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Comparison of motorcycle and car tyre/road friction

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Transport Research Laboratory

PROJECT REPORT PPR 496

Comparison of motorcycle and car tyre/road friction

by R F Lambourn (TRL) and A Wesley (TRL)

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Executive summary

It is frequently asserted by accident investigators that sports or "performance" motorcycle tyres have a higher friction than car tyres. There has long been a pressing need for firm data on this point, both to ensure the accuracy of accident investigators' conclusions and also to improve the knowledge of safety researchers. This project has looked for any differences in performance on wet and dry surfaces, and any variation at different speeds. For the testing a KJ Law Pavement Friction Tester (PFT) was used to measure the friction properties of the various tyres on two different surfaces on the TRL track. This tester consists of a two-wheeled trailer, where one of its wheels can be braked independently of the other wheel and of the wheels of the towing vehicle. Instrumentation measures the braking force and the instantaneous load on the wheel, from which the braking coefficient is continuously calculated. During testing, while the vehicle is travelling at constant speed, the test wheel is braked under computer control until it locks and is then kept locked for approximately one second. This data is recorded and processed in an on-board computer system and displayed as the test proceeds. Water, from a tank in the towing vehicle, can also be sprayed in front of the test wheel so that the friction can be measured in both the dry and wet conditions.

The testing involved three different types of Bridgestone Battlax motorcycle tyres and a standard Pirelli car tyre. All tyres were tested on stone mastic asphalt (SMA) and hot rolled asphalt (HRA) surfaces at approximately 32, 64 and 100 km/h (20, 40 and 60 mph), in both wet and dry conditions.

The testing did not produce the expected result, that tyres constructed for sports and high-performance motorcycles would have a markedly higher tyre/road friction than an ordinary motorcar tyre.

Although it was the case that in nearly all the tests the car tyre delivered the lowest friction of the four, its friction was generally very close to the lowest of the motorcycle tyres, and apart from one particular test, the car tyre did not did not stand out as being different in its friction properties from the motorcycle tyres.

With all the tyres on the dry HRA, peak friction tended to increase with increasing speed, while the locked-wheel friction stayed fairly constant. On the dry SMA, however, peak friction stayed fairly constant with increasing speed, while the locked-wheel values tended to decrease. Generally, on the dry surfaces peak friction coefficients of around 1.2 were found, with locked wheel coefficients of around 0.7-0.9.

The wet HRA tests displayed much the same behaviour with increasing speed as the dry SMA, while the wet SMA shows a more marked dependence of friction on speed.

Abstract

The straight-line tyre/road friction coefficients of three motorcycle tyres designed for high-performance or sports motorcycles have been measured and compared with a representative ordinary car tyre. Both peak and locked-wheel friction was measured on two different surfaces (hot rolled asphalt and stone mastic asphalt), dry and wet, at speeds between 32 and 100 km/h. A substantial difference between the friction of the car tyre and the motorcycle tyres was not found, and while the car tyre did tend to deliver the lowest friction of the four, this was, with one exception, no more than the variation among the three motorcycle tyres.

Generally, on the dry surfaces peak friction coefficients of around 1.2 were found, with locked wheel coefficients of around 0.7-0.9. The exception was in the measurement of the peak friction on dry hot rolled asphalt, where the coefficient of friction of the car tyre was about 0.2 less than that of the motorcycle tyres. The same difference was not found in the locked-wheel friction on the dry hot rolled asphalt.

Some observations are also made on the reduction in the coefficient of friction when the tyres wear through to the cords of the carcass, the amount being noticeable but only in the region of 0.2.

1 Introduction

1.1 Background

It is the authors' experience that, by way of anecdote, accident investigators will often assert that sports or "performance" motorcycle tyres have a higher friction than car tyres, and some speculation on this will be found in the manual by Fricke [1]. However, there appears to have been no published data produced in recent times. There has long been a pressing need for such data, both to ensure the accuracy of accident investigators' conclusions and also to improve the knowledge of safety researchers. This investigation therefore encompasses the need for values for the tyre/road friction of motorcycle tyres, the difference in performance on wet and dry surfaces, and any variation observed at different speeds.

Three different tyres, all from Bridgestone, were tested. Also, a representative ordinary car tyre, a Pirelli P6, was tested in the same way.

For the testing a two-wheeled trailer, designed as a highway friction measuring device, was employed. One of its two wheels can be braked independently of the other wheel and of the wheels of the towing vehicle. Instrumentation measures the braking force and the instantaneous load on the wheel, from which the braking coefficient is continuously calculated. Water, from a tank in the towing vehicle, can also be sprayed in front of the test wheel so that the friction can be measured in both the dry and wet conditions.

Two road surfaces on the Transport Research Laboratory (TRL) test track with differing characteristics were used.

1.2 Research Method

A KJ Law Pavement Friction Tester (PFT) was used to measure the friction properties of the various tyres on two different surfaces on the TRL track. The PFT is a standard highway friction measurement device conforming to ASTM E274 [7], and consists of a Chevrolet Silverado pulling a two-wheeled trailer. The vehicle is shown in Figure 1, while Figure 2 shows the trailer.

One wheel of the trailer is fitted with the test tyre, while the tyre on the other wheel is of the same size to keep the trailer level and to ensure an equal weight distribution. During testing, while the vehicle is travelling at constant speed, the test wheel is braked under computer control until it locks and is then kept locked for approximately one second. Transducers on the two wheels measure the vehicle speed, test wheel speed and horizontal and vertical forces on the test wheel every 0.01 second. This data is recorded and processed in an on-board computer system and displayed as the test proceeds. The software gives both the locked tyre/road friction and the peak friction as a "Friction Number", which is 100 times the ratio of the horizontal and vertical forces measured by a two-axis force transducer. In the wet tests the PFT applies water immediately ahead of the test wheel just before it is braked to give approximately 1mm water depth.

The graphs that are produced after the testing shows the vehicle speed, wheel speed, friction and water flow, Figure 3, for each separate test.

Figure 1: The KJ Law Pavement Friction Tester (PFT)

Figure 2: The PFT Trailer

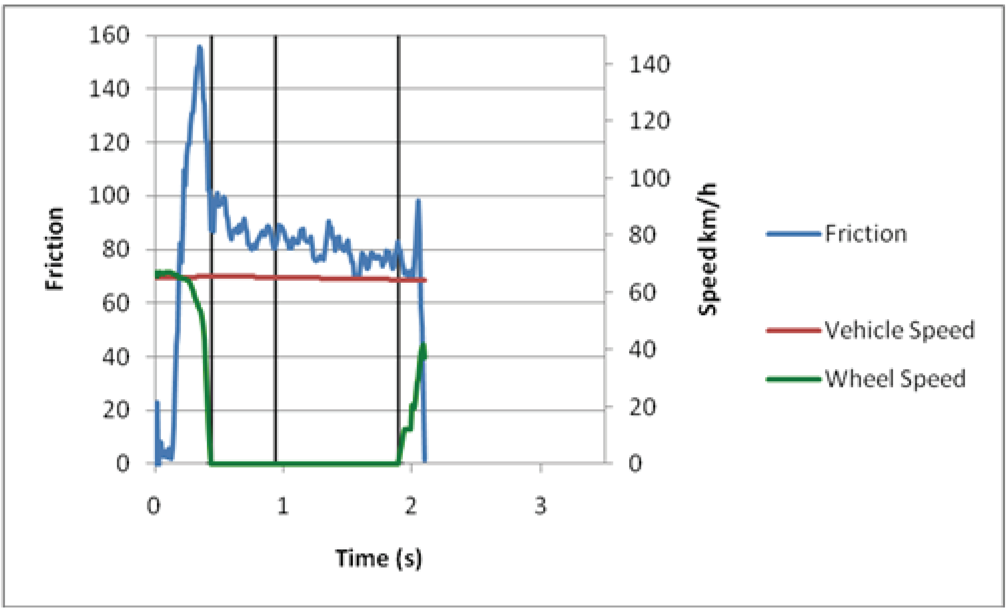

Figure 3: Friction number, vehicle speed and wheel speed from the PFT (BT021 on wet HRA at 64 km/h)

The two surfaces, which were in good condition and only lightly trafficked, are shown in Figures 4 and 5 (together with tyre marks made during the testing). On the Hot Rolled Asphalt (HRA) surface the stony aggregate stands proud of the bituminous binder. By contrast, newly laid Stone Mastic Asphalt (SMA) presents a film of bitumen over the surface aggregate which persists for a significant period before being worn away by traffic. Because of this, new SMA has a lower dry friction coefficient than is usually expected and indeed displays some of the characteristics of a wet surface. For this reason it has been the subject of some concern and controversy in the UK [8].

All tyres used were tested on the two surfaces at approximately 32, 64 and 100 km/h (20, 40 and 60 mph).

Figure 4: The Hot Rolled Asphalt surface, together with motorcycle tyre marks from two separate runs

Figure 5: The Stone Mastic Asphalt surface, together with mark from car tyre

The three motorcycle front tyres that were tested, were all Bridgestone Battlax and of size 120/70ZR17, their characteristics, according to the manufacturer [9], were:

BT003 "*gives racers superior grip in the full lean angle and the opportunity for higher cornering speeds*";
BT014, "*designed to maximise the street performance of hyper-sport replica motorcycles*"; and
BT021, "*a true luxury sport tyre, with confident front-end feel, high stability both on motorways and winding roads, strong grip on wet and dry … designed to provide a wide range of heavier sport touring motorcycles with the highest possible levels of comfort, speed and an exciting feel through corners off the highway, in all conditions*".

The car tyre was the "normal" car tyre in the testing, this being a Pirelli P6 of size 195/55R15. According to its manufacturer [10], this tyre's profile "*is designed to reduce deformation in the critical areas and to improve pressure distribution in the contact area. The cap and base compound reduces energy consumption resulting in increased integrity and reliability of the whole structure*". This tyre was chosen as being similar to the "normal" tyre used in previous testing by Grover et al. [11] which is discussed in the Conclusions and Discussion section of the present paper.

