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FRICTION TESTS ON CONTAMINATED ROAD SURFACES

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Executive summary

Objective of study

The presence of contaminants in the tyre/road interface can reduce the friction generated between the tyre and the road. The sudden reduction in this friction experienced by the driver of a vehicle who traverses an area of road surface subject to contamination could potentially contribute to a loss of control of the vehicle and thus could pose a serious hazard. The objective of the study was to test various selected contaminants to identify the contaminants which, on a typical road surface, cause the greatest loss of friction and to provide guidance as to the importance of this effect.

Summary

There is extensive anecdotal evidence that the presence of contaminants in the tyre/road interface can reduce the friction generated between the tyre and the road. Such contamination is not common on most of the road network, but there are places where contamination can occur regularly, for example, contamination by mud or manure at site or farm entrances. Conversely, isolated incidents such as fuel spillage could occur anywhere on the network. In either case, a sudden reduction in friction resulting from contamination could potentially contribute to a vehicle losing control while attempting to manoeuvre on a contaminated surface. Depending on the nature and quantity of the contaminant and the nature of the site (i.e. whether vehicles are likely to need to brake or corner at that point) it could potentially pose a serious hazard to road users.

This report presents the results of an investigation into the effect of road surface contamination. Tests were carried out on two surfaces at an ex-USAF base at Bentwaters Park, Suffolk - one asphalt, the other concrete. Peak and sliding coefficients of friction were measured at speeds up to 80km/h with a locked-wheel pavement friction tester (PFT) and two skid cars. The PFT used a completely smooth test tyre and the skid cars were fitted with normal road tyres in roadworthy condition. The contaminants with which the road surfaces were tested were diesel oil, engine oil, clay and coarse sand. Additional tests were carried out after a proprietary absorbent material had been applied to the diesel oil and engine oil. Control tests were carried out with the surfaces dry and wet.

This work was jointly funded by the Highways Agency and by the Institute of Traffic Accident Investigators, with a substantial in kind contribution provided by Steetley Bentonite and Absorbents Ltd.

The results show that, for the skid cars, the reduction in friction observed with the contaminants, as compared to the dry and wet conditions, is clear but modest. The lowest figures, of 0.41 for oil on the asphalt and 0.44 for diesel on the concrete, are lower than the corresponding measurements on these surfaces when wet, but comparable with figures which may be found on other road surfaces that are wet. These figures may be surprising in view of the commonly held belief that spilt diesel fuel will make a road dangerously slippery, and that engine oil might make it more slippery still.

Unlike the results with the cars, the friction coefficients recorded with the PFT in the presence of contaminants are below the range of values expected from road surfaces in wet conditions and, in the worst case, are virtually zero. The comparison of the PFT results with those from the skid cars provides an indication of the relative influence of tyre condition and surface texture: this analysis shows that relatively high friction coefficients are recorded with the treaded tyres irrespective of the presence of the contaminant and the nature of the underlying surface, but that with the combination of the smooth tyre and the lower texture of the surface, even a relatively small quantity of contaminant reduces the friction coefficient.

The decrease in the friction coefficients in the presence of water, diesel and engine oil follows the same order as the increasing viscosity of the three liquids, suggesting that the surface texture is progressively less effective in cutting through the more viscous contaminants to maintain good friction. Notably, the tread on the tyres of the skid cars is more effective, maintaining friction levels above 0.4 in both cases.

The sand and clay contaminants were applied in thick layers in this investigation and, unsurprisingly, the underlying surface texture does not appear to influence the friction. Fluctuations were observed in

the detailed measurements that presumably result from unevenness in the consistency or rate of spread of the contaminant material, or from the material building up in front of the tyre until it is compacted sufficiently for the tyre to ride over it. In either case, the amount of fluctuation suggests that the friction values could be very dependent on the quantity and nature of the contaminant; the results of the two skid cars agree less well than was the case on the wet surfaces or with the liquid contaminants.

The proprietary absorbent appears to have performed well, absorbing the oil and diesel contaminants and giving improved friction while still spread over the road, and leaving better friction again after it had been swept away. After sweeping, the friction was still significantly less than that of the clean dry surfaces, but comparable with that of the wet surface. Conversely, sand applied in a thick layer gave low friction values even in the absence of contaminants.

The following conclusions have been drawn from this study:

- For small or medium sized cars with tyres in good condition, skidding on a surface with good skid resistance and moderate or high texture depth, friction coefficients above 0.4 could be expected for all the contaminants tested, even when spread copiously or in a thick layer. This performance is no worse than might be expected on many road surfaces when wet.
- The tyre tread is critically important to delivering this performance and, with smooth tyres, friction coefficients of practically zero can be observed in some circumstances. This worst-case scenario may apply even when the underlying surface is highly skid resistant and with a good texture depth.
- Other than the tyre tread, the important parameters influencing the result seem to be the viscosity of the liquid contaminants followed by the surface texture (with the engine oil - the most viscous contaminant - a virtually zero friction coefficient was recorded on a surface with good underlying surface texture).
- The performance of the proprietary absorbent material in clearing up the contamination was superior to that of sand.

It is not possible to define “good” tyre condition or surface condition from the work undertaken here; this could be the subject of further work, but given the number of factors it would be necessary to consider, it may not prove possible to define general values for the various contaminants for use in reconstructing the circumstances of accidents involving surface contamination.

The main implication of this work for highway authorities is that, given the worst-case scenario it is clearly important to avoid contamination or clear it up as quickly and effectively as possible. For areas where contamination may occur regularly, such as agricultural accesses or entrances to refuse disposal facilities, it is recommended that a regime of regular inspection and decontamination of the road surface be enforced. Where spillage of liquid contaminants is involved, it is recommended that a proprietary absorbent product is used to remove the contamination in preference to the use of sand for this purpose. Consideration should also be given to whether the risks to road users as a result of the presence of contamination could be mitigated by the use of warning signs or speed restriction.

1 Introduction

It is well known that the presence of contaminants in the tyre/road interface can reduce the friction generated between the tyre and the road. Water has a similar effect, which has been extensively investigated. Skidding on ice has also been studied extensively in northern European countries and America. However, the effect of contaminants such as mud, fuel and oil has not been quantitatively established, although there is extensive anecdotal evidence that their presence contributes to road slipperiness.

While such contamination is not common on most of the road network, there are places where contamination can occur regularly, as well as isolated cases of spillage. For example, contamination by mud or manure can be common at site accesses, farm entrances or crossings; drivers could therefore be warned of these and similar predictable occurrences if the effect on skid resistance was substantial enough to merit it. Conversely, isolated incidents such as fuel spillage could occur anywhere on the network. In either case, a sudden reduction in friction resulting from contamination could potentially contribute to a vehicle losing control while attempting to manoeuvre on a contaminated surface. Depending on the nature and quantity of the contaminant and the nature of the site (i.e. whether vehicles are likely to need to manoeuvre at that point) it could potentially pose a serious hazard to road users.

This report presents the results of an investigation into the effect of road surface contamination. This work was jointly funded by the Highways Agency and by the Institute of Traffic Accident Investigators. In addition, a substantial contribution of cleaning products and services was provided by Steetley Bentonite and Absorbents Ltd and the effect of their absorbent material on skid resistance was brought into the tests.

2 Equipment for full-scale tests

The contaminants selected for inclusion in the full-scale trials were diesel oil, engine oil and clay. These materials were selected on the basis of the results from previous laboratory tests carried out using a portable skid resistance (pendulum) tester on cores from road surfaces with a range of texture depths. Coarse sand was also included in the test programme. The measuring equipment used comprised a pavement friction tester, supplied by the Highways Agency, and two skid cars, supplied by the Suffolk Constabulary, described below. The test procedure and results are described in Sections 3 and 4.

2.1 Pavement Friction Tester

The Pavement Friction Tester (PFT) is a locked-wheel friction tester consisting of a towing vehicle and purpose built test trailer fitted, for this study, with ASTM standard smooth tyres (ASTM E524-88). This equipment is common in the United States and is used in England by the Highways Agency for research. It is shown in Figure A1. For each test, the vehicle was driven onto the test surface at the target speed and the test wheel brakes were applied, under computer control, until the wheel locked and for approximately 1 second afterwards. The vehicle speed, test wheel speed and the horizontal and vertical forces on the test wheel were recorded every 0.01 second during each test.

In standard operating conditions, water is applied in front of the PFT test tyre at a rate corresponding to a nominal water depth of 1mm. This system was used for some of the tests on wet surfaces but, in general, it was switched off.

For analysis, the peak friction and average locked wheel friction recorded over 0.5 second were reported. As the speed of the vehicle does not change significantly during the test, the locked-wheel friction coefficient is measured at one speed.

2.2 Skid cars

Two skid cars were used, a Peugeot 306 and a Ford Fiesta. For each test, the car was driven onto the test surface at the target speed and the brakes applied sharply until a stop was reached. The cars were fitted with normal road tyres, in roadworthy condition, and neither had anti-lock braking systems. Both cars were fitted with the SkidMan measuring system.

