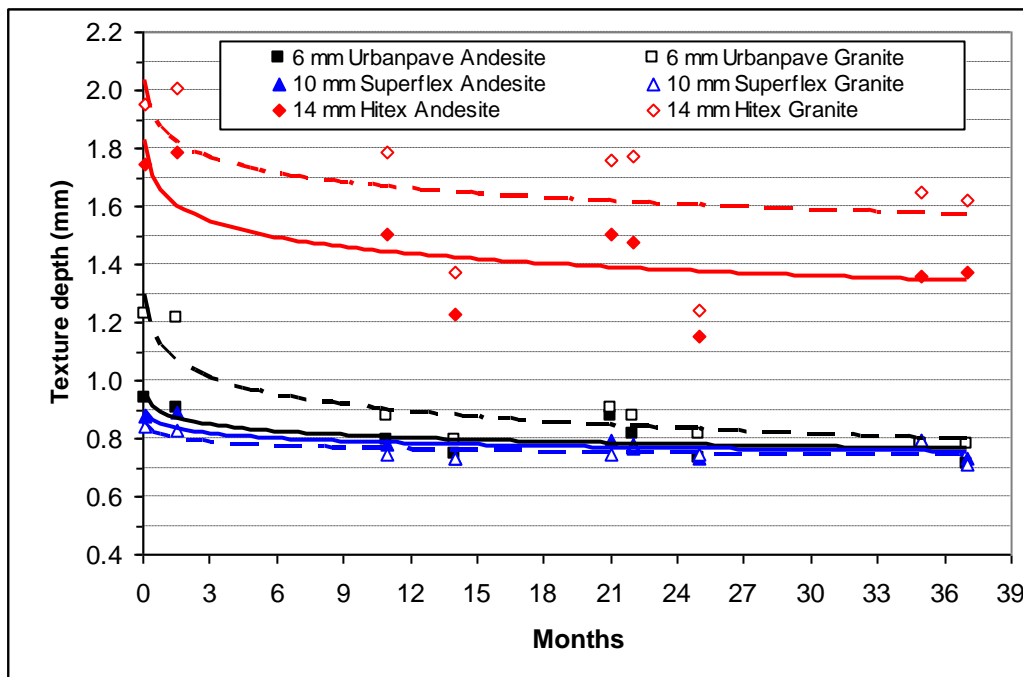


Figure 5: Evolution of texture depth (TD_{SMTD}) with time

4.3 Wehner-Schulze test results

The results of the Wehner-Schulze tests are presented in Figure 6. The figure shows the evolution of friction, measured at 60 km/h, with number of polishing cycles. It can be seen that there is an initial increase in the friction coefficient due to the removal of the bitumen film surrounding the aggregates and the subsequent exposure of the microtexture of the aggregates. Maximum friction values occurred at 10,000 polishing passes approximately. After this point, the friction coefficient tended to decrease as the exposed aggregate started to polish. Also, although an equilibrium friction level is expected, this was not reached after 180,000 polishing cycles.

Data presented in Figure 6 indicate that after 180,000 polishing cycles the 10 mm Superflex with andesite aggregate had higher friction than the 6 mm Urbanpave with the same aggregate. Friction values for the 10 mm Superflex and 6 mm Urbanpave with the granite aggregate were practically the same. Also, the results clearly show that for the same type of materials, those produced with the granite aggregate ($PSV = 55$) had higher friction values than those produced with andesite ($PSV = 60$). The same was observed for in situ measurements of skid resistance using both SCRIM and GripTester. This suggests that the WS test is a more reliable tool to characterise in the laboratory the skid resistance of a particular aggregate and mixture combination compared to the PSV test.