While the car tyre was being tested the total weight of the trailer was 988 kg (i.e. 494 kg on each wheel). This was reduced to the trailer's minimum weight of 600 kg (300 kg per wheel) for the testing of the motorcycle tyres.

The tyres pressures (motorcycle and car) were all set at 210 kPa (30 psi). The ambient temperature throughout the testing was close to 15°C.

2 Literature Review

Measuring the tyre/road friction of motorcycle tyres when fitted to an actual motorcycle is problematical because of the difficulty of keeping the vehicle upright whilst applying the brakes to the point where one or both wheels lock. Some researchers have attempted to overcome this problem by adding 'out rigger' skids to the motorcycle to prevent it from falling over, for example Lambourn [2]. However, problems still arise because of the need to keep the motorcycle travelling straight ahead when wheels have locked and through there being a different braking rate once the outriggers have touched the ground. An alternative approach is to simply measure the friction of an isolated tyre mounted on some other kind of vehicle: in particular, to use a trailer which has at least one wheel fitted with a motorcycle tyre, where that wheel can be braked independently of the rest of the vehicle.

An example of this is the investigation by Walker [3], who used a single wheeled trailer. Seventeen different bias-belted tyres were tested on two surfaces at speeds between 32 and 97 km/h (20 and 60 mph), but only in the wet condition. On a fine textured asphalt surface peak friction coefficients ranging from 1.01 to 1.18 were recorded, and locked-wheel coefficients from 0.49 to 0.68. The author states, "These values are equal to or, in most cases, better than those recorded for car and commercial vehicle tyres on the same surfaces". However, he gives no direct or contemporaneous data for car or commercial vehicle tyres, and of course there was no testing in the dry condition.

There are many examples in the literature where motorcycle braking is explored, including references [1] and [2]. Two more which may be mentioned are by Hugemann & Lange [4], which looks at the abilities of riders with differing amounts of experience, and by Green [5], which also looks at the effects of anti-lock braking. A discussion has also recently been given by Frank et al. [6]. However, such tests address only very indirectly the issue of tyre/road friction.

3 Results

The results for the individual tyres, showing all the data points, are given in the Appendix to this paper. The average peak and locked-wheel coefficient values for each tyre at the three speeds on the two surfaces, dry and wet, are presented below.

Figures 6 and 7 show the values on the dry Hot Rolled Asphalt surface.

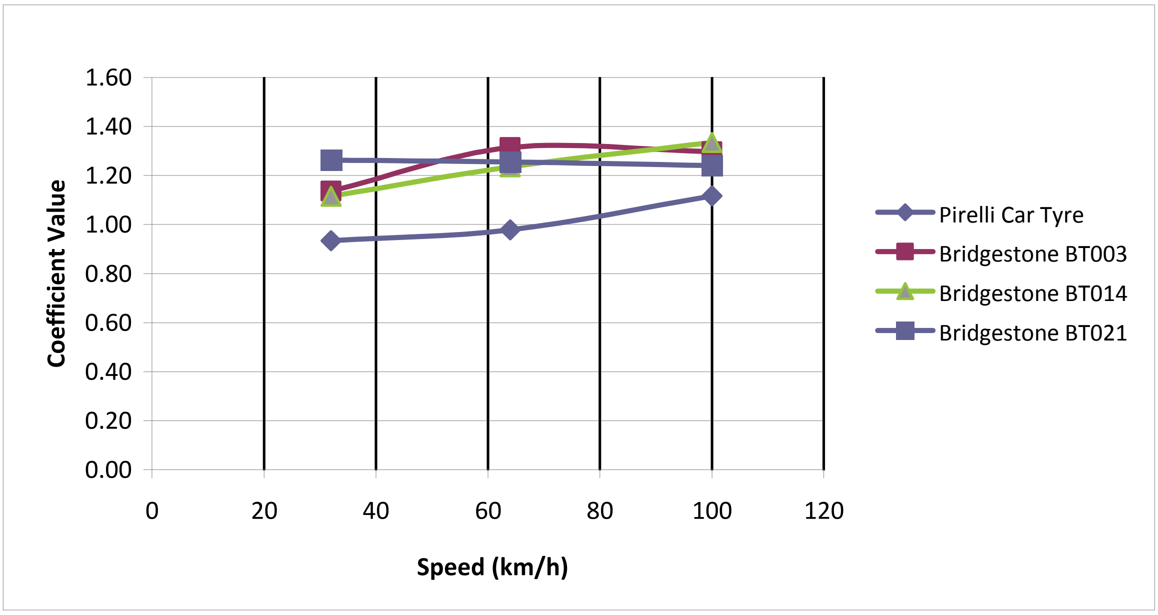

Figure 6: Averaged peak friction values on dry Hot Rolled Asphalt

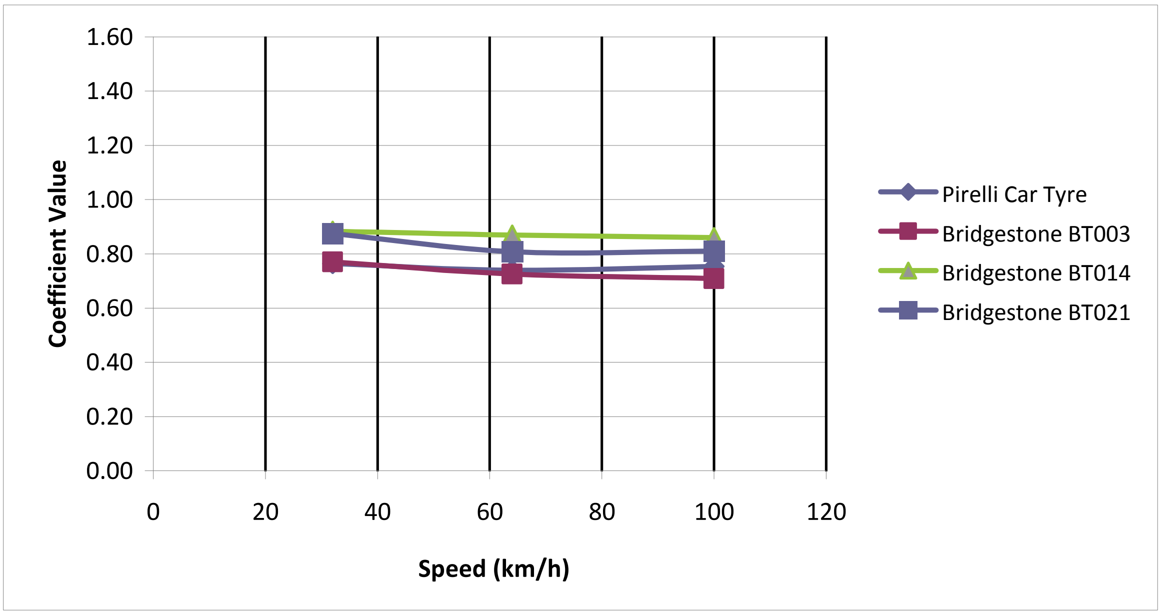

Figure 7: Averaged locked-wheel friction values on dry Hot Rolled Asphalt

The peak friction values for all the tyres show a small rise with increasing speed. The three motorcycle tyres, when averaged, are grouped closely together, and show a value which rises somewhat from about 1.2 at 32 km/h to about 1.3 at 100 km/h. Reference to Figure A1 in the Appendix will, however, show that tyre BT003 in particular (the racing tyre), shows quite a wide scatter in the values found, especially at 64 km/h, where the three values are 1.07, 1.30 and 1.58.

The peak friction value for the car tyre is (when averaged) significantly less, rising from 0.93 at 32 km/h to 1.12 at 100 km/h.

The locked wheel values show all four tyres grouped quite close together, and falling slightly with increasing speed. Notably, the car tyre gave very similar values to motorcycle tyre BT003, falling slightly from about 0.76 at 32 km/h to about 0.73 at 100 km/h. The figures for tyres BT014 and BT021 are slightly higher, going from about 0.88 to about 0.83.

Figures 8 and 9 show the values on the dry Stone Mastic Asphalt surface.

The peak friction values on dry SMA for all the tyres hardly vary with increasing speed. Furthermore, all four tyres are grouped closely together, with the car tyre being the lowest, but by a barely significant amount. The figures are all in the range 1.10 to 1.23.

The locked wheel values are similarly grouped together, and falling more markedly with increasing speed (as might be expected with the liquid-like behaviour of SMA surfacings). The car tyre and motorcycle tyre BT003 are again closest together, being about 0.83 at 32 km/h, dropping to about 0.65 at 100 km/h. Tyres BT014 and BT021 drop from about 0.88 to about 0.75 at 100 km/h.