SkidMan records the deceleration (and therefore, by inference, the coefficient of friction) throughout the period of braking. It presents a plot of the deceleration as a function of time, together with figures for the peak and average deceleration. However, since the wheels of a skid car do not lock absolutely simultaneously, the peak coefficient of friction indicated by the SkidMan will tend to be a “smeared out” value for the individual wheels, and therefore tend to be somewhat less than the peak coefficient of a single tyre.

In addition to the Peugeot and the Fiesta, a Vauxhall Omega, with anti-lock brakes, was used in just one set of tests, on the asphalt contaminated with coarse sand.

3 Test procedure

3.1 Selection of test surfaces

Considerable difficulty was experienced in finding surfaces for testing due to the environmental and physical effects of the application of diesel and engine oil. The location eventually found was at Bentwaters Park, Suffolk, until recently a USAF base. The two surfaces on which measurements were made were the main asphalt runway and a concrete taxi-way. Both were in good condition, with good micro- and macro-texture, but the surface texture will not be directly comparable to that of normal road surfaces. The actual texture depth was not measured but, as the asphalt was constructed using a relatively coarse stone size it is likely to have a higher overall texture depth than the concrete surface.

Before embarking on the full programme of testing, tests in standard wet condition (1 mm water film at 20 km/h) were carried out on each surface with the PFT. In previous work it has been found that the coefficients of friction recorded in wet, 20km/h PFT tests are similar to SCRIM Readings[1] divided by 100 (Roe et al., 1998). Both surfaces yielded high locked-wheel friction values which were consistent across the length and width of the test surfaces, as shown in Table 3.1.

Table 3.1 Coefficient of friction measured by the PFT (standard wet condition)

Surface	Coefficient of friction	
	Mean	Standard deviation
Asphalt	0.65	0.02
Concrete	0.62	0.01

3.2 Test description

Skid resistance testing in the presence of contaminants was conducted on the two surfaces in April 2004. Temperatures during the tests were generally around 15°C.

For each set of tests on a surface in a particular condition, the test cars were driven at nominal approach speeds of 60 and 80 km/h, with a number of tests also being carried out at 40 km/h. The exact speeds were measured with a stationary radar device. Similarly, the PFT was operated at nominal speeds of 40 and 60 km/h, with a few tests at 80 km/h. In each case, the measurement was completed within the length of the surface to which the contaminant had been applied.

The surfaces were tested in the following conditions:

- Dry and uncontaminated
- Wet, either sprayed by fire hose, or by steady rain, or, for some of the tests with the PFT, wetted by the PFT's on board system
- Saturated with used engine oil (asphalt only) or diesel oil (concrete only)
- The same, with absorbent material spread liberally over the oil

[1] Values of skid resistance measured by a SCRIM under standard test conditions (BS 7941-1:1999).

- The same, after the absorbent material had been swept away
- Diesel oil and rain water (concrete only)
- Heavily coated with coarse wet clay
- The same, after the clay had been swept away
- Coarse sand

3.3 Notes on tests with each contaminant

3.3.1 Engine oil

This was used waste engine oil. It was spread liberally onto the asphalt surface: however, a consistent thickness of coating could not be maintained. Figure A2 shows it being spread.

3.3.2 Diesel oil

This was ordinary diesel fuel, and was poured liberally over the concrete surface (Figure A3). Again, the depth of contaminant varied somewhat during the tests.

3.3.3 Absorbent

This was Steetley diatomaceous earth, a naturally occurring material composed of the fossil remains of microscopic organisms (diatoms). Because of the large surface areas and cavities within the particles, this material is highly absorbent. It was spread copiously over the area that had previously been contaminated with diesel or engine oil, following the recommended procedure for use. A photomicrograph of the material is shown in Figure A4, while A5 shows it spread on the engine oil, together with the Peugeot skid car.

3.3.4 Clay

Clay was dug from the Bentwaters site and deposited thickly on the test surfaces. It rained throughout the tests on this material, and it was therefore additionally wetted. Figure A6 shows it spread on asphalt, together with the Ford skid car.

3.3.5 Sand

Coarse sand was made available with the intention of using it simply on a run-off area for the testing devices to absorb some of the contaminant on the tyres. In the event it was decided to use it as another contaminant in the testing, and it is shown, with brake marks from the skid cars, in Figure A7.

4 Results and analysis

4.1 General remarks

Results are presented below for the PFT and the skid cars as plots of peak and sliding coefficients of friction versus speed. It should be remembered that for the PFT the speed is consistent throughout the test, whereas for the skid cars it is the speed from which the vehicles slid to a halt. Therefore, in those circumstances where the deceleration of the cars exhibits a dependence on speed, the figures plotted will be an average value for the braking sequence rather than the value at the plotted speed.

Although the results from the skid cars are plotted separately, it will be seen that there is barely any difference between them. The data, therefore, which emerge from these tests are figures for the coefficient of friction of the different surface conditions, the difference between the cars and the PFT in the various conditions, and the dependence of the friction coefficient on speed.

4.2 Results for each surface and condition

4.2.1 Asphalt and concrete surfaces, dry

Tests with both skid cars on the two test surfaces in the dry condition produced high and essentially speed-independent results. On the asphalt the average peak coefficient was 0.79, with a range of ±0.03, while the average sliding coefficient was 0.78 with a range of ±0.04. On the concrete the peak was 0.88 ±0.03 and the sliding figure was 0.85 ±0.05.

The friction proved too high for the PFT to be able to lock the test wheel and it was therefore not possible to record any results.

4.2.2 Asphalt and concrete surfaces, wet

Figure 4.1 shows the results on the asphalt and concrete when wet. The figures for sliding friction on asphalt are high and very similar for all three devices, being in the region of 0.6 to 0.7, with the Peugeot giving the lowest values and the PFT the highest. There is very little tendency for the coefficient to decline as the speed increases. The similarity of the PFT values to those from the cars, and the lack of speed dependency in the PFT results were unexpected in view of the fact that the tyre on the PFT was smooth, and must be a reflection of the good texture of the surface.

On wet concrete, the cars again give similar results to one another, with figures very similar to those on asphalt. In this case the two sets of data recorded with the PFT are distinctly different. One dataset declines linearly with increasing speed from about 0.6 at 20 km/h to about 0.3 at 80 km/h: these points were measured where the surface was wetted by the on board system. The speed dependent behaviour and the friction values are consistent with past experience of smooth tyre tests with this equipment on lower textured surfaces (Roe et al., 1998). The other points, all at around 0.5, are more similar to, but somewhat lower than the values recorded by the skid cars. These were measured after the surface had been wetted with fire hoses: absence of a decline at higher speeds may well be the result of the rapid draining of the water from the surface.