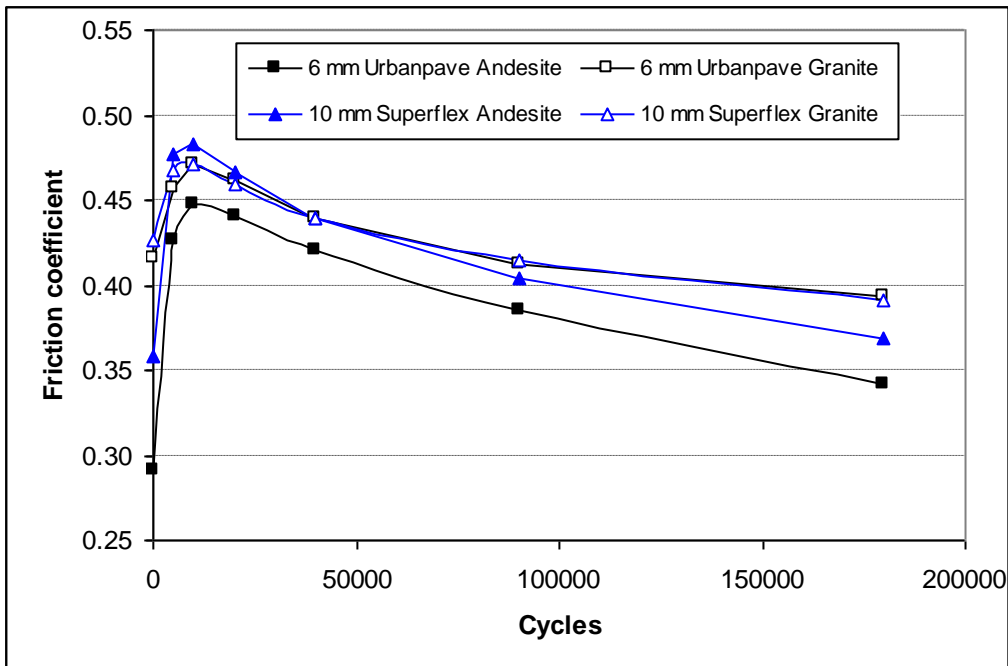


Figure 6: Evolution of friction with polishing cycles

4.4 Prediction of the deterioration of skid resistance

Results from the laboratory tests have been used to predict the evolution of skid resistance of the surfacing materials. In order to do this first the polishing cycles in the WS test have to be converted to actual traffic counts. Tang [10] proposed the following relationship between the polishing duration or number of cycles (N) in the WS machine and the cumulative number of commercial vehicles (T),

$$N = 0.024 \times T \quad (4)$$

Thus, Equation 4 can be used to determine the traffic required to cause the same polishing as the WS machine by dividing the number of cycles by 0.024. For instance, 180,000 polishing cycles represent 7.5 million commercial vehicles. If as in the current study, the estimated number of commercial vehicles per day is 3250, this corresponds to approximately 6 ½ years of trafficking. Moreover, Huschek [11] showed that the friction values obtained with the WS after 90,000 polishing cycles corresponds to a surface condition after 4 to 5 years of very heavy traffic. Thus, 180,000 polishing cycles will represent between 8 to 10 years heavy traffic.

Next step to predict the evolution of the skid resistance with traffic based on laboratory WS measurements was to convert the friction coefficient determined during the test to a skid resistance measurement value determined on-site, for example the SCRIM coefficient. Huschek [11] proposed the following relationship between SC values determined at a speed of 80 km/h using the German SCRIM and the friction coefficient (μ_{WS}) obtained in the WS test,

$$SC (80 \text{ km/h}) = 0.96\mu_{WS} + 0.06 \quad (5)$$

This relationship was determined by performing WS test on cores taken from the wheel path on locations where SCRIM measurements had previously taken place. In this work, to evaluate this relationship SC values measured at 50 km/h were converted to SC values at 80 km/h using the following relationship [5],

$$SC (50 \text{ km/h}) = SC (80 \text{ km/h}) + (80 \times 2.18 \times 10^{-3} - 0.109) \quad (6)$$

Calculated and predicted SC values at 80 km/h using Equations 5 and 6 for 6 mm Urbanpave Andesite and 10 mm Superflex Granite are presented in Figures 7 and 8, respectively. It can be seen that the model proposed by Huschek (Equation 5) underestimates the calculated SC values (Equation 6). These differences might be attributed to differences between the two types of SCRIM machines.

