FRICTION & TYRE ABRASION CHARACTERISTICS OF NEW ZEALAND ROAD SURFACES

Transfund New Zealand Research Report No. 94

Cover

FRICTION & TYRE ABRASION CHARACTERISTICS OF NEW ZEALAND ROAD SURFACES

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EXECUTIVE SUMMARY

This report presents the results of a research project carried out in 1994 to investigate the suitability of fixed slip friction meters for on-road determination of pavement surface abrasiveness characteristics of New Zealand sealed roads. The research was intended to establish the degree of correlation between tyre rubber abrasion and the road surface friction coefficient, as measured by the Findlay Irvine GripTester operated by Opus Central Laboratories (formerly Works Central Laboratories). From the research, the following conclusions and recommendations have been derived.

1. Measurement of Tyre Abrasion

A procedure was developed during the study for measuring the loss of tyre rubber from the GripTester test wheel by weighing the test wheel after it had traversed an abrasive surface. The rubber loss measured during the tests was insufficient to derive detailed conclusions from the measurements.

Recommendations

- For detailed analysis of tyre abrasion measurements, the rubber loss must be at least five times that achieved during this research project.
- For any future similar measurements the use of a purpose-built abrasion meter, operating independently of the GripTester, should be considered.

2. Relationship Between Wet Friction and Dry Abrasion Rate

The measurements of rubber loss indicate a general trend of dry abrasion rate increasing as Grip Number increases. The Grip Number is a measure of wet pavement friction as determined by the GripTester. Some of the data indicate that the abrasion rate may increase severely for only a moderate increase in wet pavement friction. However this increase must not be treated as conclusive evidence because large potential inaccuracies were recorded in the measurements.

Recommendation

- In order to confirm the true relationship between dry abrasion rate and wet pavement friction, as measured by Grip Number, a new set of measurements is required. The sites should be specifically selected to include surfaces covering a wide range of wet Grip Number.

3. Use of the GripTester for Determining Road Surface Abrasiveness

Measurement of pavement friction using the GripTester, or any other similar friction meter, is unlikely to be developed as the most appropriate method for on-road determination of pavement surface abrasiveness.

Recommendation

- To measure road surface abrasiveness, accurate procedures for measuring the abrasiveness more directly are required. These may include measurement of the abrasion of a test sample (e.g. a rubber block rubbed on the road surface, and weighed immediately before and after), or measurement by microscopic techniques of the size and shape of the surface asperities which cause the abrasion.

4. Validation of HDM III Micro-Tread Wear Model

The most commonly used model for predicting tyre tread wear as a function of vehicle and road characteristics is the micro-tread wear model employed in the World Bank's HDM III model. However, the rubber loss measurements do not fit well to the predictions of the micro-tread wear model but it is not known whether the observed discrepancy may be related to the inaccuracies of the rubber loss measurements.

Recommendations

- Considerably improved accuracy of rubber loss measurements is required so that the results can be compared with predictions of the HDM III micro-tread wear model.

- The GripTester is essentially intended for measurement of wet pavement friction. In order to apply the micro-tread wear model in the form proposed for application to the resulting Grip Number measurements, the current study has attempted to apply the dry Grip Number measurements. Careful consideration of the suitability of dry Grip Number measurements is therefore required for any future validation studies of the HDM III micro-tread wear model.

5. Road Aggregate Geometry Effects

The influence on rubber loss of macrotexture effects such as chip size, appears to be small from the results of this research. However, the influence of microtexture has not been examined. Previous researchers have suggested that asperities on the surface of the aggregate material do play a major role in determining road surface abrasiveness.

Recommendation

- Consideration of the microtexture geometry is essential for any future study of this type. This may include close-up photography of the road surface, laser profilometer measurements, and microscopic examination of the surface texture.

6. Influence of Microtexture Amplitude

All things being equal, the main increase in wet friction occurs if the microtexture (i.e. microscopic roughness on the surface of the roading aggregate) is in the amplitude range 0.01 to 0.1 mm. Aggregates with microtexture amplitude above this range afford relatively little additional increase in friction. In contrast, the tyre abrasion rate increases substantially for microtexture amplitude in the range 0.1 to 1 mm.