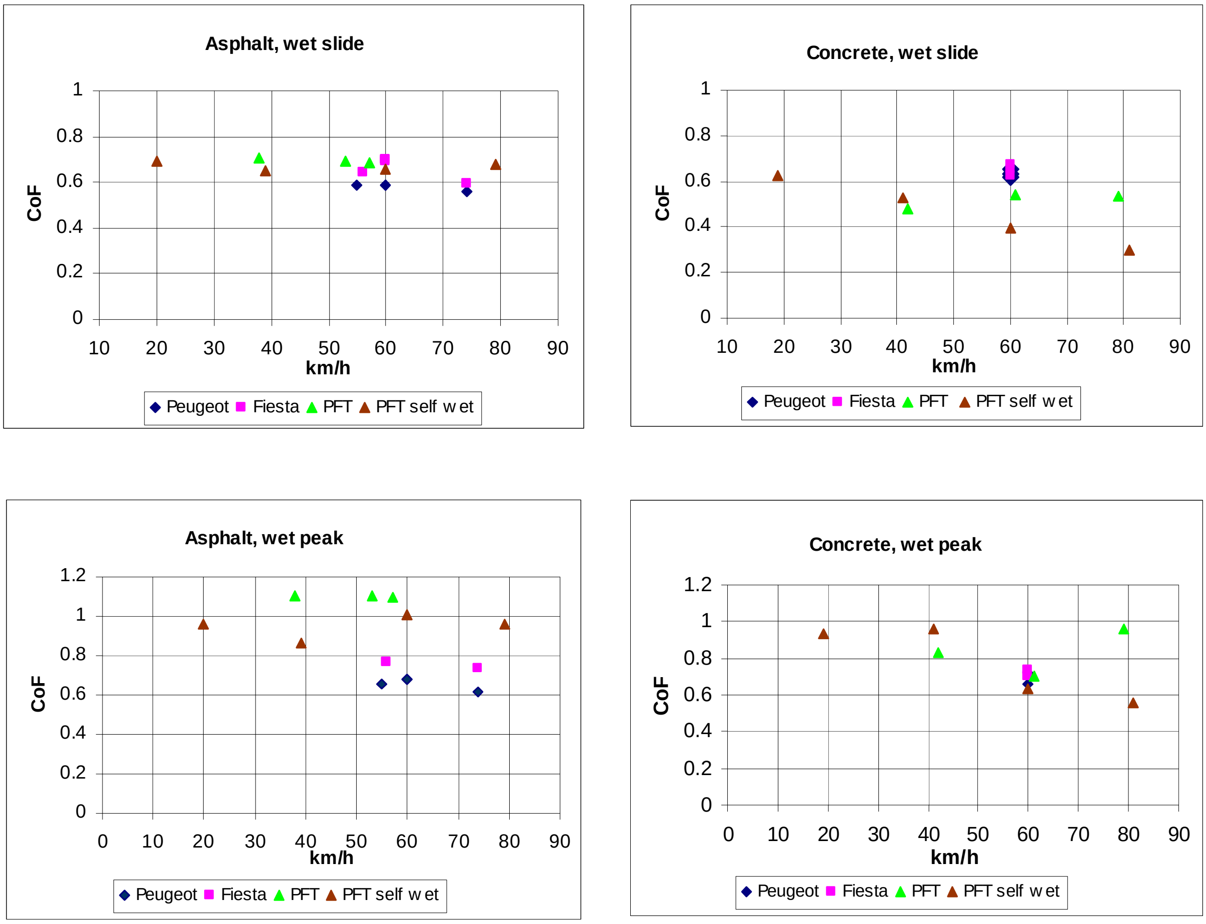

Figure 4.1 Coefficients of friction on wet asphalt

Examining the peak friction values, the skid cars are again very similar, with figures between 0.6 and 0.8 on both surfaces. The PFT shows values noticeably higher on the asphalt and at low speed on the concrete, in the region of 1.0. The lower values recorded by the skid cars are presumably a result of the “smearing out” of the peak friction described in 2.2. The decline in peak friction values recorded by the PFT at higher speeds again is consistent with previous tests on low textured materials (Viner et al., 2000).

The dependence on speed of the deceleration of the skid cars is illustrated in Figure 4.2. This shows the well-known tendency of the friction on a wet surface to increase as the speed decreases. In this particular example, the increase is from about 0.55 (at 60 km/h) to about 0.75. The average sliding value from this test was 0.59, while the peak was calculated as 0.68.

The PFT graph from a corresponding test is shown in Figure 4.3. The peak observed in the friction trace is higher and broader than the corresponding skid car result and, because the vehicle tows the test trailer at a constant speed during the test, the sliding friction also remains constant during the test.

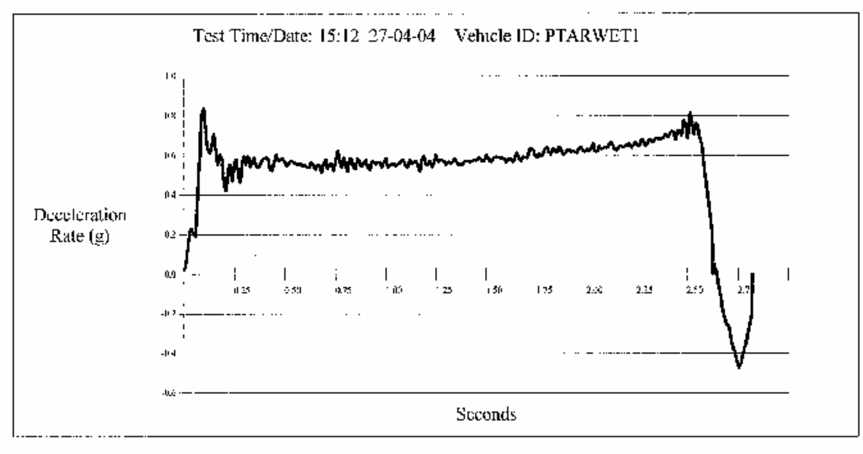

Figure 4.2 SkidMan graph for Peugeot sliding to a halt from 60 km/h on wet asphalt

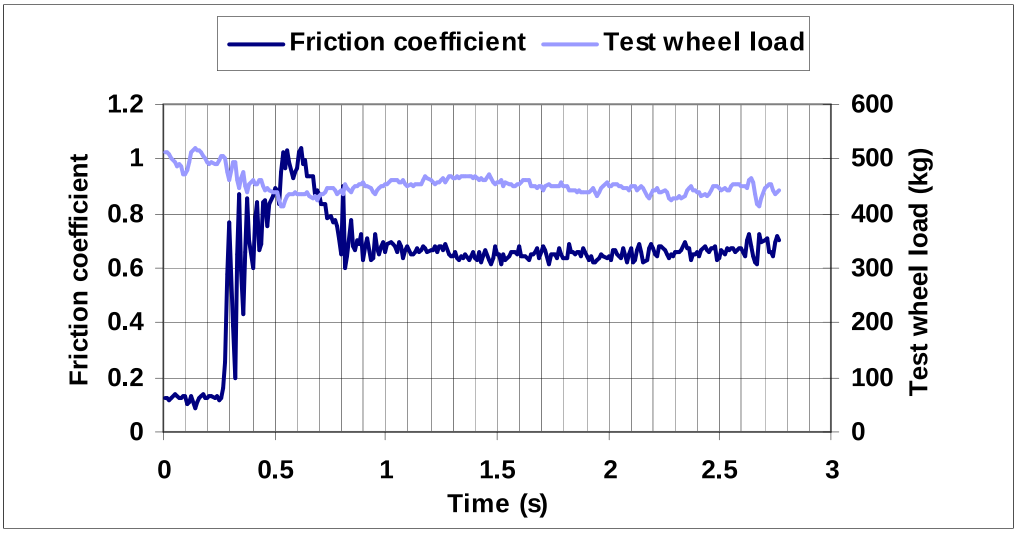

Figure 4.3 PFT graph for 60km/h test on wet asphalt

4.2.3 Asphalt, waste engine oil

Figure 4.4 shows the results on the asphalt after coating with waste engine oil. Although less than the coefficients found on the wetted surface, the values from the skid cars, at 0.4 to 0.5, are not remarkably low, and still amount to a firm level of braking. However, the PFT values for sliding friction are essentially zero.

There was little or no dependence of skid car deceleration on speed (unlike the situation with water), and Figure 4.5 shows an example SkidMan trace. The PFT trace in Figure 4.6 confirms the extremely low sliding friction observed.

After the oil-contaminated asphalt surface was spread with diatomaceous earth absorbent, the skid car friction coefficients increased to around 0.55 (both peak and slide), while the PFT values, although still less than those for the cars, had increased to around 0.3 to 0.4. Again, with the cars, there was negligible dependence of the coefficient on speed.

Figure 4.4 also shows the values measured after the absorbent material had been swept away with brooms. In these tests the PFT values have increased markedly, and are now similar to those for the cars. The slide values for the cars, however, are little different from the preceding oil-plus-absorbent condition, lying between 0.50 and 0.65: this may be compared with the range of about 0.75 to 0.80 found on the clean dry surface and 0.60 to 0.70 on the wet surface.