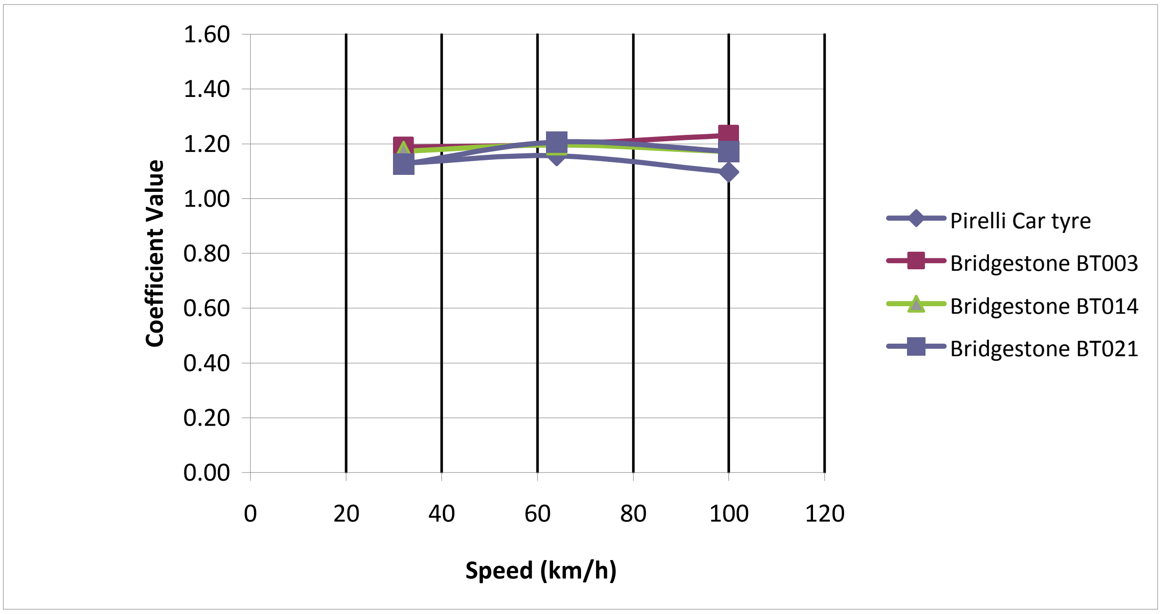

Figure 8: Averaged peak friction values on dry Stone Mastic Asphalt

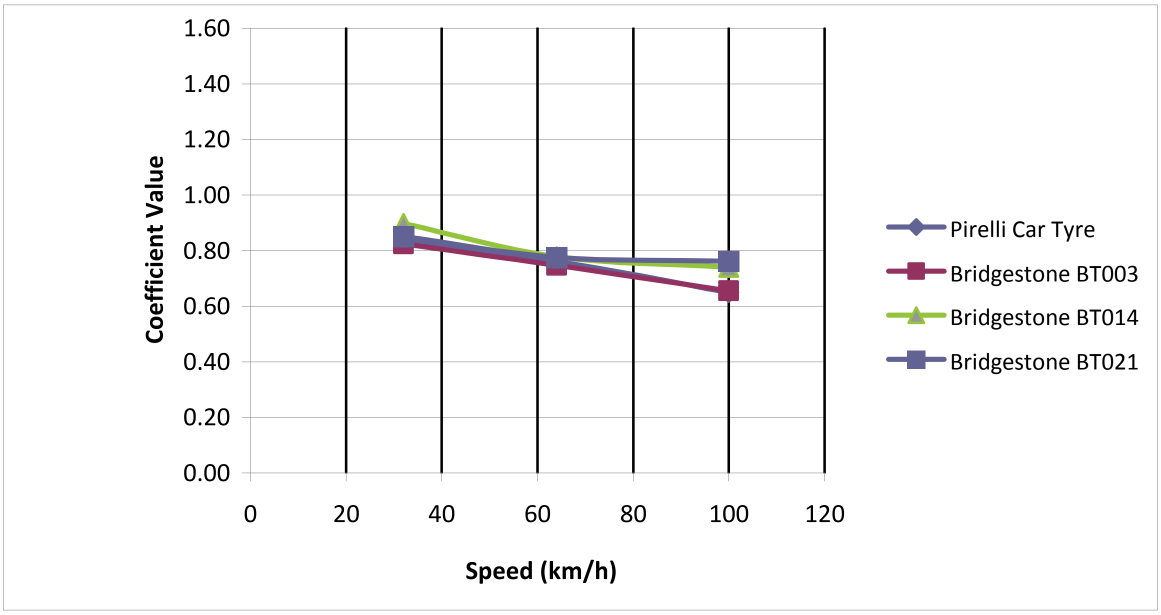

Figure 9: Averaged locked-wheel friction values on dry Stone Mastic Asphalt

Figures 10 and 11 show the values on the wet Hot Rolled Asphalt surface.

With both the peak and locked wheel coefficients, the four tyres are grouped quite closely together. In both the car tyre tends to be the lowest, but not by any marked amount.

The peak values range between 0.99 and 1.36, while the locked wheel values range between 0.64 and 0.90 at 32 km/h, dropping (as would be expected on a wet surface) to 0.52 to 0.67 at 100 km/h.

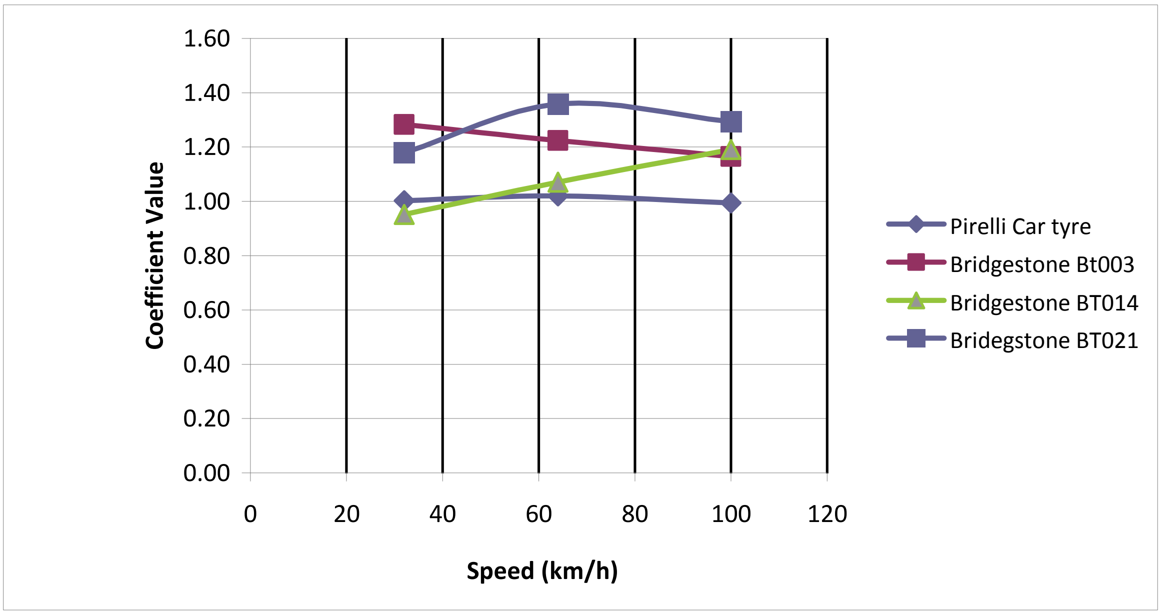

Figure 10: Averaged peak friction values on wet Hot Rolled Asphalt

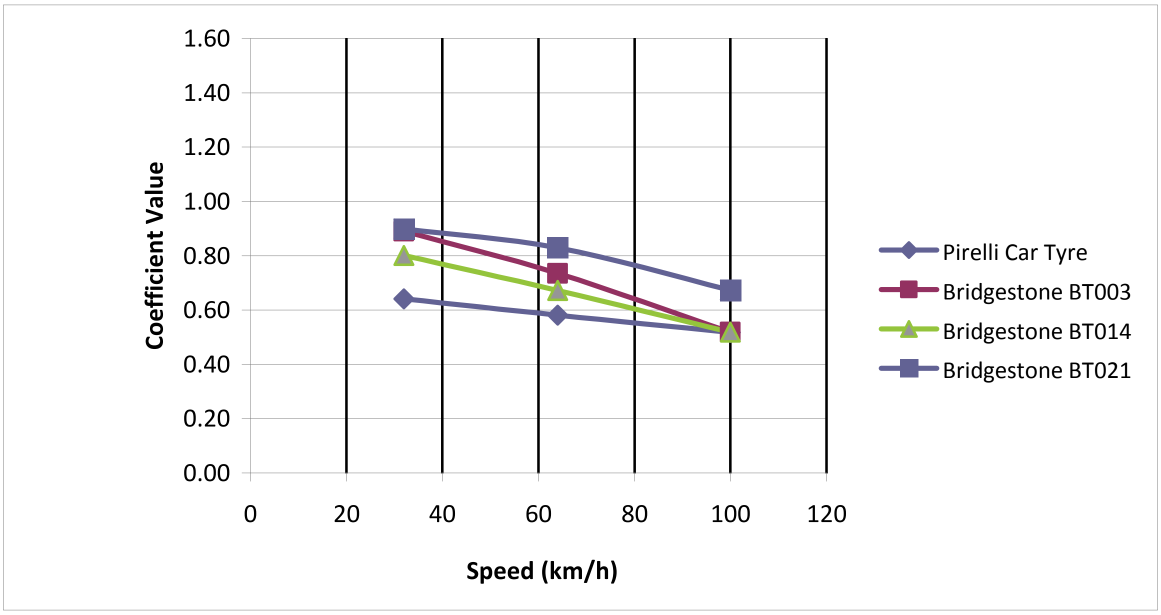

Figure 11: Averaged locked-wheel friction values on wet Hot Rolled Asphalt

Finally, Figures 12 and 13 show the values on the wet Stone Mastic Asphalt surface.

The peak values for the three motorcycle tyres on the wet SMA are again closely grouped and show little variation with speed. At 32 km/h they range between 1.03 and 1.12, while at 100 km/h they are all 1.01. The car tyre starts at a close-by value of 0.99 at 32 km/h, but falls to 0.76 at 100 km/h.

The locked wheel values for all four tyres are more closely grouped and show a clear drop with increasing speed. The car tyre is the lowest throughout, but not remarkably so. At 32 km/h the car tyre is at 0.66, while the motorcycle tyres range between 0.68 and 0.76; at 100 km/h the car tyre and motorcycle tyres BT003 and BT014 are all at 0.37, while tyre BT021 is higher by an insignificant amount, at 0.40.