Control of microtexture amplitude therefore appears to have potential to reduce road user costs through reduced tyre wear while maintaining a reasonably high level of wet friction. This potential reduction in road user costs can be achieved by selecting pavement surfaces with microtexture amplitudes that are sufficiently large to maintain most of the benefits of high friction, but are not sufficiently large to cause excessive tyre wear.

On the other hand, as the most abrasive surfaces also produce the highest values of wet friction, their widespread use may possibly be justified because they contribute to improved road safety.

Recommendations

- The relative benefits of reduced tyre abrasion should be balanced with improved road safety, and also these benefits should be incorporated in the total road maintenance costs/road user costs equation.

- The combination of pavement surface characteristics which maximise the wet friction of a tyre should be identified. This will permit the most desirable surface characteristics which increase friction, and therefore safety, to be determined and differentiated from those characteristics which cause increased tyre abrasion.

7. Bituminous Sealing Manual

Very little distinction in tyre abrasion rates was observed among the different types of pavement surfaces tested, apart from the slurry seals. This result was attributed to the road aggregates being sourced from only the Wellington region. The slurry seals, which incorporate a sandy aggregate mix rather than aggregate chips, can achieve high levels of wet friction but cause substantially increased tyre abrasion rates.

Recommendation

- Road aggregates produced by quarries in New Zealand should be assessed for their abrasiveness, in addition to their polished stone value and resistance to crushing, properties which are presently (1996) measured. This requirement will necessitate the development of an appropriate test method for determining the abrasiveness of aggregate samples that can be incorporated in the Transit New Zealand (1993) Bituminous Sealing Manual.

ABSTRACT

This report presents the results of a research project, carried out in 1994, to investigate the suitability of fixed slip friction meters for on-road determination of pavement surface abrasiveness of New Zealand SEALED roads. The research was intended to establish the degree of correlation between tyre rubber abrasion and the road surface friction coefficient, as measured by the Findlay Irvine GripTester. The procedures used for the study, and the recommendations for improved procedures, are described.

The degree of correlation has not been satisfactorily established because:

- The accuracy of the tyre abrasion measurements was insufficient;
- The range of friction values of the various pavement surfaces, and the accuracy of the measurement of rubber loss, was insufficient to determine the influence of friction on pavement surface abrasiveness;
- The influence of the pavement surface microtexture was not measured. The geometry of the microtexture is believed to play an important role in determining pavement surface abrasiveness, which may be independent of the influence of the surface friction.

The GripTester or any other similar friction meter is unlikely to be developed as the most appropriate method for on-road determination of pavement surface abrasiveness. The inherent difficulties of friction measurements, and the likely influence of surface texture geometry which may be independent of the friction, impede the use of friction meters for this purpose.

1. INTRODUCTION

The objective of the "Tyre Consumption" research project (Transit New Zealand project PR3-0042) carried out in 1994 was to investigate the suitability of fixed slip friction meters for on-road determination of pavement surface abrasiveness of New Zealand sealed roads. This involves establishing the degree of correlation between tyre abrasion and the road surface friction coefficient, as measured by a Findlay Irvine GripTester. The general operation of the GripTester is described in Appendix 1 of this report.

The output of this stage of the project was intended to be:

- the development of a reliable method for on-road determination of road surface abrasiveness; and
- provision of technical information related to the influence of aggregates on friction and tyre wear characteristics of road surfaces that can be readily incorporated in road design guides and cost analysis procedures.

Eighteen separate test sites, located in the Wellington region, New Zealand, were selected for study, each of about 400 m length. These included at least two examples of each of a range of different pavement surface types: grade 2 to grade 6 chipseal, friction course, asphaltic concrete, and slurry seal (see Appendix 2 of this report).

Tests were performed during the period 28 July 1994 to 8 September 1994. Figure 1.1 shows a typical test in progress. The measurement procedure is described in Appendices 3 and 4 of this report.

The report includes the following sections:

- Discussion of the background to the current research, and the proposed procedures at the outset of the project.
- Description of the test results.
- Analysis of the wear coefficient measurements, and discussion of the micro-tread wear model, employed in the World Bank's HDM III model (Watanatada et al. 1987).
- Comments on tyre abrasion studies by several international researchers, in relation to the current study.
- Discussion of the research findings, conclusions and recommendations.
- Appendices describing technical aspects of the research procedure.