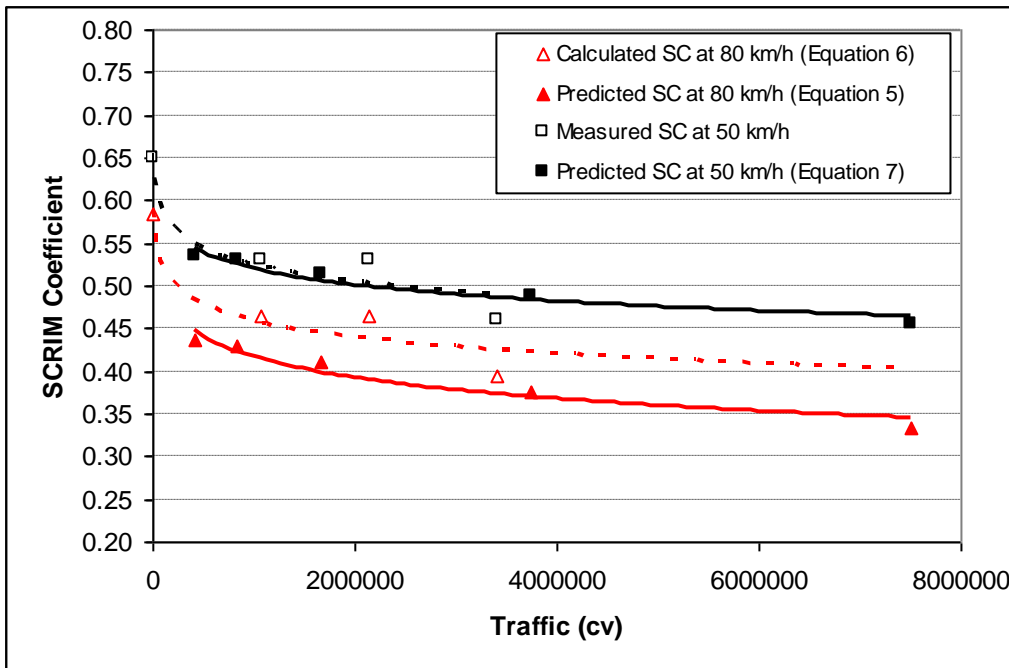


Figure 7: Measured and predicted SCRIM coefficient values (6 mm Urbanpave Andesite)

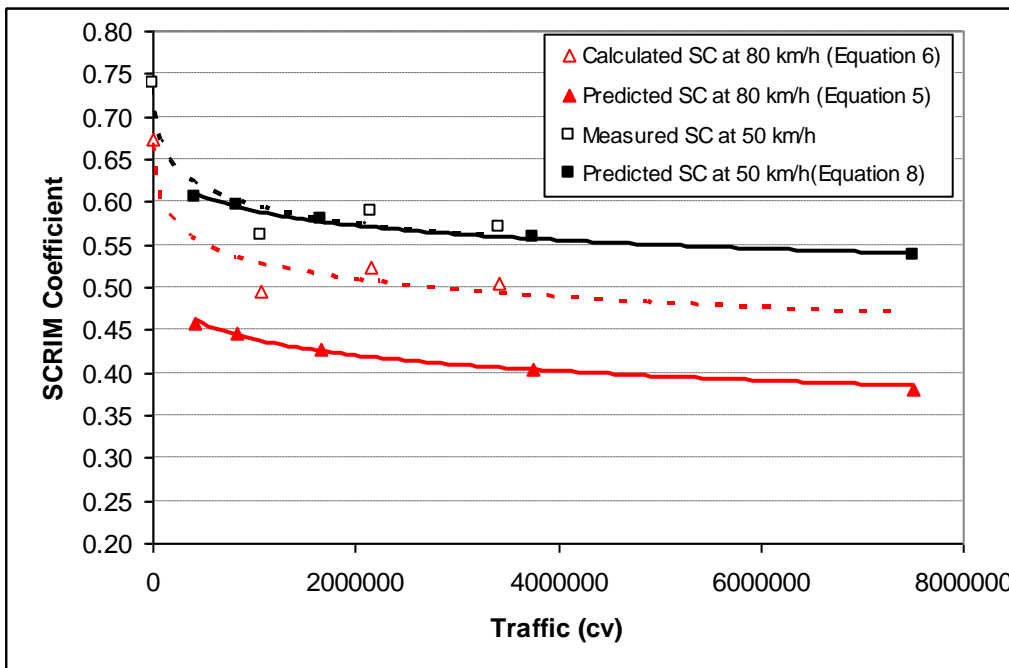


Figure 8: Measured and predicted SCRIM coefficient values (10 mm Superflex Granite)

In order to obtain a relationship between the SC at 50 km/h and the WS friction coefficient, the values determined from the regression equations for both sets of data at the same traffic levels were used. Figure 9 shows the relationship between the SC values at 50 km/h and the WS friction coefficient for the mixtures investigated. Eight data points per mixture are presented in Figure 9 corresponding to traffic levels from 1 and 8 million commercial vehicles. Data presented in Figure 9 suggests that the relationship between the SC at 50 km/h and the WS friction coefficient depends on the level of friction and consequently on the type of aggregate. The relationships found in this study for the two types of aggregates are as follows,

$$SC (50 \text{ km/h}) = 0.75\mu_{ws} + 0.20 \quad (\text{Andesite}) \quad (7)$$

$$SC (50 \text{ km/h}) = 0.88\mu_{ws} + 0.19 \quad (\text{Granite}) \quad (8)$$

It should be noted that these relationships are only approximations as they have been found using SC and WS friction values from regression analysis and not actual test values. Furthermore, in order to find a more accurate relationship between SC at 50 km/h and WS friction values, the WS test should be carried out on cores specimens taken from the road after SCRIM measurement at 50 km/h. Nevertheless, measured and predicted SC values at 50 km/h using Equations 7 and 8 for 6 mm Urbanpave Andesite and 10 mm Superflex Granite are presented in Figures 7 and 8, respectively. It can be seen that the predicted SC values are similar to the values measured on site.