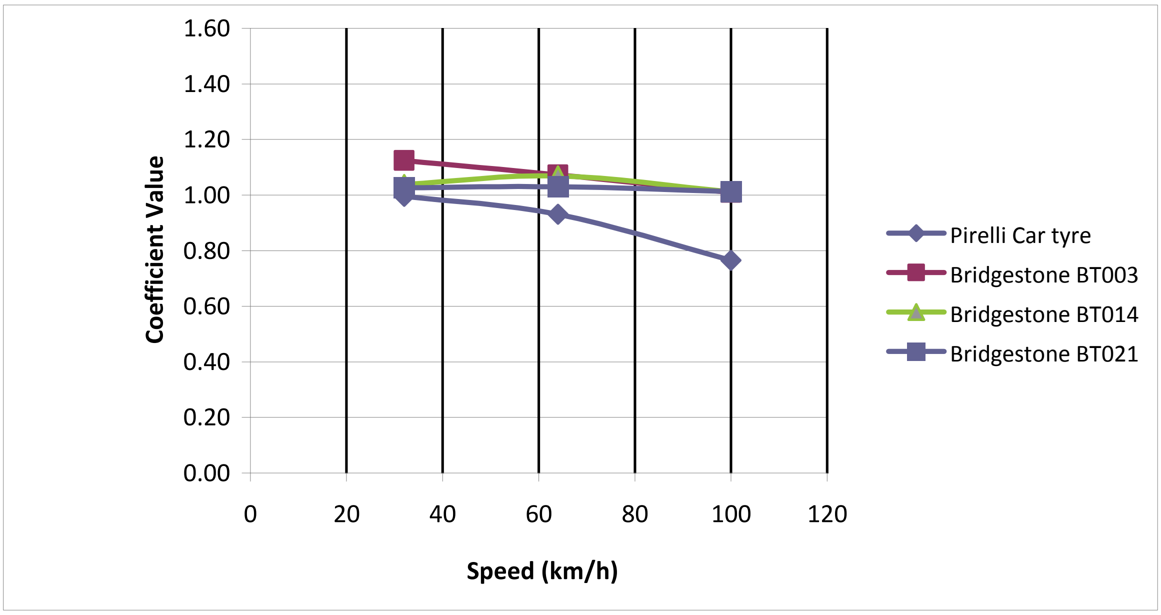

Figure 12: Averaged peak friction values on wet Stone Mastic Asphalt

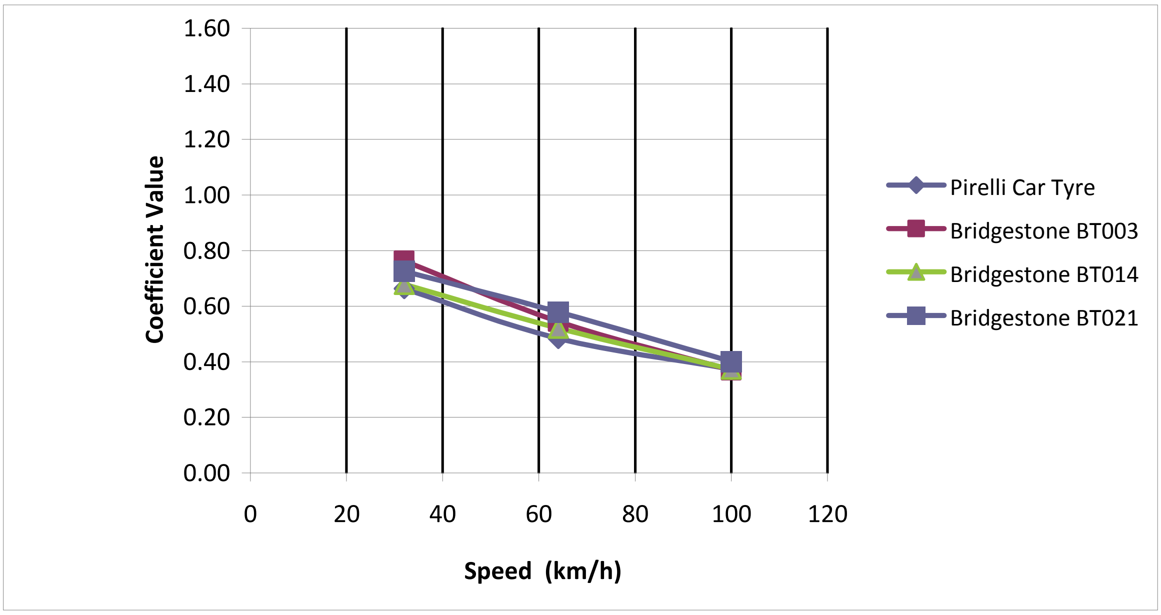

Figure 13: Averaged locked-wheel friction values on wet Stone Mastic Asphalt

4 Effects of Severe Wear

The wet testing caused little wear to the tyres, but in the dry testing considerable wear was produced, such that some tyres wore through to the cords of the carcass and one was worn through creating a hole. The friction values measured in these cases are of some interest. The data points from them are included in the graphs in the Appendix, but, where indicated, they were not included in the averaging for the graphs presented above.

Before the cords became exposed there was no discernable change in the coefficient of friction even when the tread pattern had worn away.

However, in the last test with motorcycle tyre BT014 on dry HRA (Figure 14 and Figure A3) at 100 km/h, the tread wore through, starting to expose the cords. This produced a locked wheel value of 0.68, as opposed to the averaged value (which excludes this point) of 0.86. Figure 14 shows tyre BT014 at this stage.

Similarly, starting with a new example of the same model of tyre on dry SMA (Figure 15 and Figure A4), at 100 km/h the tread again wore through to the carcass, producing a locked wheel value of 0.57. The averaged value, of only two other points, was 0.74. Figure 15 shows this tyre BT014 after the last test.

Most interesting were the figures with tyre BT021 on the dry HRA (Figure A5). In the fourth test the tyre was again worn to the carcass, giving a locked wheel value of 0.61, as against the average from the three previous tests of 0.82. Nevertheless, two more tests were conducted with it which wore through the cords and produced a substantial hole (Figure 16). For these the values found were higher, at 0.78 and 0.72. A new tyre was then tested twice, and this gave 0.85 on both occasions.

Our conclusion with the tyre BT021 tests is that, once the carcass cords had been worn away, the improved friction was due to the rubber of the structure underlying the carcass, while it lasted, and then to the rubber surrounding the hole. This then yielded a higher value than the material of the carcass.

Figure 14: Tyre BT014 after completion of dry tests on HRA

Figure 15: Tyre BT014 after completion of dry tests on SMA

Figure 16: Tyre BT021 after completion of dry tests on HRA

5 Conclusion

This program of testing did not produce the expected result, which was that tyres constructed for sports and high-performance motorcycles would have a markedly higher tyre/road friction than an ordinary motorcar tyre.

It was the case that in almost all the tests – of peak and locked-wheel friction, wet and dry – the car tyre delivered the lowest friction of the four. With the one exception, its friction was generally very close to the lowest of the motorcycle tyres, resulting in the car tyre not standing out as being different in its friction properties to the motorcycle tyres.

The one exception was the peak friction on the dry HRA (Figure 6), where the car tyre had a coefficient which was less than that of the motorcycle tyres by around 0.2. It will also be noted that the peak friction of the car tyre on the wet SMA (Figure 12) did diverge significantly from the values found for the motorcycle tyres at the highest speed. Other features which may be noted for all the tyres are that on the dry HRA peak friction tended to increase with increasing speed, while the locked-wheel friction stayed fairly constant. On the SMA, however, peak friction stayed fairly constant with increasing speed, while the locked-wheel values tended to decrease: this is as expected for this surfacing, which is known to display characteristics similar to those of a wet road in its early life.

The wet HRA tests, then, display much the same behaviour with increasing speed as the dry SMA, while the wet SMA shows a more marked dependence of friction on speed.

Only one car tyre was tested, and it could be that a range of car tyres would produce a somewhat different finding. However, the one chosen, of size 195/55R15, was of a common and unremarkable type and was very similar the "normal" tyre tested in Reference 10. In that work (which is largely concerned with the effects of under-inflation) two other car tyres from the same manufacturer were also tested, being classified as "low profile" and "run-flat". The three types were tested on the dry SMA surface with the PFT at 64 km/h, while the normal and run-flat tyres were also tested on that surface in maximum braking-to-stop tests from 64 km/h in a car with anti-lock brakes. The findings are summarized in the table below. The MFDD figure is the "mean fully developed deceleration".

Table 1: Data for three different car tyres from Reference 11

Tyre type	PFT coefficient at 64 km/h		ABS brake to stop from 64 km/h	
	peak	locked	MFDD (g)	stop dist (m)
normal	1.13	0.68	1.11	18.85
low profile	1.15	0.70	-	-
run-flat	1.15	0.59	1.04	18.90

It can be seen that there was no significant difference between the three tyres apart from the locked wheel friction of the run-flat type, which may be expected to be of an unusual composition and which had a significantly lower value. The general similarity between these tyres supports the finding in the present testing that motorcycle tyres do not have remarkably higher friction to car tyres.

An incidental but unsurprising finding of the present testing is that when the tyres were worn through to the carcass there was a significant drop in locked-wheel friction. However, once the tyre was worn to the extent that there was a hole, and therefore zero inflation pressure, the friction was substantially restored.

Acknowledgments

The work described in this report was carried out in the Incident Investigation and Reconstruction Group of TRL Limited. The authors are grateful to Derek Meachen for driving and managing the Pavement Friction Tester, to William Chislett for help with the preparation of the tests, and to James Manning for assistance with processing the data.

The work would not have been possible without the use of the Pavement friction tester (PFT), which is owned by the Highways Agency (HA). The authors would like to thank the HA for their permission to use this equipment.