Figure 1.1 GripTester tyre abrasion measurements in progress at site no. 16.

2. BACKGROUND

As part of Stage 1 of this Transit New Zealand Research Project PR3-0042, a detailed analysis of the World Bank's HDM III micro-tread wear model (Watanatada et al. 1987) was performed. This analysis highlighted that the energy generated by horizontal tyre forces and abrasiveness of the pavement surface are the major factors that determine wear rates of tyre rubber.

Horizontal tyre forces over a road section can readily be determined either by direct or indirect on-road measurements, or analytically if the road section attributes (geometric and surface characteristics) are known. By comparison, no simple reliable means of determining the abrasiveness of a road section presently exists.

Previous work by Kienle et al. (1972) has shown that friction at the tyre–road interface consists essentially of a hysteretic component and an adhesive component. The hysteretic component is dominant under wet skid and wet traction conditions, particularly on road surfaces with high macrotexture (i.e. surface profile wavelengths between 0.5 mm to 50 mm) such as coarse chipseals. The adhesive component becomes more important on surfaces with high microtexture (surface profile wavelengths less than 0.5 mm) or under dry skid or dry slip conditions. However, the adhesive component promotes abrasive wear because sharp microstructure road asperities (0.1-0.4 mm diameter) scratch the surface of the tread rubber during sliding associated with cornering, braking and accelerating. Therefore, on relatively clean road surfaces, the friction usually improves with an increase in the number of asperities of road microtexture dragging through the body of the tread rubber, but at the expense of increased tyre abrasion. This suggests that a high degree of correlation can be expected between the output from friction meters in use in New Zealand as at 1994, such as the GripTester, Mu Meter and SCRIM (Sideways-force coefficient routine investigation machine), and the abrasiveness of the road surface.

Because the GripTester was available at Opus Central Laboratories (formerly Works Central Laboratories), the opportunity was taken to investigate its suitability in measuring the relative abrasiveness of road surfaces. The main component of this device is a blank rubber measurement wheel rolling on a road surface under controlled operating conditions (constant wheel load, constant slip, constant speed). The relative abrasiveness of the surface can therefore be determined by the wear of the measurement wheel per distance of travel. Since measurements will be performed under controlled operating conditions, the only variables affecting differences between the wear of the measurement wheel on different surfaces will be the abrasive properties of the surfaces. A study was therefore performed to establish the relation between the output from the GripTester, which is the Grip Number representing a measure of friction coefficient, and the wear of the slipped measuring wheel represented by its weight loss. The dependency of friction and tyre wear on other significant parameters, such as polished stone value, macrotexture depth and tyre surface temperature, was also investigated, together with the masking effects of surface water.

The controlled tests were conducted on homogeneous road sections, typically 200 m or more in length, to promote a weight change in the slipped measuring wheel that can be measured reliably by precision electronic scales (i.e. accuracy greater than 0.2 g. The selected road sections had comprehensive surfacing construction details available about them, and included most of the surface types commonly encountered on New Zealand roads. Special effort was made to include several road sections of the same surface type so that the effects of roading aggregate source and traffic loading on friction and tyre wear characteristics could be established.

As flexibility is required to measure the surface abrasiveness of both short road sections (of around 400 m length) and long test routes (of several 100 km in length), either of which may be used in future tyre wear studies, the effect of measuring the Grip Number at different speeds was also investigated. Thus the GripTester was manually pushed over short test sections and towed behind a vehicle over long test road sections so that a range of speeds from walking pace to 100 km/h could be used.

The research was carried out to advance our understanding of surface characteristics affecting friction and wear of tyres, thereby leading to optimised surfacings for different traffic conditions.

3. TEST RESULTS

3.1 Presentation of Results

The results are listed in Table 3.1. Of the 18 sites tested, the abrasion measurements from four sites have been discarded (refer Appendix 5 of this report). The columns in the table list the following facts:

1. The site number.
2. The pavement surface designation.
3. The NAASRA[1] road roughness vehicle measurement for the site (obtained from the site selection report).
4. The average least dimension (ALD), in mm, of the chip size for the chipseal surfaces (from site selection report).
5. The polished stone value (PSV) of the pavement aggregate material (from site selection report).
6. The sensor-measured texture depth (SMTD), in mm, of the pavement surface. This was measured using a WDM mini texture meter (MTM), which is a laser-based surface texture measurement device. The SMTD value was measured on the listed test date.
7. The order in which the 18 road sites were tested.
8. The date on which test was carried out.
9. The identification number of the measuring wheel used for the dry abrasion test.
10. The identification number of the measuring wheel used for the wet abrasion test.
11. Length of the test strip (in metres) (as measured during the wet abrasion test).
12. The dry Grip Number, measured with the GripTester water supply switched off.
13. The wet Grip Number, measured with the GripTester water supply switched on.
14. The dry tyre abrasion (abr.) in grams.
15. The wet tyre abrasion (abr.) in grams.
16. The dry tyre abrasion (abr.) rate in g/km.
17. The wet tyre abrasion (abr.) rate in g/km.
18. The dry volumetric tyre abrasion (abr.) rate in $dm^3/1000$ km.
19. The tyre tread wear coefficient (CT) in dm^3/MJ, after Watanatada et al. (1987).

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[1] National Association of Australian State Road Authorities

Table 3.1 Summary of GripTester test results.

Site	Type	NAASRA	ALD	PSV	SMTD	Test Order	Test Date	Dry Wheel	Wet Wheel	Length	Grip No. (dry)	Grip No. (wet)	Abrasion (dry)	Abrasion (wet)	Abr. Rate (dry)	Abr. Rate (wet)	Volumetric Abr. Rate (dry)	CT (dry)
			(mm)		(mm)					(m)			(g)	(g)	(g/km)	(g/km)	(dm^3/1000km)	(dm^3/MJ)
1	Gr2/1	74	12	54	1.98	17	06/09/94	R1	R9	481	1.022	0.812	0.21	0.16	0.44	0.33	0.39	0.0016
2	Gr2/2	64	10	55	1.68	2	01/08/94	R2	R3	402	0.987	0.816						
3	Gr3/1	51	9	55	1.38	4	11/08/94	R2	R3	402	1.020	0.876	0.17	0.14	0.42	0.35	0.37	0.0016
4	Gr3/2	68	8	55	1.19	13	25/08/94	R2	R3	381	1.042	0.846	0.22	0.04	0.58	0.10	0.51	0.0021
5	Gr3/3	39	9	56	1.72	12	25/08/94	R8	R9	459	1.014	0.887	0.24	0.16	0.52	0.35	0.46	0.0020
6	Gr3/4	45	10	56	1.59	11	22/08/94	R2	R3	407	1.022	0.871	0.34	0.05	0.84	0.12	0.74	0.0031
7	Gr4/1	61	7	55	1.65	9	18/08/94	R2	R3	507	1.028	0.940						
8	Gr4/2	66	7	55	1.00	5	11/08/94	R8	R9	382	1.030	0.866	0.25	0.18	0.65	0.47	0.58	0.0024
9	Gr5/1	35	7	55	1.35	8	18/08/94	R9	R8	443	1.062	0.905	0.51		1.15		1.02	0.0040
10	Gr5/2	79	5	56	0.84	10	22/08/94	R9	R8	462	1.096	0.831	0.32	0.18	0.69	0.39	0.61	0.0023
11	Gr6/1	91	5	55	0.74	18	08/09/94	R3	R2	442	1.161	0.892	0.31	0.06	0.70	0.14	0.62	0.0020
12	Gr6/2	52	4	54	0.66	14	29/08/94	R3	R2	518	1.073	0.853	0.28	0.01	0.54	0.02	0.48	0.0018
13	FC/1	39		55	0.65	1	28/07/94	R9	R8	409	1.091	0.870						
14	FC/2	37		55	0.64	16	05/09/94	R2	R3	504	1.149	0.875	0.28	0.07	0.56	0.14	0.49	0.0017
15	AC/1	64		56	0.47	3	01/08/94	R8	R9	360	1.047	0.901						
16	AC/2	48		56	0.41	15	31/08/94	R9	R8	537	1.113	0.906	0.38	0.21	0.71	0.39	0.63	0.0022
17	SS/1	88		54	0.39	7	16/08/94	R3	R2	377	1.108	0.925	0.44	0.31	1.17	0.82	1.03	0.0037
18	SS/2	130		55	0.37	6	16/08/94	R9	R8	375	1.066	0.971	1.08	0.61	2.88	1.62	2.55	0.0099
Av.										436	1.063	0.880	0.36	0.17	0.85	0.40	0.75	0.0029