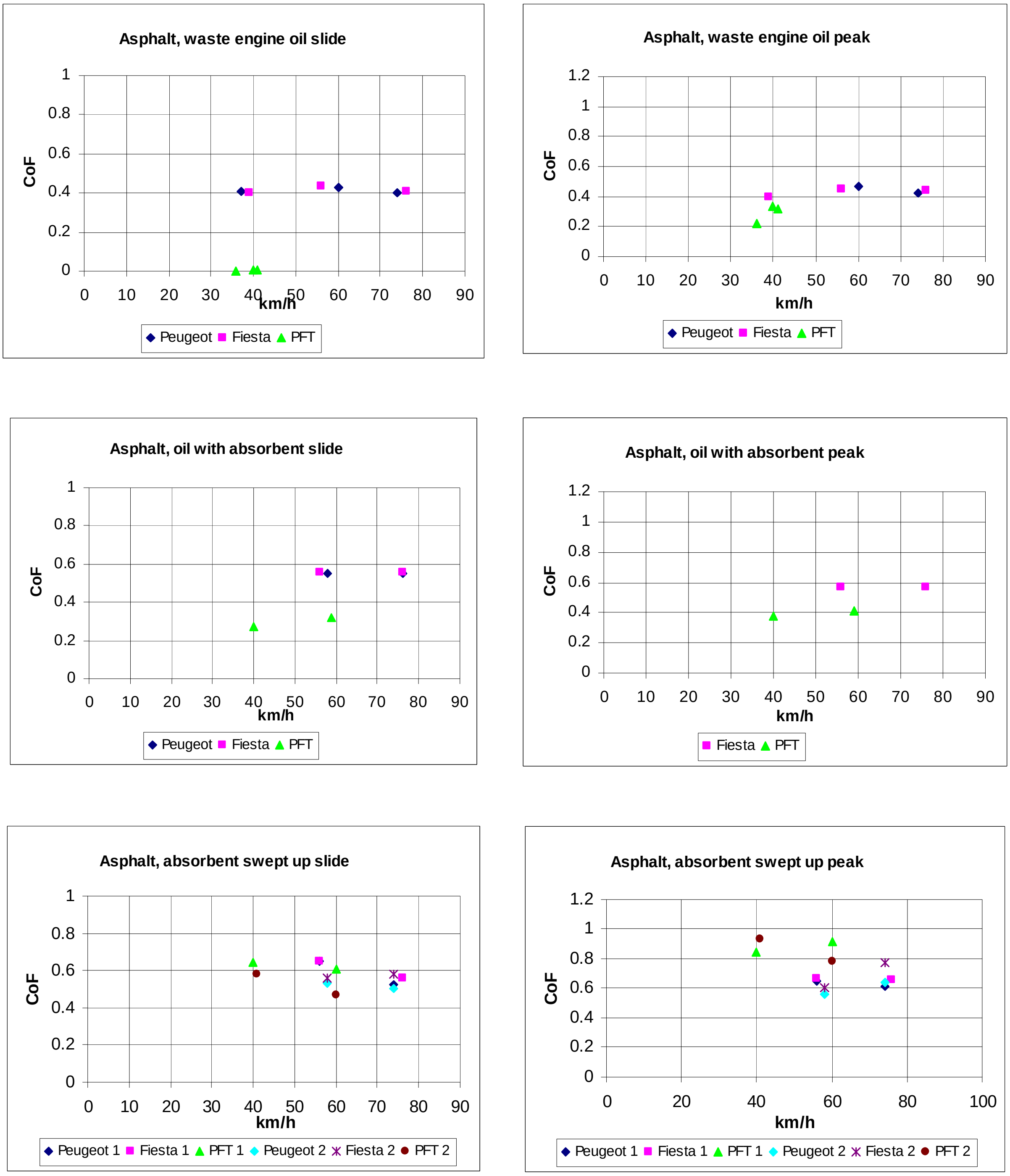

Figure 4.4 Coefficients of friction on asphalt with waste engine oil

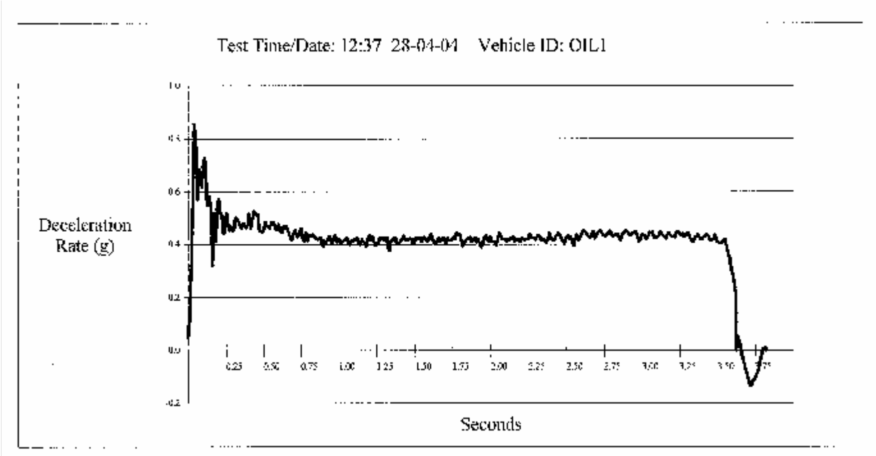

Figure 4.5 SkidMan graph for Fiesta sliding to a halt from 60 km/h on asphalt contaminated with waste engine oil

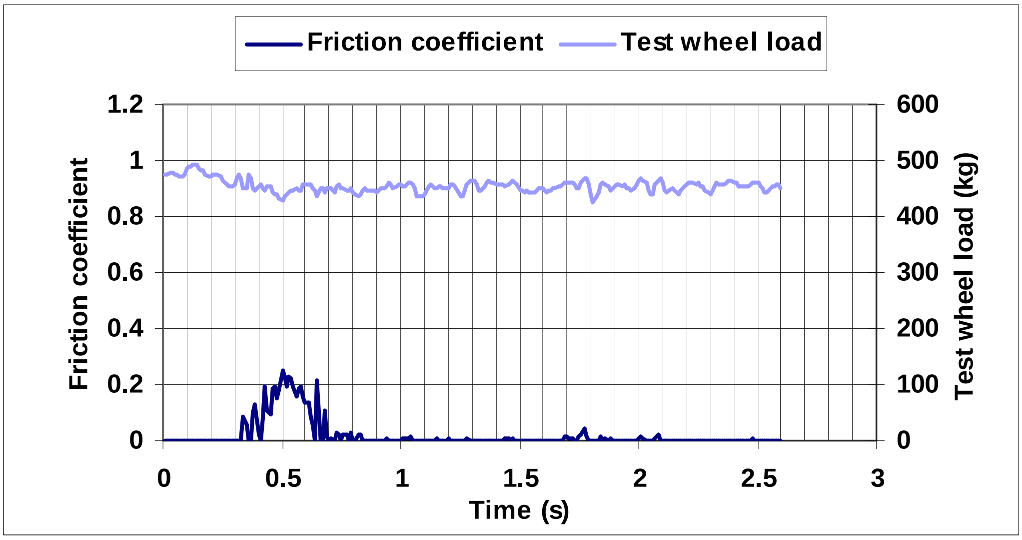

Figure 4.6 PFT graph for 35km/h test on asphalt contaminated with waste engine oil

4.2.4 Concrete, diesel

Figure 4.7 shows the results on concrete when covered with diesel fuel. As was the case with the oil on asphalt, the friction recorded by the skid cars is less than in the wetted condition, but not markedly low, with both peak and sliding friction coefficients in the region of 0.4 to 0.5. The PFT figures for sliding friction are substantially less than those for the skid cars but not vanishingly small, as was the case with the oil on the asphalt. The peak figures are very similar to those of the skid cars (unlike the finding of oil on asphalt), but given the difference between the measurement of peak friction by the skid cars and with the single PFT tyre (see 2.2) this is probably coincidental.

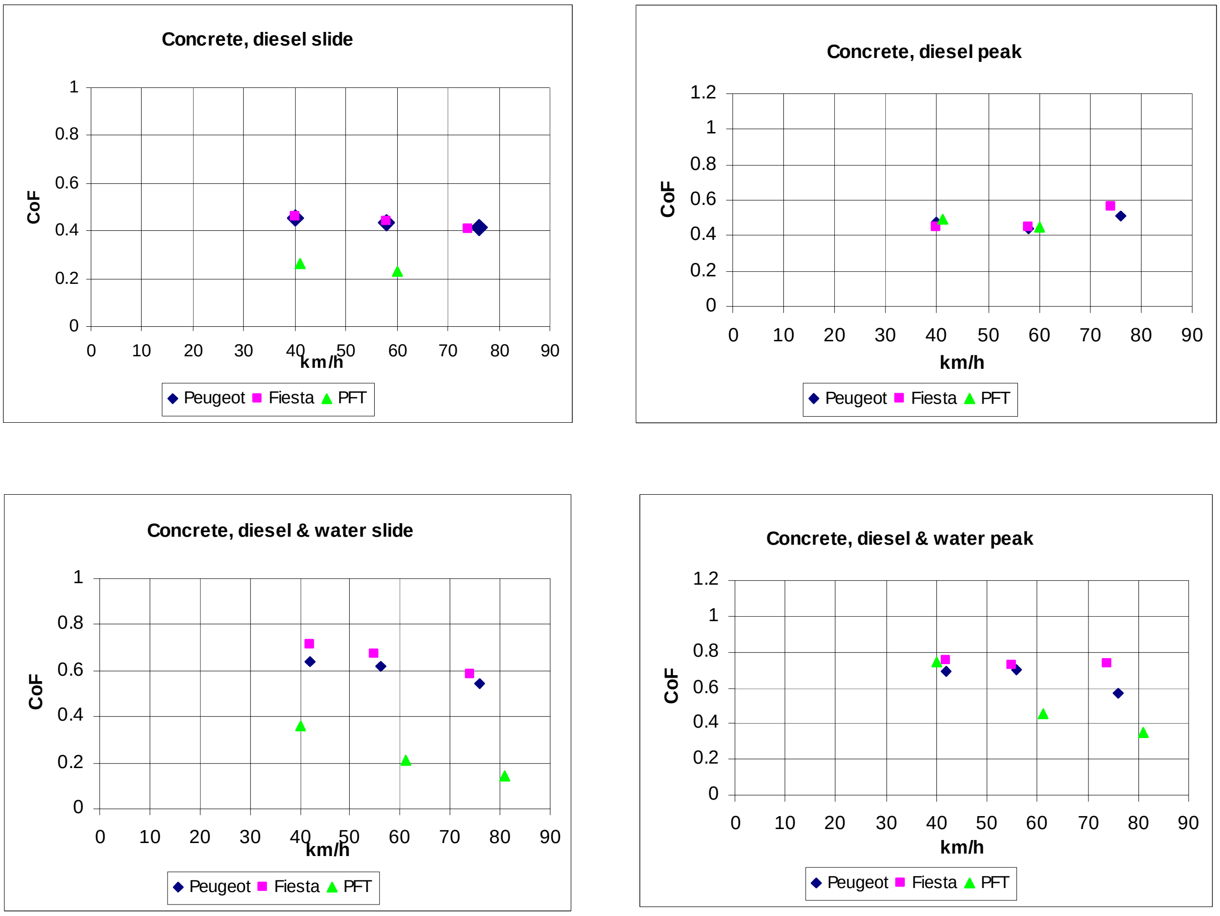

Figure 4.7 Coefficients of friction on concrete covered with diesel fuel

The skid cars show a decrease in friction with increasing target speed but, curiously, this is not reflected by the deceleration within the individual tests, where there was essentially no speed dependence. Figure 4.8 shows the SkidMan plot for the Peugeot braking to a halt from 60 km/h. Both the SkidMan plot and the PFT graph in Figure 4.9 are noticeably more noisy than for the other liquid contaminants, possibly indicating that the diesel has less of a lubricating effect than either waste engine oil or water.