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Appendix

DATA FROM DRY SURFACE TESTS

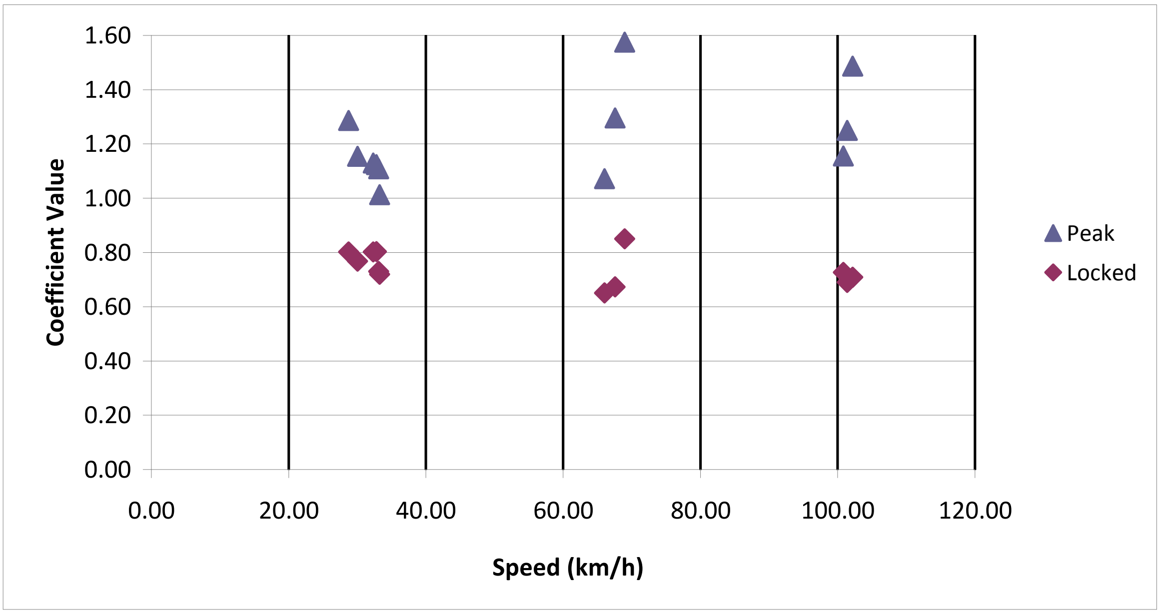

Figure A1: Bridgestone BT003 on dry Hot Rolled Asphalt

Note the large spread of peak friction values. These correlate with the highest, middle and lowest values of locked wheel friction.

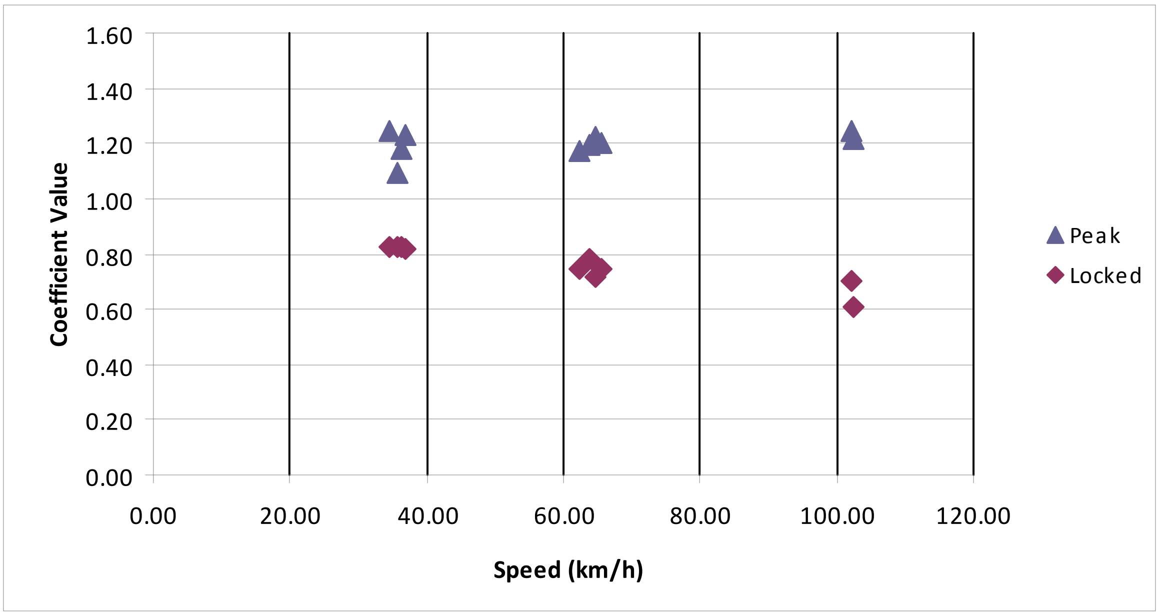

Figure A2: Bridgestone BT003 on dry Stone Mastic Asphalt

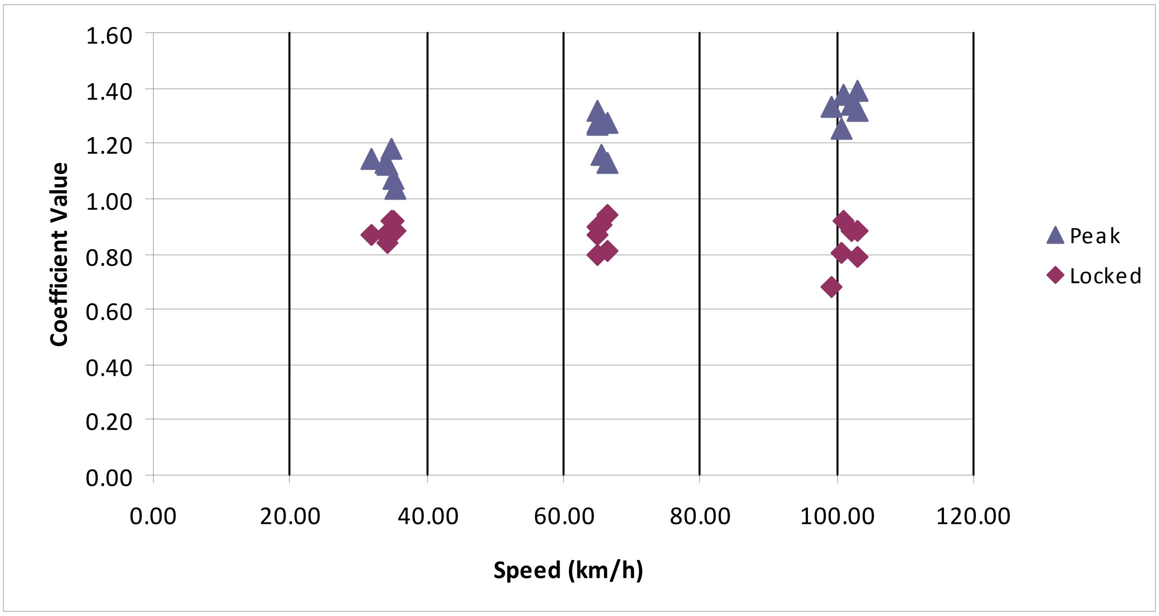

Figure A3: Bridgestone BT014 on dry Hot Rolled Asphalt

The lowest locked wheel point at 100km/h was produced when the tyre carcass was exposed.
It was not included in the averaging of the 100 km/h values.

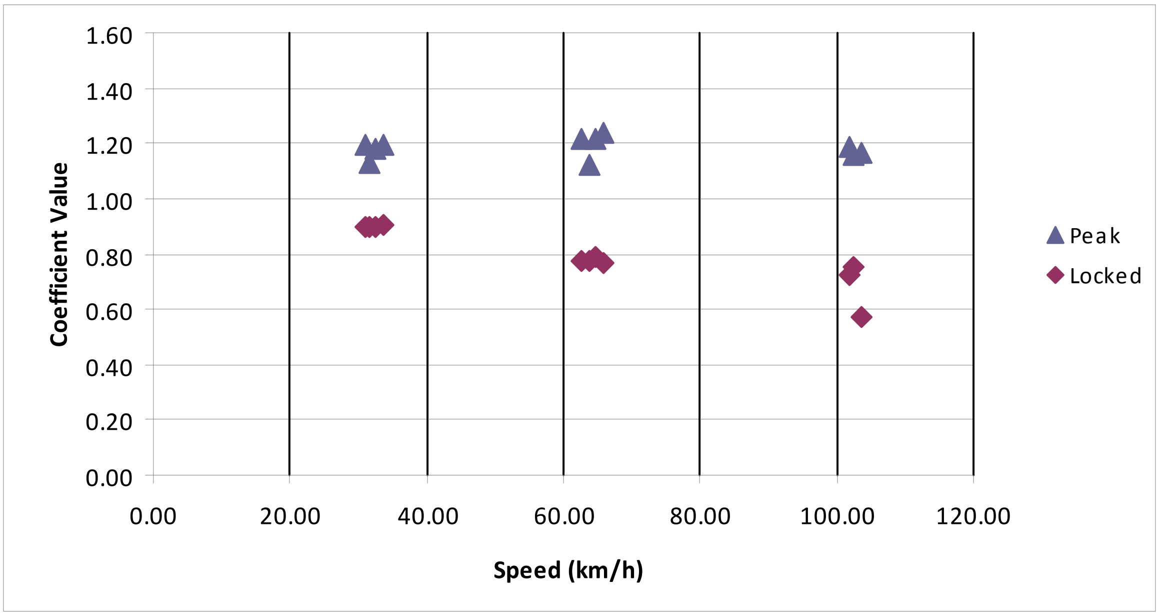

Figure A4: Bridgestone BT014 on dry Stone Mastic Asphalt

Again, the lowest locked wheel point at 100km/h was produced when the tyre carcass was exposed. It was not included in the averaging of the 100 km/h values.