Columns 1 - 19: explanations are listed on p.12.
Gr1 to Gr6 = Grades 1 to 6 chip; FC = friction course; AC = asphaltic concrete; SS = slurry seal; /1 - /4 = site identifier
R1, R2, R3, R8, R9 = wheel identifier ; Abr. = abrasion; Av. = average; ALD = average least dimension; PSV = polished stone value; SMTD = sensor-measured texture depth

3.2 General Comments

1. The average dry abrasion weight loss (average of 0.36 g) was too small to be measured accurately and reliably. Therefore the weight loss results need to be treated with some caution. This problem is discussed in Appendix 5 of this report.

   The wet abrasion weight loss measurements were even smaller than the dry measurements, being approximately half the dry rate. Individual measurements may therefore be quite unreliable. The individual wet abrasion measurements are not discussed in detail. This difference in weight loss may be compared with a comment by Lowne (1970) who suggests that abrasion in the dry is about 2 to 5 times that in the wet. As road surfaces are wet for much less than half the time, most researchers used this difference to come to the conclusion that tyre abrasion on wet surfaces is only a minor consideration.

   The significant issue pertaining to tyre wear is how road surface friction in wet conditions correlates with tyre abrasion rates in dry conditions.

2. NAASRA road roughness measurements have been reproduced for reasons of completeness. However, these values are a measure of the large scale roughness of the road surface (i.e. profile wavelengths between 0.5 mm and 50 mm), and therefore have little or no relationship to the road surface friction or tyre abrasion rates, especially at very slow speeds. For example, the speed at which the Grip Number and tyre abrasion measurements were performed is 5 km/h, and so little or no wheel bounce is generated by surface irregularities such as cracks, potholes and ruts.

3. The PSV measurement is the skid resistance of a road surface aggregate material as measured by a British Pendulum Tester (BPT). The material has been set in a prepared mortar surface that has been subjected to polishing under controlled conditions. In general, the skid resistance of a well worn road surface correlates well with the PSV measurement.

   The PSV measurements for the road surface aggregate materials for this study are all in the range 54 to 56 because all of the roads used for the tests had been constructed of similar greywacke surface aggregate material. However typical PSVs range between 43 and 60 throughout New Zealand, depending on the source of aggregate in the region. Values up to 75 are required for some heavily trafficked locations to provide extra skid resistance (Transit New Zealand 1993). Consequently the test road surfaces have similar skid resistance characteristics, and do not give a range of PSVs typical of New Zealand roads. This failing in the experimental design is confirmed by the wet Grip Number measurements, which show a relatively small range of variation for the different road surfaces.

4. The SMTD value provides a measurement of the macrotexture of the road surface, with large chip size corresponding with a large SMTD measurement. A weak inverse correlation between SMTD and wet Grip Number is shown, to the extent that the largest SMTD (coarse Grade 2 chip, site 1) had the lowest wet Grip Number, and the smallest SMTD (slurry seal, site 18) had the highest wet Grip Number.

3.3 Grip Number and Tyre Abrasion Rate Comparisons

The measured values of wet Grip Number and dry tyre abrasion rate for the 14 sites where the data have been retained are plotted in Figure 3.1(a). Clearly the one significant outlier, SS/2 at site 18, has a substantial impact on any conclusions which may be drawn from the plot. Nevertheless, there is a suggestion of an exponential relationship between wet Grip Number and dry tyre abrasion rate. Also the abrasion rate must tend to zero as the wet Grip Number tends towards zero, and this reinforces the suggestion of an exponential relationship.

If the same data are plotted with a logarithmic y-axis, as in Figure 3.1(b), then a straight line can be fitted to the data, as shown. Such a proposed relationship would have important consequences for tyre wear considerations, as a small change in the wet Grip Number would have a major impact on tyre abrasion rate. However, the data are unfortunately not conclusive, and additional data points over a wider range of wet Grip Number are required.

Considering the different road surface types, the two slurry seal (SS) surfaces have the highest wet Grip Number and also produced the highest tyre abrasion rates. Unfortunately, only one data point is available for each of the asphaltic concrete (AC) and friction course (FC) surfaces. They both lie on the low side of the data fit, but this result may not be significant. Given the degree of error in both the Grip Number and tyre abrasion rate measurements, the data suggest that a fairly simple relationship may exist between wet Grip Number and dry tyre abrasion, which may apply over the full range of different surface types.