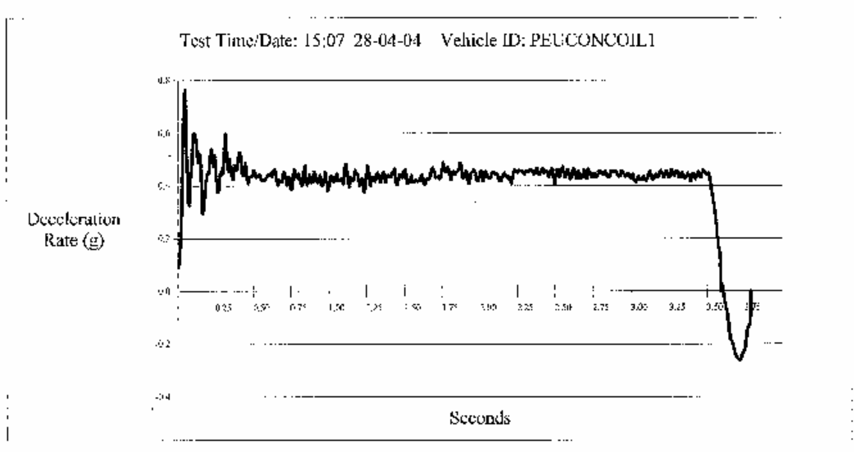

Figure 4.8 SkidMan graph for Peugeot sliding to a halt from 60 km/h on concrete covered with diesel fuel

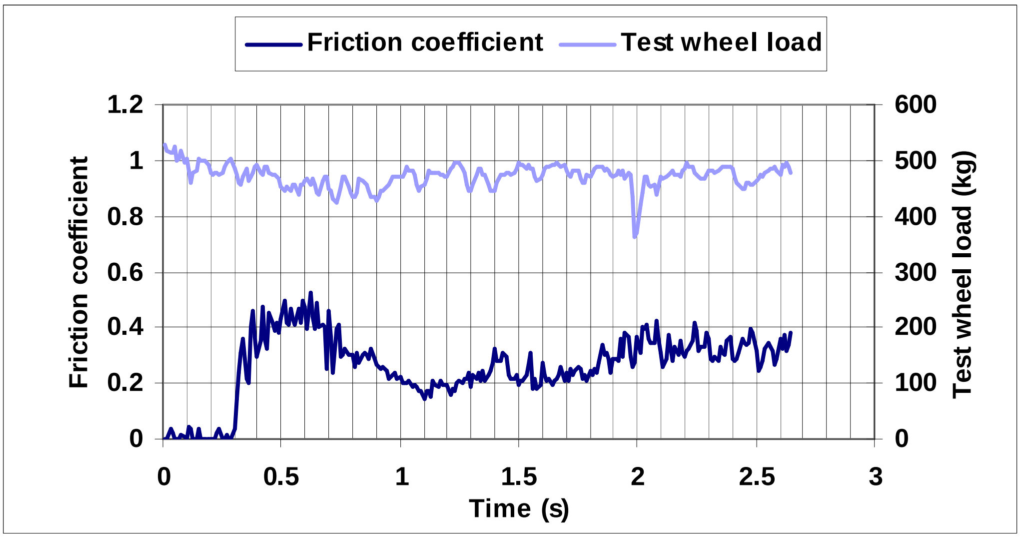

Figure 4.9 PFT graph for 60km/h test on concrete contaminated with diesel

Figure 4.10 shows the results when the diesel contaminated concrete surface is spread with diatomaceous earth absorbent.

The skid car coefficients have increased to around 0.55 (both peak and slide), while the PFT values have increased to levels a little above those for the cars, to about 0.55 to 0.6. Again, with the cars, there was negligible dependence of the coefficient on speed.

After the absorbent material had been swept away with brooms, the PFT values have increased, and are now well above those for the cars. The slide values for the cars have also increased, lying between 0.60 and 0.70: this may be compared with the range of about 0.80 to 0.90 found on the clean dry surface and 0.55 to 0.70 on the wet surface.

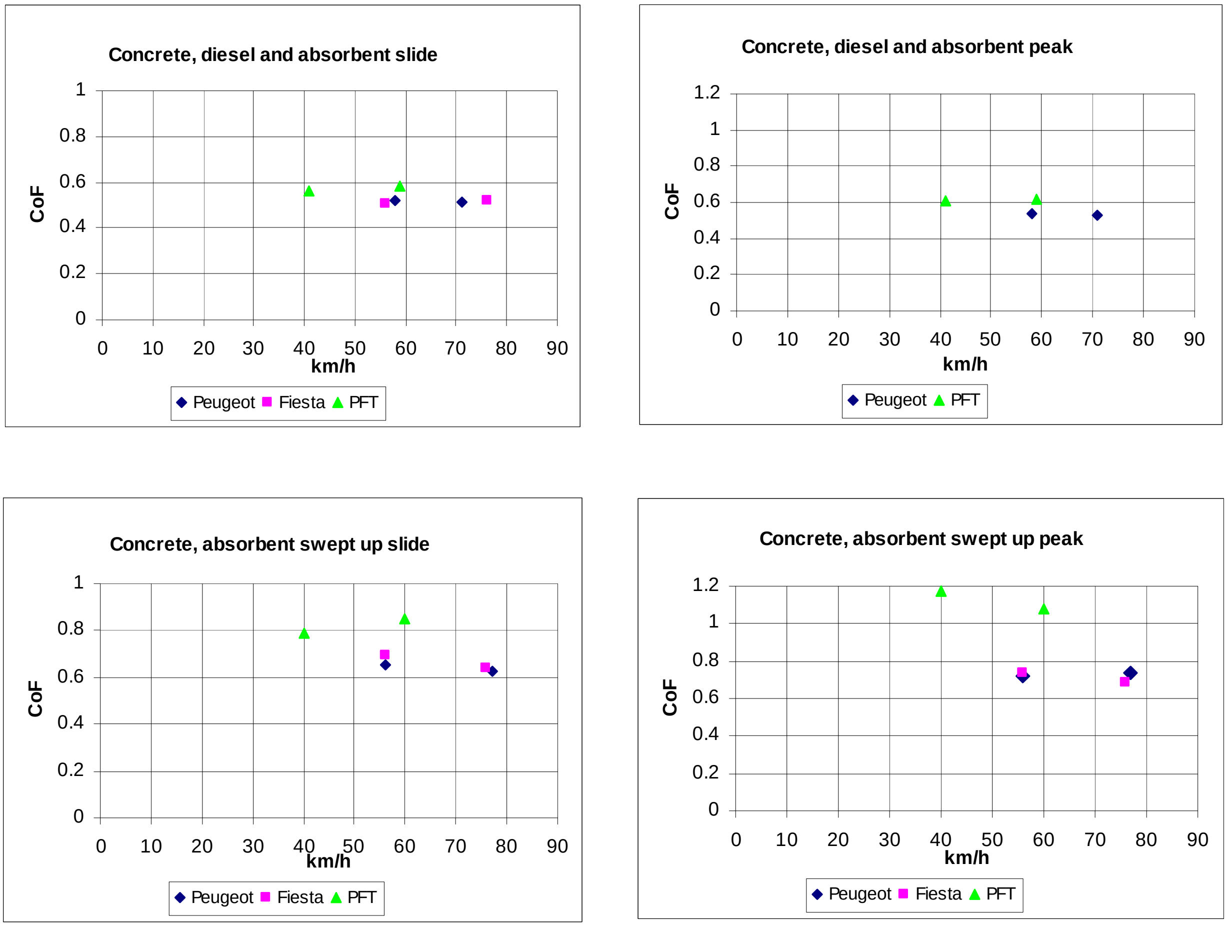

Figure 4.10 Coefficients of friction on concrete covered with diesel fuel and absorbent

4.2.5 Asphalt, clay

Figure 4.11 shows the values measured on asphalt when covered with wet clay. The results are rather erratic, due, no doubt, to the irregular nature of the contaminant. Figure 4.12, for example, shows how the deceleration varied during the braking of the Fiesta from 80 km/h. Again, it can be seen that the friction, with sliding values of around 0.5, and lower than the wet friction on this surface, is not markedly low. Figure 4.13 shows the variation in friction observed during a PFT test on the wet clay. The spikes in friction observed at around 0.5s coincide with variations in the test wheel load, presumably as a result of lumps in the clay, but the variation in friction coefficient between 1s and 2.5s must indicate a variation in the friction characteristics of the clay since the test wheel load remains constant.

The results found after sweeping the clay off the asphalt for the skid cars are very close to those found with the wet asphalt, while the figures from the PFT appear to be a little lower (notably the sliding value at 60 km/h).