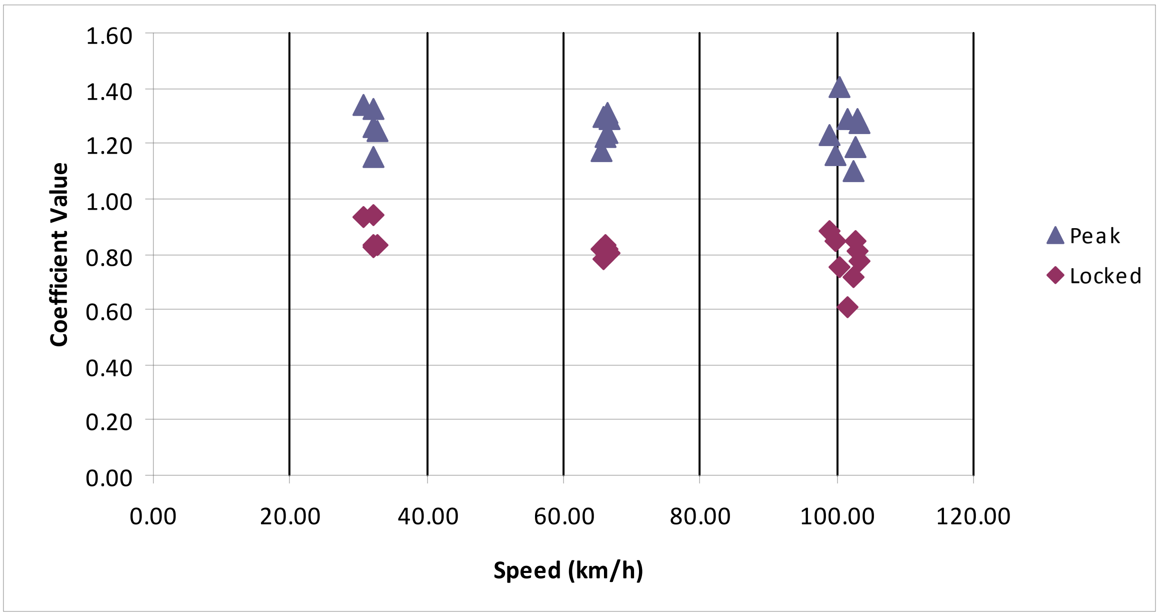

Figure A5: Bridgestone BT021 on dry Hot Rolled Asphalt

The lowest locked wheel point at 100km/h was produced when the tyre carcass was exposed. It was not included in the averaging of the 100km/h values. However, two more points, at 0.72 and 0.78, we obtained after this, when the tyre was worn completely through, and they have been included in the averaging.