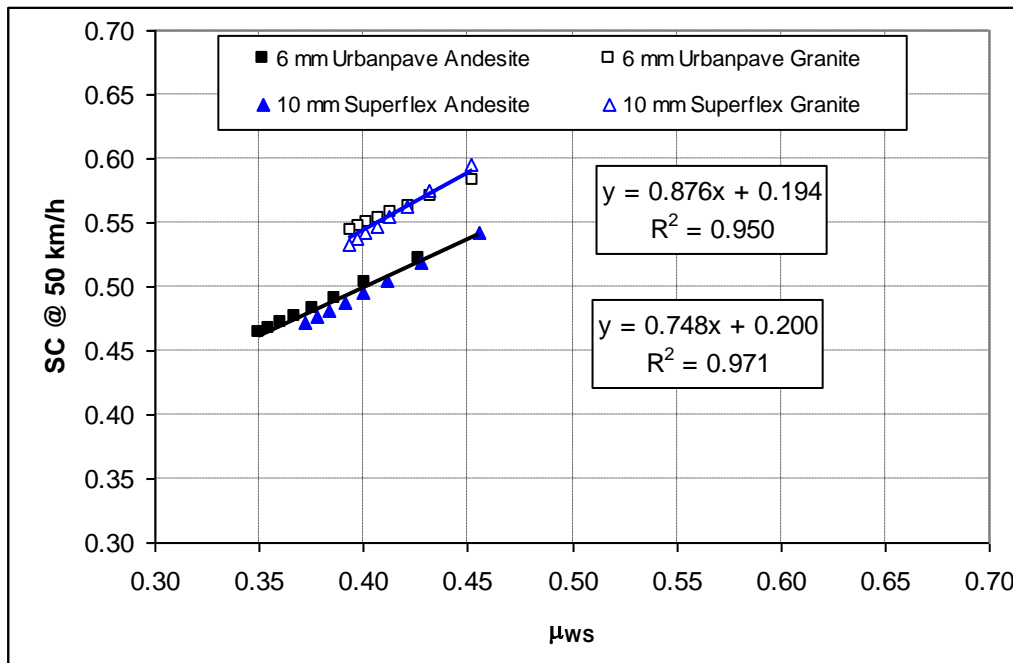


Figure 9: Relationship between SCRIM coefficient at 50 km/h and WS friction coefficient

5. CONCLUSIONS

Based on in-situ measurements of the skid resistance and texture depth and the laboratory tests to evaluate polishing and friction properties of different surfacing materials, the following conclusions can be drawn:

- SCRIM and GripTester values indicated that for the same aggregate type, the 14 mm materials had lower low speed (< 50 km/h) skid resistance than the 10 mm and 6 mm mixtures. Furthermore, the 10 mm mixtures performed marginally better than the 6 mm materials
- Comparison between the materials produced with the two aggregate types i.e. andesite and granite, showed that despite of having lower PSV the granite mixtures performed better than the andesite mixtures in terms of resistance to skidding.
- Texture depth of 14 mm Hitex was the highest followed by 6 mm Urbanpave and 10 mm Superflex. The decrease in texture depth with time as a result of traffic was, however, more pronounced for mixtures with higher initial texture. Furthermore, the texture depth of 10 mm Superflex, did not practically change during the first 3 years in service.
- Wehner-Schulze test results showed that mixtures produced with the granite aggregate (PSV = 55) had higher friction than those produce with andesite (PSV = 60). The same was observed from in situ measurements of skid resistance using both SCRIM and GripTester. This suggests that the WS test is a more reliable tool to characterise the skid resistance of asphalt mixtures in the laboratory than the traditional PSV test.
- Relationships between SCRIM and Wehner-Schulze friction coefficient were determined and used to predict the evolution of the skid resistance with traffic. It was found that the Huschek model under estimated the skid resistance values at 80 km/h. Good correlations were found, however, between the predicted and measured skid resistance values at 50 km/h using regression analysis. Further work is, however, needed to relate laboratory measurements to in-situ methods.

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