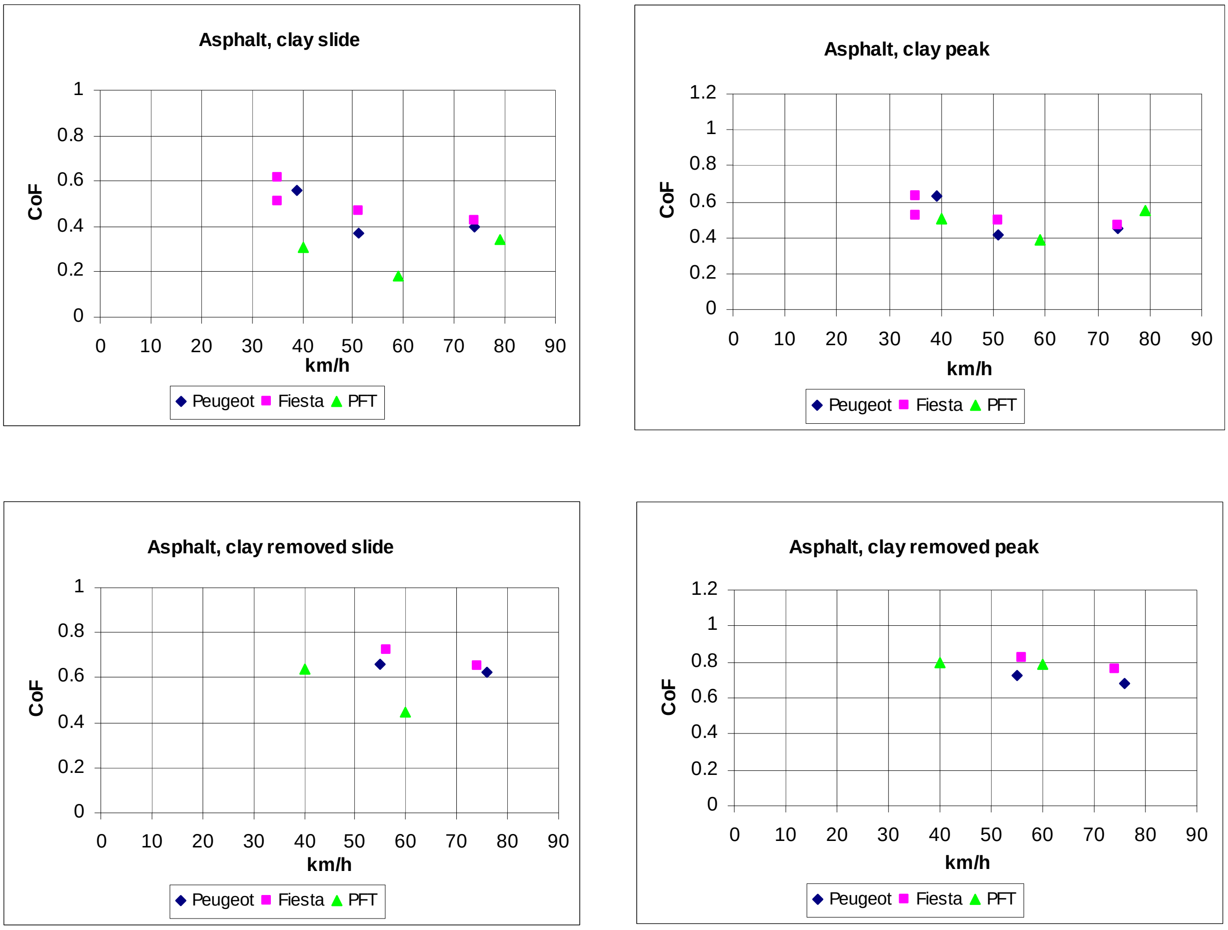

Figure 4.11 Coefficients of friction on asphalt covered with wet clay

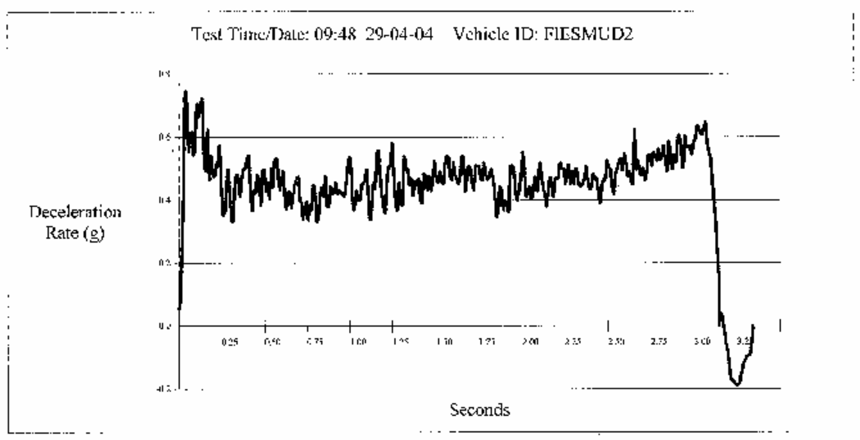

Figure 4.12 SkidMan graph for Fiesta sliding to a halt from 60 km/h on asphalt covered with wet clay

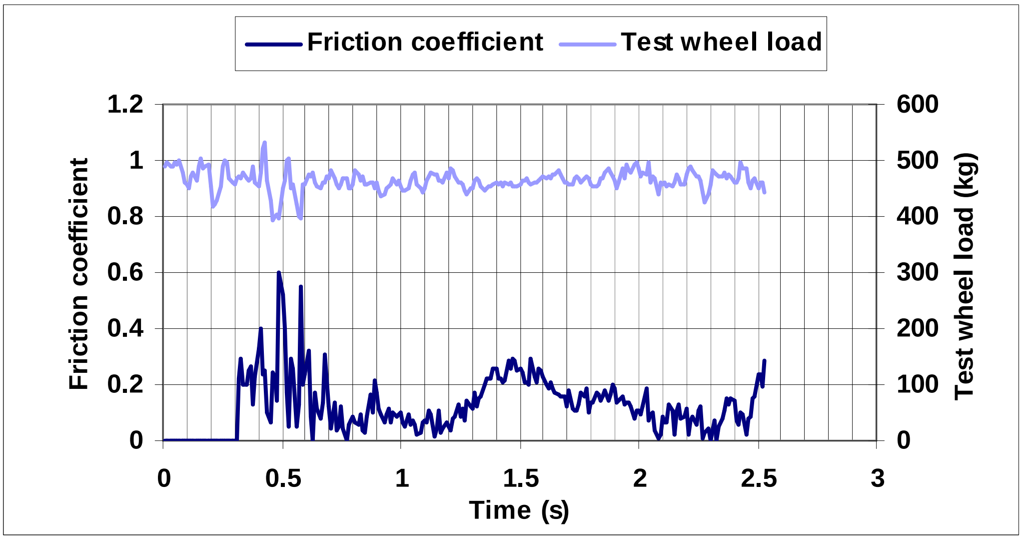

Figure 4.13 PFT graph for 60km/h test on asphalt contaminated with clay

4.2.6 Concrete, clay

Figure 4.14 shows the values measured on concrete when covered with wet clay. The results are, again, rather erratic, but are comparable to the asphalt. This is unsurprising since the clay was applied in a layer thick enough to mask the characteristics of the underlying surface.

After sweeping the clay off the concrete, the results for the skid cars are close to those found with the wet concrete; a similar result to that found on the asphalt. However, the figures from the PFT remain low, at values similar to those on the fully clay-contaminated surface. The greater effect that the remaining clay has on the friction coefficients for the concrete surface, in comparison with the PFT results on the asphalt after the clay was removed, probably reflects the combination of the smooth test tyre with the lower texture of the surface.