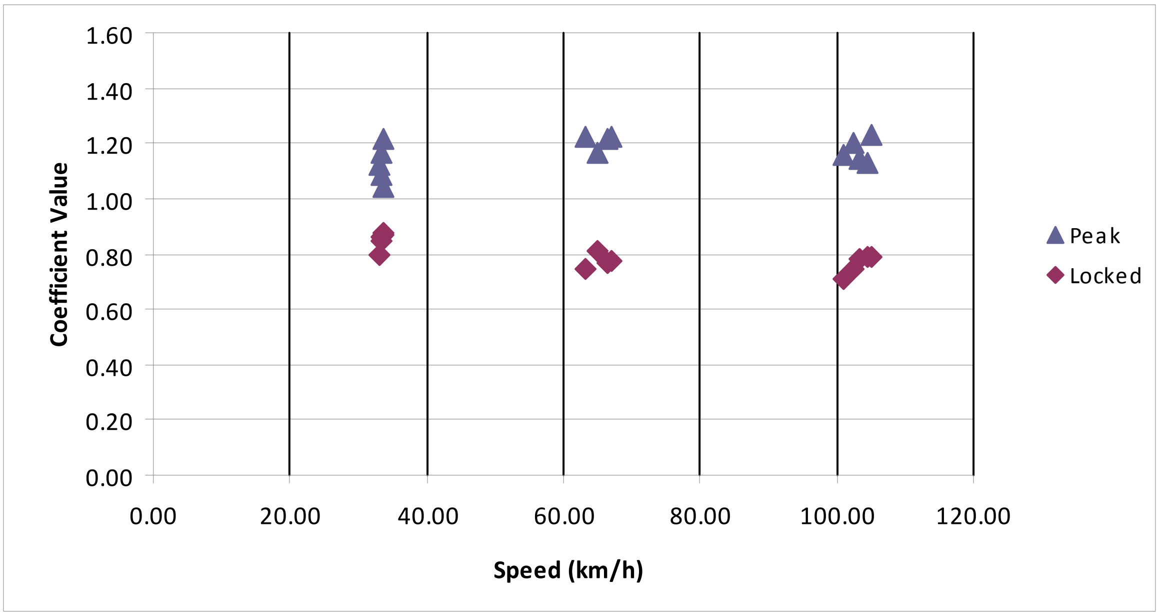

Figure A6: Bridgestone BT021 on dry Stone Mastic Asphalt

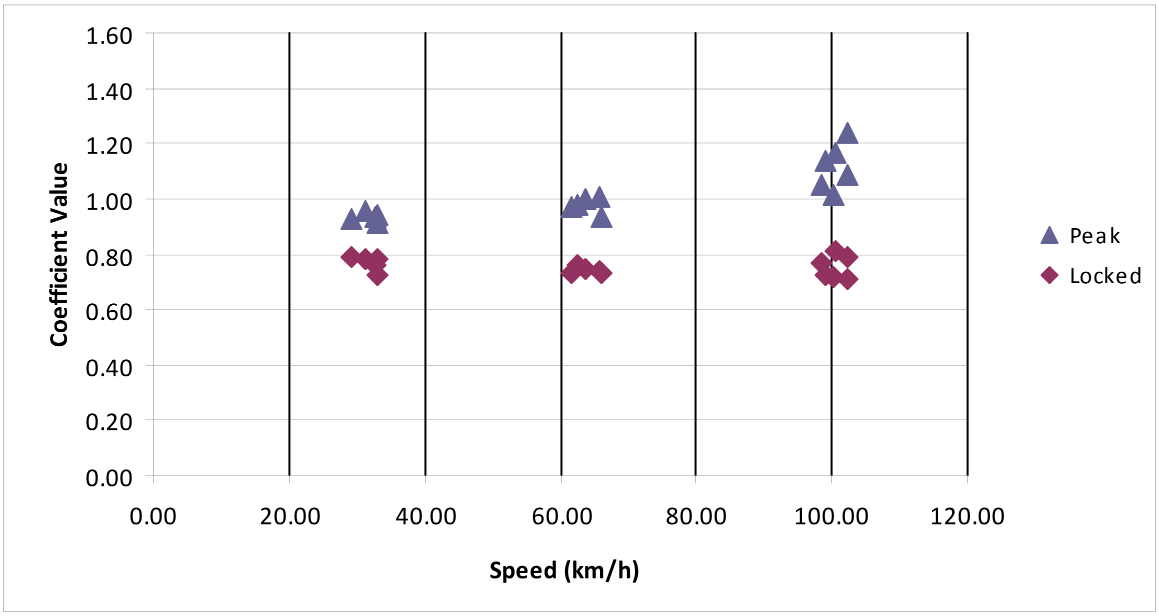

Figure A7: Pirelli Car Tyre on dry Hot Rolled Asphalt

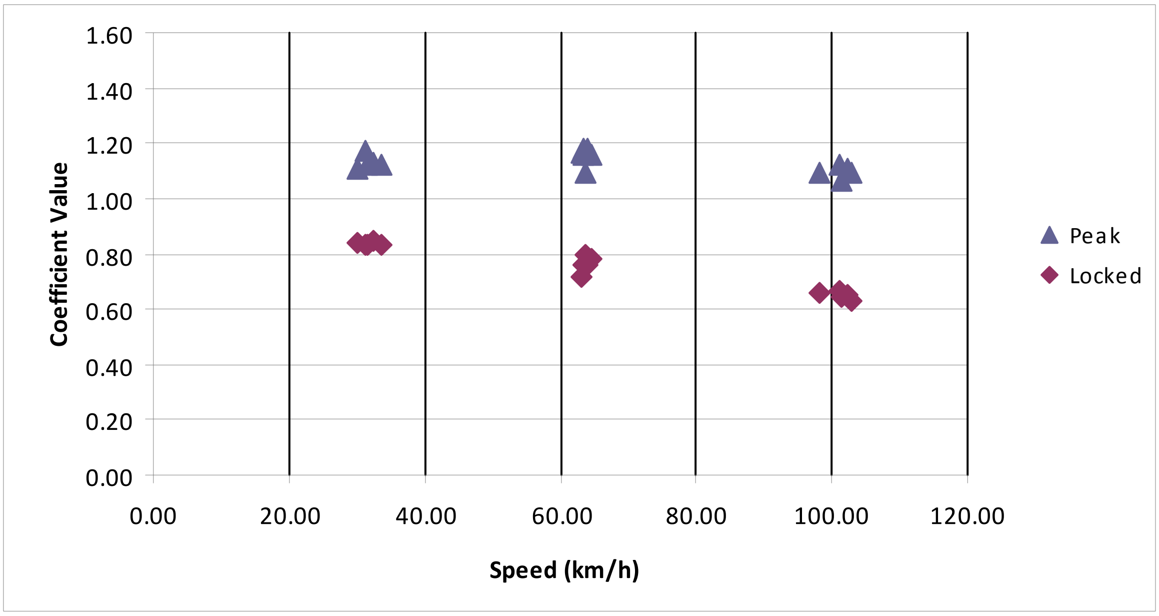

Figure A8: Pirelli Car Tyre on dry Stone Mastic Asphalt

DATA FROM WET SURFACE TESTS

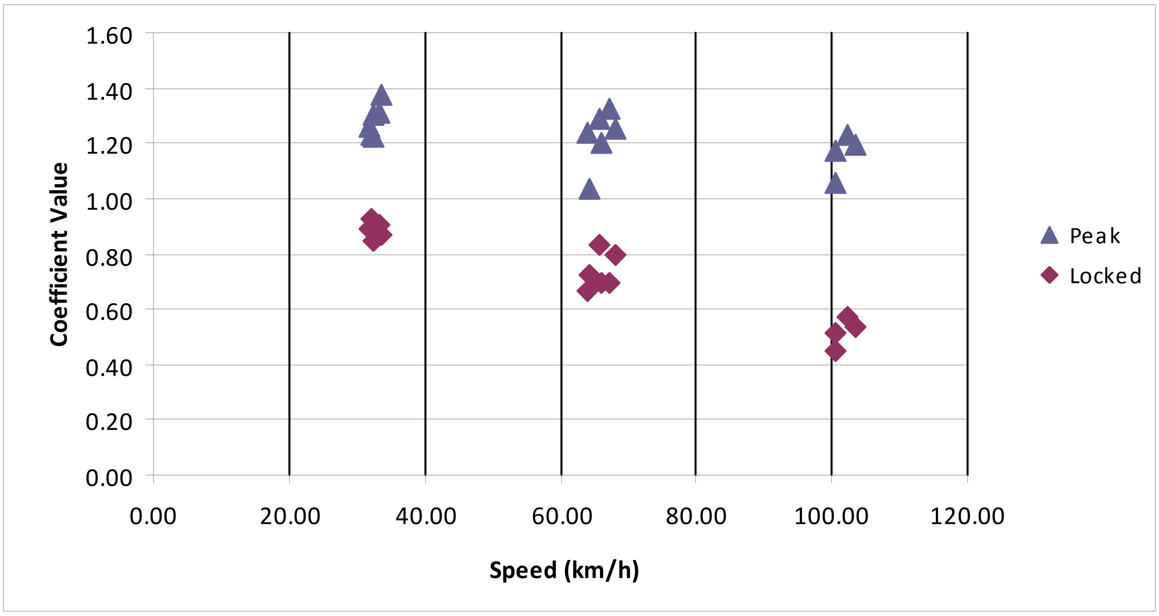

Figure A9: Bridgestone BT003 on wet Hot Rolled Asphalt

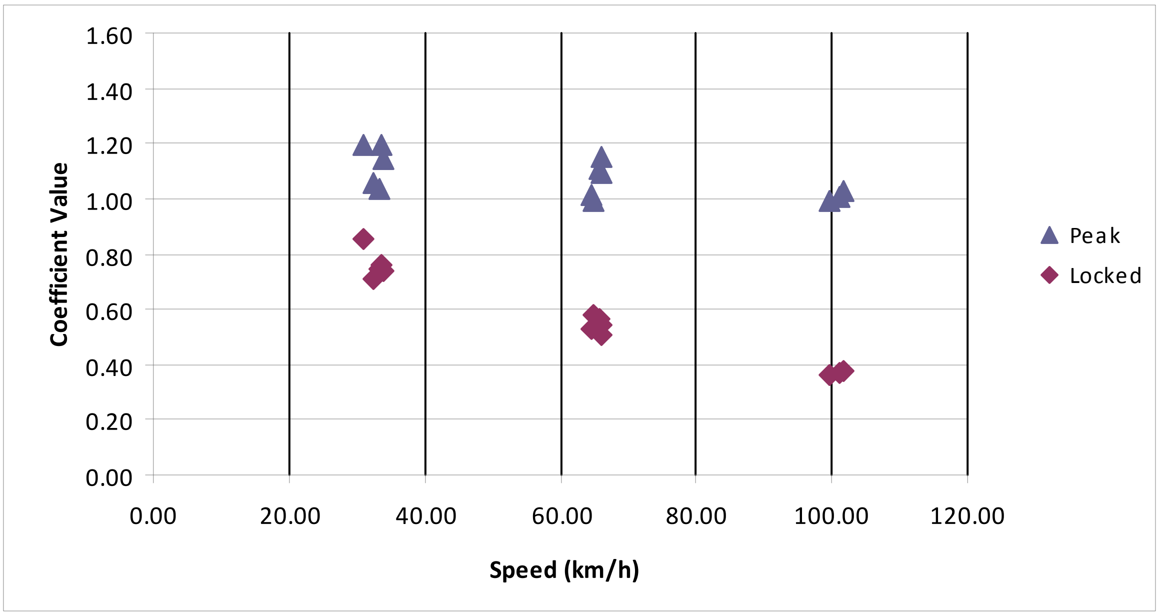

Figure A10: Bridgestone BT003 on wet Stone Mastic Asphalt

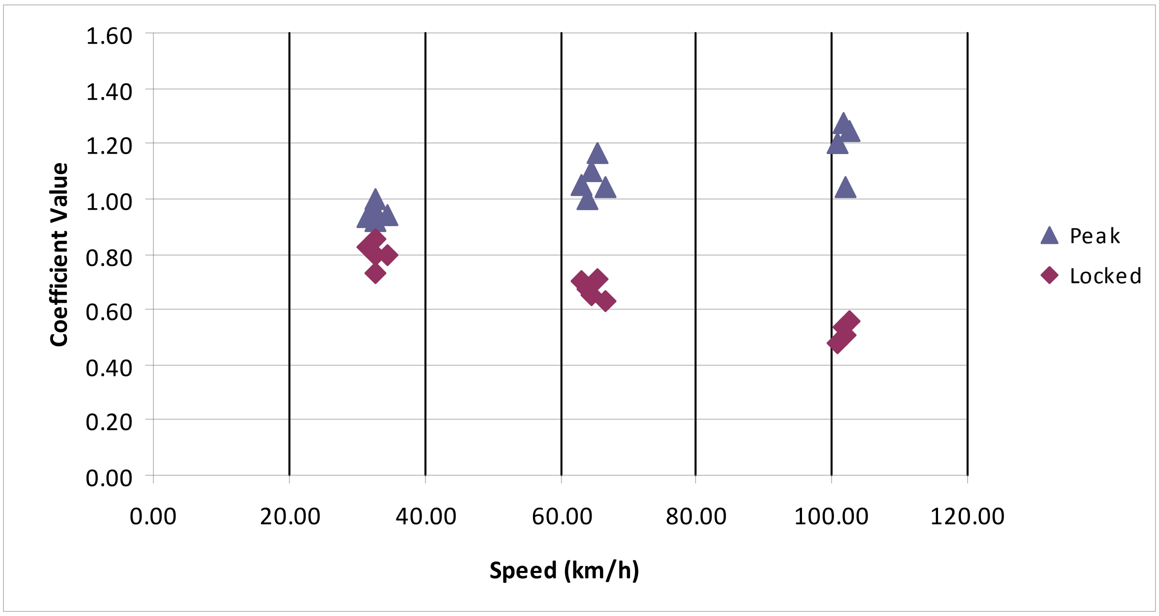

Figure A11: Bridgestone BT014 on wet Hot Rolled Asphalt

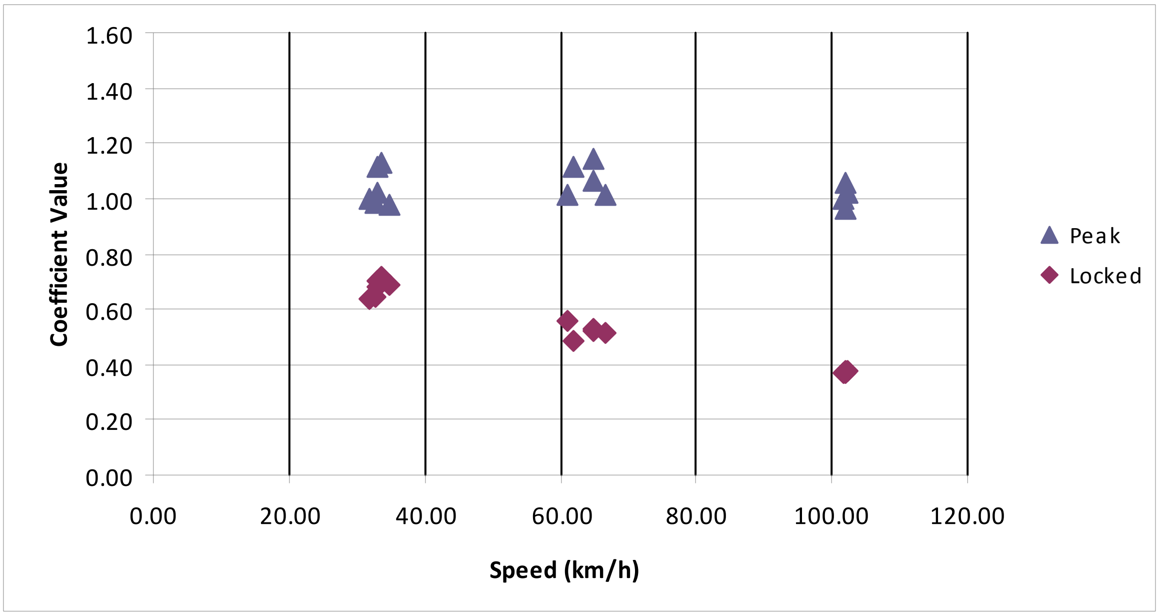

Figure A12: Bridgestone BT014 on wet Stone Mastic Asphalt

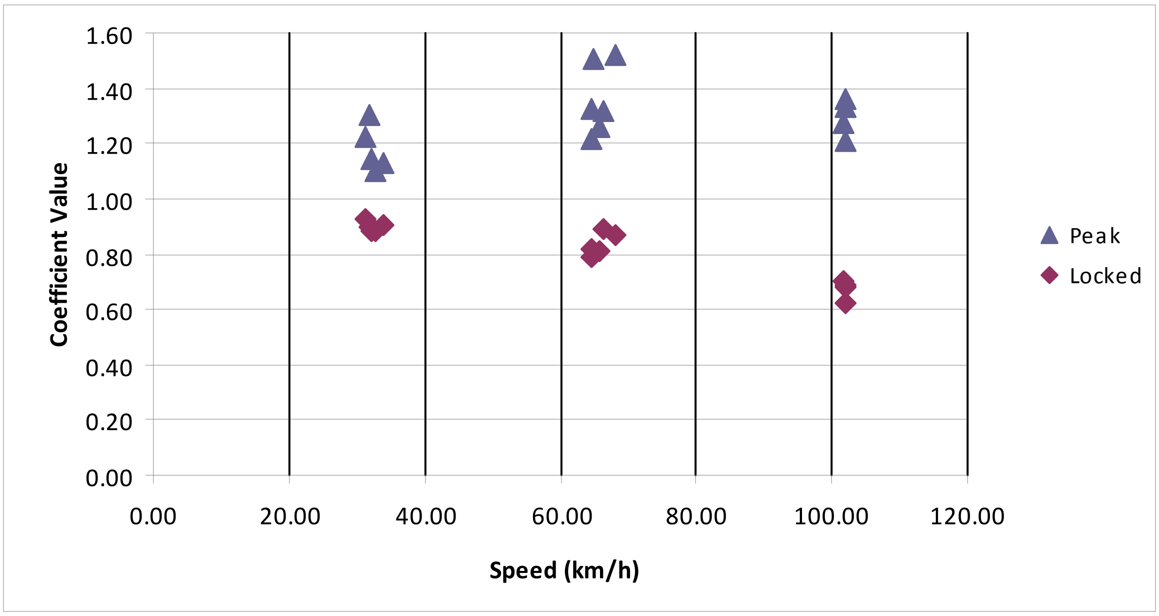

Figure A13: Bridgestone BT021 on wet Hot Rolled Asphalt

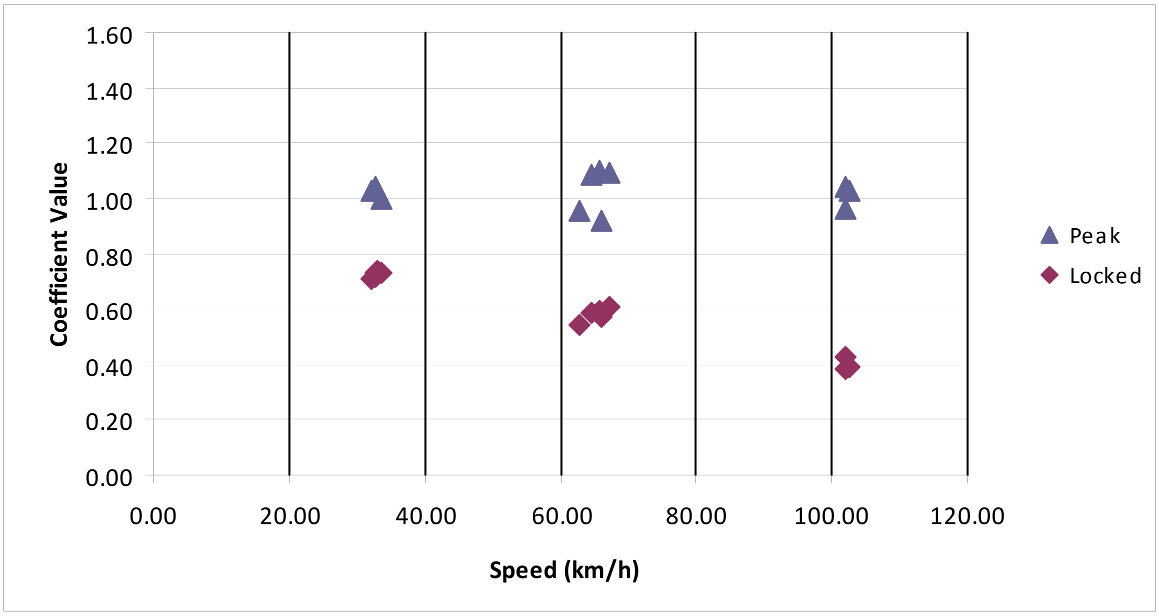

Figure A14: Bridgestone BT021 on wet Stone Mastic Asphalt

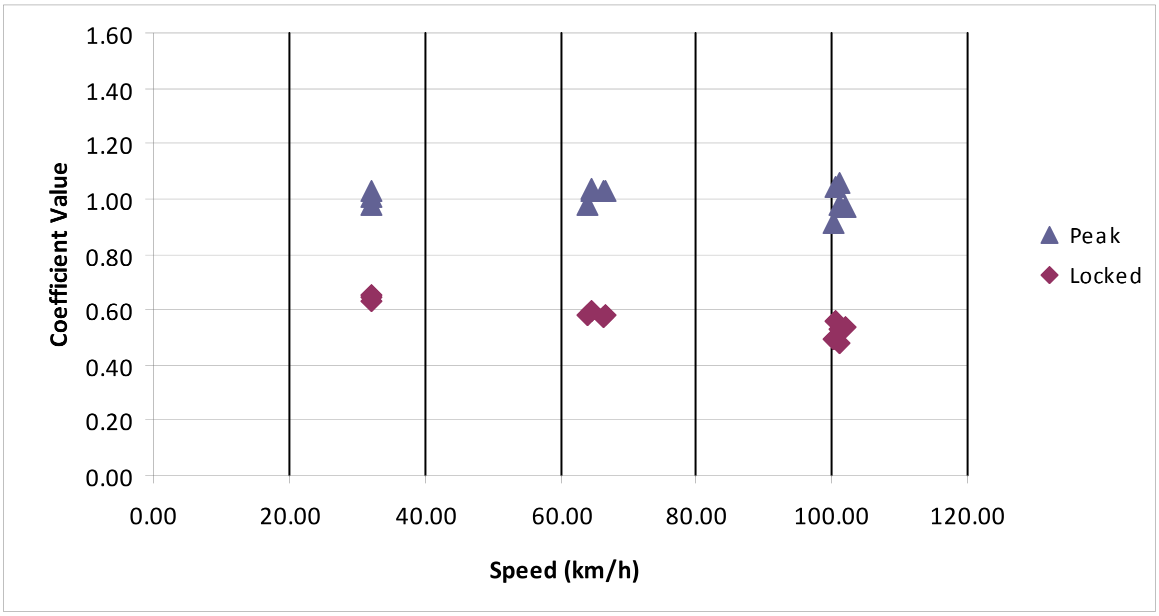

Figure A15: Pirelli Car Tyre on wet Hot Rolled Asphalt

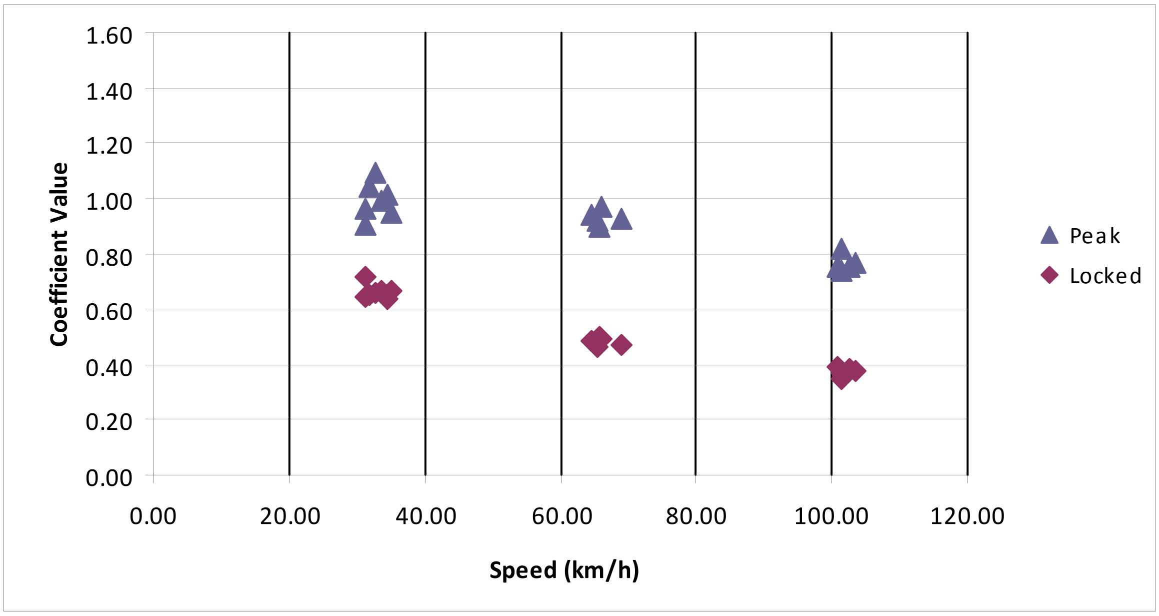

Figure A16: Pirelli Car Tyre on wet Stone Mastic Asphalt

Comparison of motorcycle and car tyre/road friction

The straight-line tyre/road friction coefficients of three motorcycle tyres designed for high-performance or sports motorcycles have been measured and compared with a representative ordinary car tyre. Both peak and locked-wheel friction was measured on two different surfaces (hot rolled asphalt and stone mastic asphalt), dry and wet, at speeds between 32 and 100 km/h. A substantial difference between the friction of the car tyre and the motorcycle tyres was not found, and while the car tyre did tend to deliver the lowest friction of the four, this was, with one exception, no more than the variation among the three motorcycle tyres.

Generally, on the dry surfaces peak friction coefficients of around 1.2 were found, with locked wheel coefficients of around 0.7-0.9. The exception was in the measurement of the peak friction on dry hot rolled asphalt, where the coefficient of friction of the car tyre was about 0.2 less than that of the motorcycle tyres. The same difference was not found in the locked-wheel friction on the dry hot rolled asphalt.

Some observations are also made on the reduction in the coefficient of friction when the tyres wear through to the cords of the carcass, the amount being noticeable but only in the region of 0.2.

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