No comparable apparent relationship has been identified between the dry Grip Number (as opposed to the wet Grip Number discussed above) and the dry tyre abrasion rate. The reason for this is unclear. However, as wet Grip Number measurements are routinely measured for different road surfaces, this may be considered fortuitous as it is the wet Grip Number that produces the better data fit.

From equation (2) in Section 4 of this report, some researchers have previously proposed that the tyre abrasion rate is proportional to the square of the friction. The results shown in Figure 3.1(a) do not readily support this hypothesis.

Figure 3.1(a). Plot of wet Grip Number vs dry tyre abrasion rate for 14 sites.

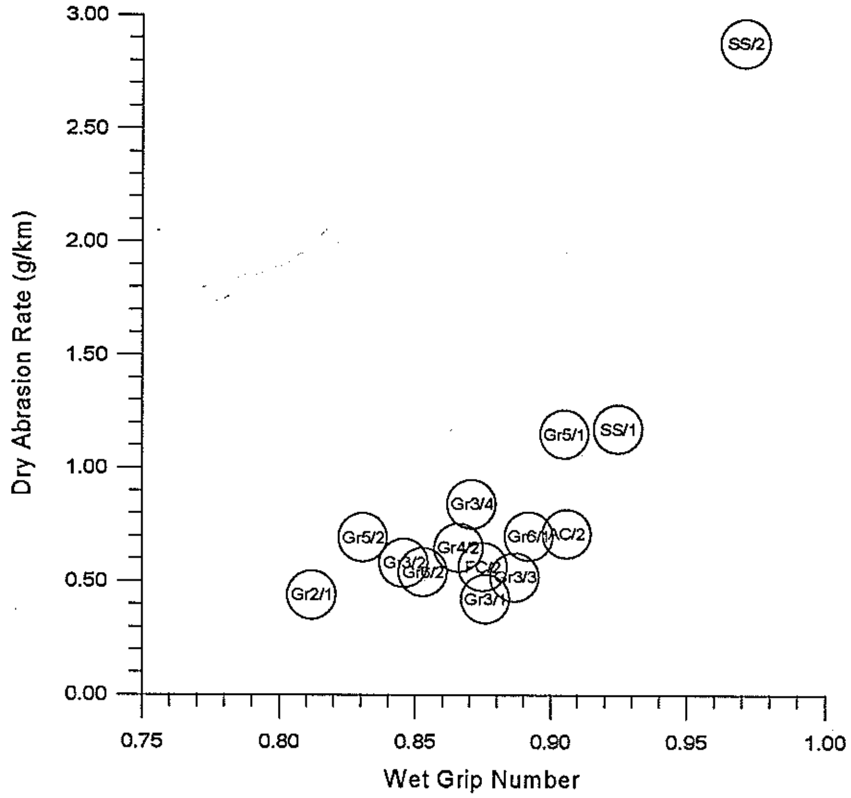
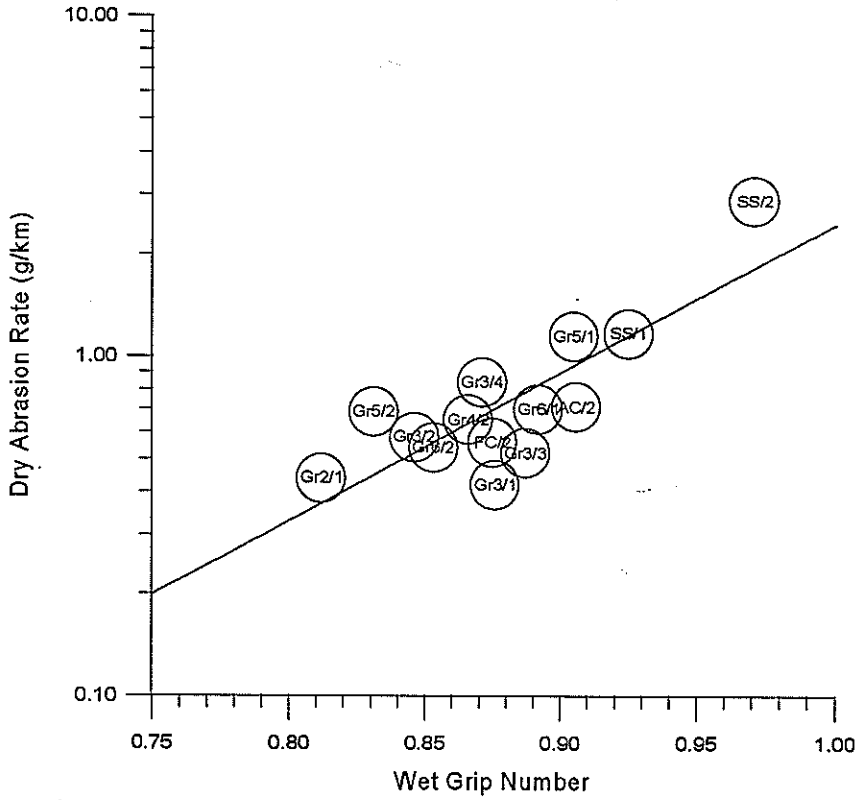