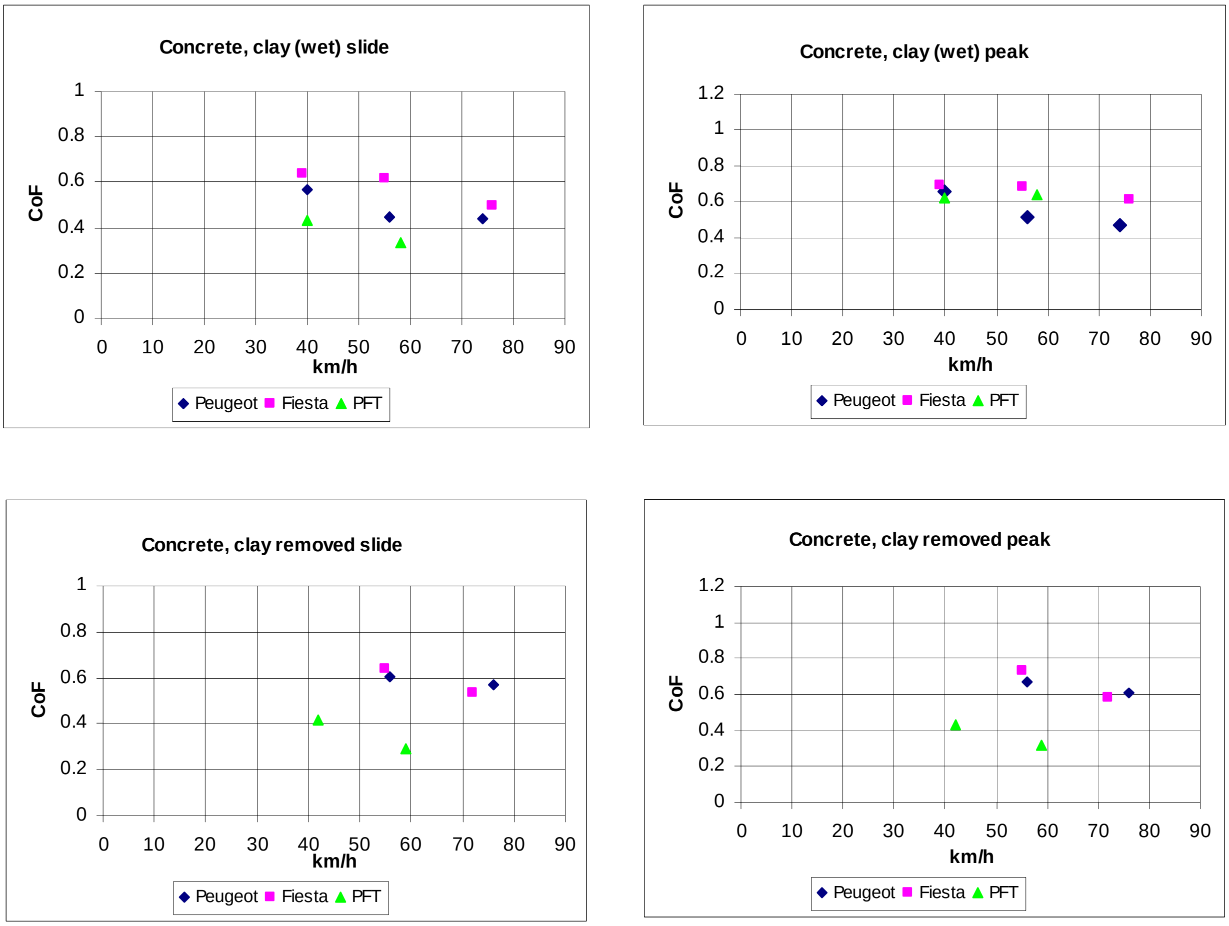

Figure 4.14 Coefficients of friction on concrete covered with wet clay

4.2.7 Asphalt, coarse sand

Figure 4.15 shows the values measured on asphalt when covered with coarse sand. In addition to the PFT and the skid cars, this surface was also tested with a Vauxhall Omega car fitted with anti-lock brakes.

The sliding and peak friction values for the Peugeot and Fiesta are similar, and above 0.5; slightly lower values were obtained from the Omega. However, the PFT shows lower values, around 0.2.

With the skid cars there was no apparent dependence of deceleration on speed, and Figure 4.16 shows the SkidMan graph for the Peugeot braking from 60 km/h. Figure 4.17 shows that, as for the PFT test on clay, there is a variation in test wheel load that appears to coincide with variation in friction coefficient. Since the sand was not lumpy when spread, a possible explanation could be that it builds up in front of the locked, smooth tyre until it is compacted to an extent that the tyre is able to ride over it, causing the variation in wheel load.

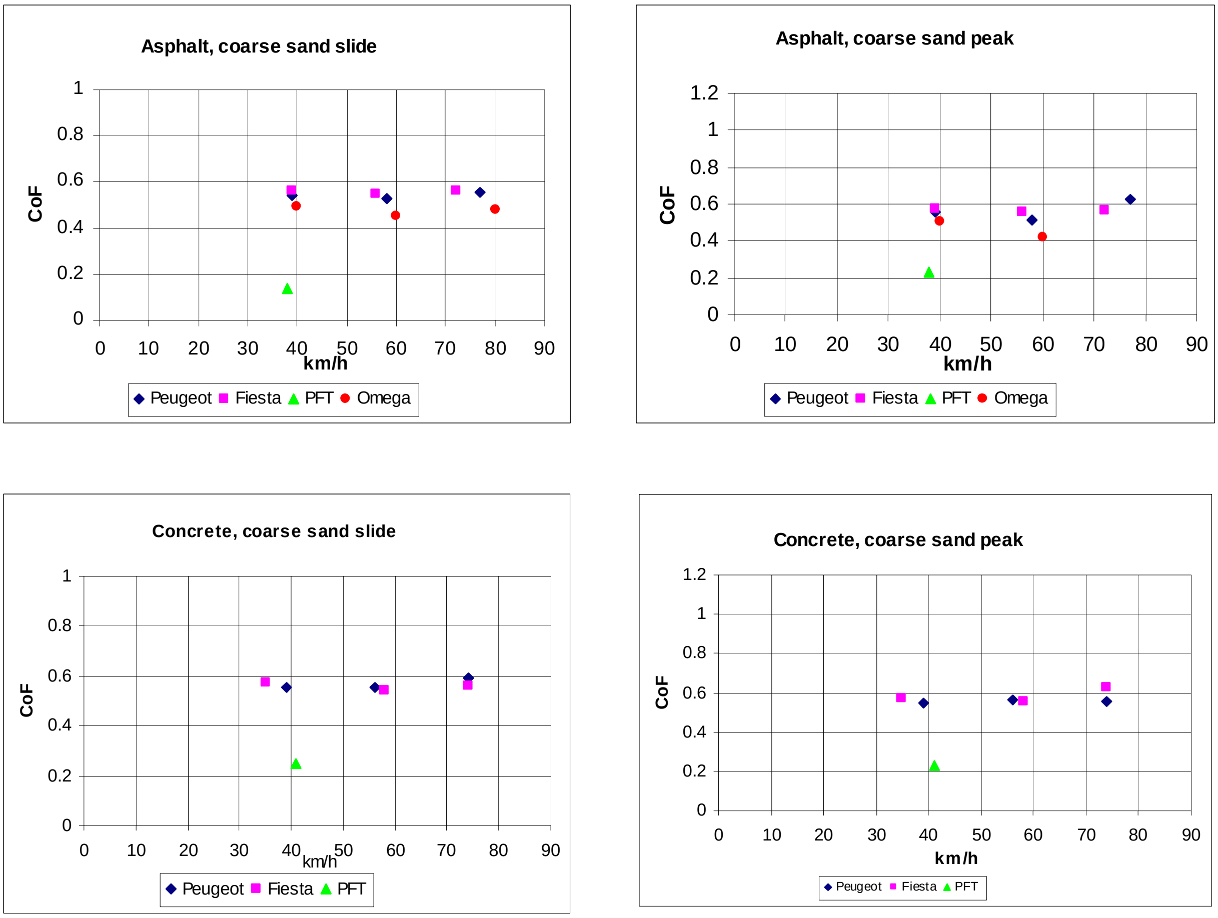

Figure 4.15 Coefficients of friction on asphalt and concrete covered with coarse sand

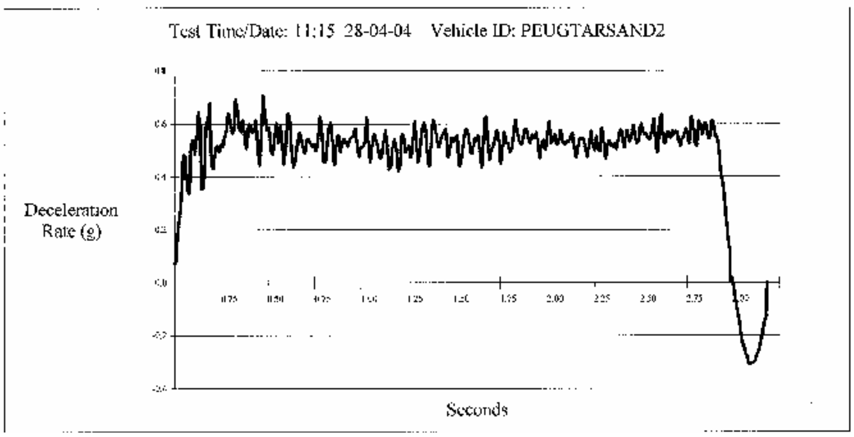

Figure 4.16 SkidMan graph for Peugeot sliding to a halt from 60 km/h on asphalt covered with coarse sand

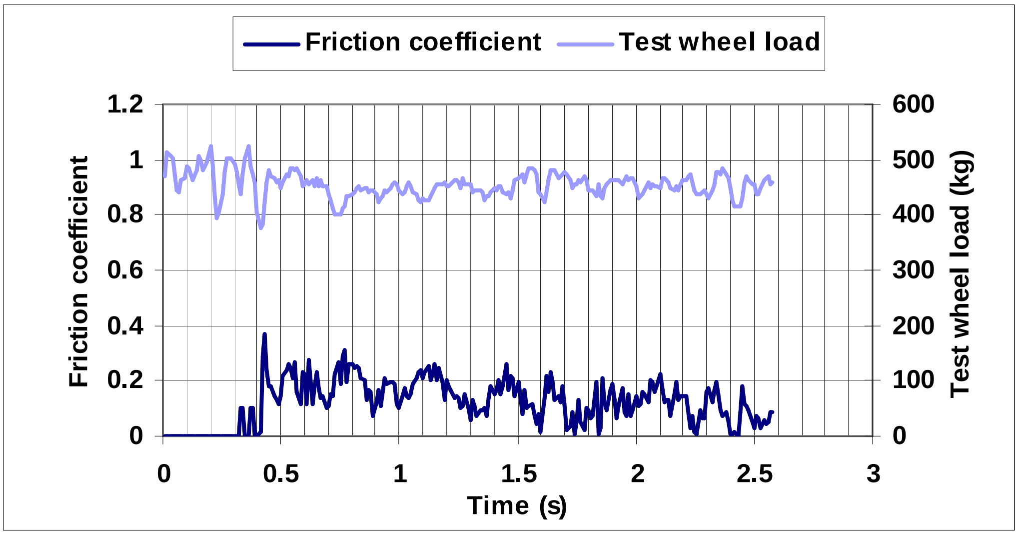

Figure 4.17 PFT graph for 60km/h test on asphalt contaminated with sand

5 Summary and discussion of results

The results presented in Section 4 are broadly summarised in Table 5.1 where the locked-wheel results from the two skid cars and from the PFT are averaged for all the results obtained from the tests on each surface condition.

Table 5.1 Averaged locked wheel coefficients of friction

Surface condition	Asphalt surface		Concrete surface	
	Skid cars	PFT	Skid cars	PFT
Dry	0.78	N/A	0.85	N/A
Wet	0.64	0.68	0.64	0.52†
Waste engine oil	0.41	0.01	-	-
Engine oil & absorbent	0.55	0.30	-	-
Oil & absorbent swept off	0.57	0.58	-	-
Diesel oil	-	-	0.44	0.24
Diesel oil & absorbent	-	-	0.52	0.57
Diesel & absorbent swept off	-	-	0.65	0.82
Diesel and rain water	-	-	0.63	0.24
Wet clay	0.48	0.28	0.54	0.38
Wet clay swept off	0.66	0.54	0.59	0.36
Coarse sand	0.52	0.14	0.56	0.25

†Value for pre-wetted tests only. Value including self-wetted tests is 0.48.

This summary of the data is crude in that it ignores any speed dependency of the coefficient of friction but it nevertheless brings out how, for the case of the skid cars, the reduction in friction with the contaminants, as compared to the dry and wet conditions, is clear but modest. The lowest figures, of 0.41 for oil on the asphalt and 0.44 for diesel on the concrete, are lower than the corresponding measurements on these surfaces when wet (both 0.64), but comparable with figures which may be found on other road surfaces that are wet. These figures may be surprising in view of the commonly held belief that spilt diesel fuel will make a road dangerously slippery, and that engine oil might make it more slippery still.

The good agreement observed between the results obtained with the Peugeot and Fiesta suggests that these values will provide a fair indication of the level of braking that may be achieved by a small or medium-sized car with tyres in good condition on a surface in good condition (i.e. with high skid resistance and with good or moderate texture depth). However, it should be noted that this study did not include a systematic study of the effect of the quantity of contaminant or the effect of the surface characteristics to be confident that these values would hold in all conditions.

Unlike the results with the cars, the friction coefficients recorded by the PFT in the presence of contaminants are below the range of values expected from road surfaces in wet conditions. Previous measurements made on a wide range of wet surfaces with good texture depth show friction values ranging from between 0.4 and 0.6 at a test speed similar to the tests in this study, with values down to 0.3 for surfaces with lower texture (Roe et al, 1998).

The comparison of the PFT results with those from the skid cars provides an indication of the relative influence of tyre condition and surface texture. The sliding friction coefficients obtained from the skid cars and the PFT on the wet asphalt surface are broadly similar, implying that there is enough texture present on the road surface for the lack of tread on the PFT test tyre not to influence the results to a great extent. On the concrete surface, the PFT results are somewhat lower than the skid cars, suggesting that the lower texture is significant. These results are consistent with earlier observations of the difference between PFT tests using smooth and ribbed tyres (Viner et al., 2000).

The sliding friction results from the skid cars and the PFT are also broadly similar when the surfaces are swept clean of contaminant. However, it is noteworthy that, for the PFT tests with clay on the asphalt surface, the friction improves to a level similar to the skid cars when the clay is swept off, but this is not the case on the concrete surface. This again suggests that, with the combination of the smooth tyre and the lower texture of the surface, even a relatively small quantity of contaminant can influence the friction. In both cases (on the wet surface and with the clay swept off), the friction improves with either more surface texture or treaded tyres. However, this does not appear to hold for the case of the concrete after removal of the diesel: the PFT results after the diesel oil and absorbent were removed were almost as high as on the dry surface, but this may be the result of a chemical interaction between the diesel and the concrete surface.

Given the similarity in the results from the skid cars and PFT on the wet asphalt and the modest reduction in friction on wet concrete with the smooth tyre, the substantially lower values recorded by the PFT with the diesel (on concrete) and oil (on asphalt) is interesting. The decrease in the friction coefficients in the presence of water, diesel and engine oil follows the same order as the increasing viscosity of the three liquids. It suggests that, with the progressively greater viscosity of the liquid contaminants, the surface texture is progressively less effective in cutting through the contaminant to maintain good friction. Notably, the tread on the tyres of the skid cars is more effective, maintaining friction levels above 0.4 in both cases. If the viscosity is, indeed, the property influencing this behaviour, then the effects might also be expected to be temperature dependent.

The sand and clay contaminants were applied in thick layers in this investigation and so it is not surprising that the effect of the underlying surface texture does not appear to influence the friction: similar values, within 0.1, were recorded on asphalt and concrete by each of the test devices. The average values in Table 5.1 presumably characterise the combination of the tyre and the amount and consistency of contaminant, without the added influence of the underlying road surface texture. The fluctuations observed in the deceleration of the skid cars and in the PFT friction vs. time trace during these skids presumably results from unevenness in the consistency or rate of spread of the contaminant material. Alternatively, it is possible that material builds up in front of the tyre until it is compacted sufficiently for the tyre to ride over it. In either case, the amount of fluctuation suggests that the friction values could be very dependent on the quantity and nature of the contaminant; the results of the two skid cars agree less well than was the case on the wet surfaces or with the liquid contaminants.

The diatomaceous earth absorbent appears to have performed well, absorbing the oil and diesel contaminants and giving improved friction while still spread over the road, and leaving better friction again after it had been swept away. After sweeping, the friction was still significantly less than that of the clean dry surfaces, but comparable with that of the wet surface. Conversely, sand applied in a thick layer gave low friction values even in the absence of contaminants. Therefore, the use of proprietary materials for removing contamination appears to be preferable.

6 Conclusions and recommendations

The following conclusions have been drawn from this study:

- For small or medium sized cars with tyres in good condition, skidding on a surface with good skid resistance and moderate or high texture depth, friction coefficients above 0.4 could be expected for all the contaminants tested, even when spread copiously or in a thick layer. This performance is no worse than might be expected on many road surfaces when wet.
- The tyre tread is critically important to delivering this performance and, with smooth tyres, friction coefficients of practically zero can be observed in some circumstances. This worst-case scenario may apply even when the underlying surface is highly skid resistant and with a good texture depth.
- Other than the tyre tread, the important parameters influencing the result seem to be the viscosity of the liquid contaminants followed by the surface texture (with the most viscous contaminant a virtually zero friction coefficient was recorded on a surface with good underlying surface texture).
- The performance of the proprietary absorbent material in clearing up the contamination was superior to that of sand.

It is not possible to define “good” tyre condition or surface condition from the work undertaken here; this could be the subject of further work, but given the number of factors it would be necessary to consider, it may not prove possible to define general values for the various contaminants for use in reconstructing the circumstances of accidents involving surface contamination.

The main implication of this work for highway authorities is that, given the worst-case scenario it is clearly important to avoid contamination or clear it up as quickly and effectively as possible. For areas where contamination may occur regularly, such as agricultural accesses or entrances to refuse disposal facilities, it is recommended that a regime of regular inspection and decontamination of the road surface be enforced. Where spillage of liquid contaminants is involved, it is recommended that a proprietary adsorbent product is used to remove the contamination in preference to the use of sand for this purpose. Consideration should also be given to whether the risks to road users as a result of the presence of contamination could be mitigated by the use of warning signs or speed restriction.

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References

ASTM E524-88. Standard specification for standard smooth tire for pavement skid-resistance tests. American Society for Testing and Materials, West Conshohocken, USA.

BS 7941-1:1999. Methods for measuring the skid resistance of pavement surfaces – Part 1: Side-way force coefficient routine investigation machine. British Standards Institution, London.

Roe P G, A R Parry and H E Viner (1998). High and low speed skidding resistance: The influence of texture depth. TRL Report 367. Crowthorne, Transport Research Laboratory.

Viner H E, P G Roe, A R Parry and R Sinhal (2000). High and low-speed skidding resistance: the influence of texture on smooth and ribbed tyre friction. Fourth International Conference on Pavement Surface Characteristics of Roads and Airfields. Nantes, France, 22-24 May 2000.

Appendix A. Photographs

Figure A1 KJ Law Pavement Friction Tester on the Asphalt Surface

Figure A2 Waste Engine Oil being spread on Asphalt

Figure A3 Diesel Oil being spread on Concrete

Figure A4 Photomicrograph of Steetley Diatomaceous Earth

Figure A5 Absorbent spread over engine oil, together with Peugeot skid car

Figure A6 Clay on Asphalt, with Ford skid car

Figure A7 Coarse sand on Asphalt (with braking marks from skid cars)