Figure 3.1(b). Plot of Figure 3.1(a), re-plotted using a logarithmic y-axis.



4. WEAR COEFFICIENT MEASUREMENTS

A tyre wear prediction model has been constructed by Zaniewski et al. (1982), and further developed by Watanatada et al. (1987). This is the micro-tread wear model, based on the concept of slip energy of the tyre–road surface interface. Watanatada et al. define slip energy as the product of tyre slip multiplied by the horizontal force on the tyre, where tyre slip is defined as:

(Vehicle speed – Peripheral speed of the tyre in the contact patch) / Vehicle speed.

A free rolling tyre therefore represents zero slip, whereas a fully locked tyre represents 100% slip.

As discussed by Cenek et al. (1993), the micro-tread wear model of Watanatada et al. can be simplified to:

$$\mathrm{TWT} = \mathrm{CT} \times \frac{\mathrm{TFT}^2}{\mathrm{NFT}} \qquad (1)$$

where TWT = volumetric tread wear of tyre(dm^3/1000 tyre-km)
CT = coefficient of tyre tread wear (dm^3/MJ)
TFT = the total tangential force acting on the tyre (N)
NFT = the load on the tyre in the direction normal to the tyre–road contact area (N)

(Note that the correct units for the values of CT are dm^3/MJ, and not dm^3/kJ as stated by both Watanatada and Cenek.)

For a slipping tyre, TFT/NFT is the slip friction coefficient μ. Therefore equation (1) may be rewritten as:

$$\mathrm{TWT} = \mathrm{CT} \times \mu^2 \times \mathrm{NFT} \qquad (2)$$

For the GripTester measurements, the following values are used:

NFT - The normal load on the test wheel
= 23 kg = 225.6 N

TWT - The dry abrasion measurements converted to volumetric abrasion rates. The measured rates are in the range 0.37 to 2.55 dm^3/1000 km.

μ - The Grip Number measured by the GripTester is similar to, but not the same as, the friction coefficient μ. However, as a first approximation, the measured dry Grip Number may be used as an estimate of the dry friction. The measured dry Grip Number values for this project are in the range 0.987 to 1.161, as listed in Table 3.1.

CT - Applying equation (2), the calculated CT values for this study are in the range 0.0016 to 0.0099 dm^3/MJ, with an average value of 0.0029 dm^3/MJ (refer Table 3.1).

Summarising the results from Watanatada et al., Cenek et al. (1993) has listed CT values measured on a range of road vehicles. These CT values varied from 0.0003 to 0.0057. The CT values measured with the GripTester and listed in Table 3.1 are therefore at the high end of the values reported previously in Cenek's 1993 report. However, it is not clear if CT values measured by a constant slip device like the GripTester may be directly compared with CT values measured for typical road vehicles. Nevertheless, the relative rankings of CT are expected to be comparable because the rubber compound of the GripTester's measuring wheel is similar to that of road vehicle tyres.

5. REVIEW OF OTHER INTERNATIONAL TYRE ABRASION STUDIES

5.1 Lowne (1970)

Lowne's (1970) conclusions included the following comments:

1. The experimental work that is described in his paper showed a large variation in the degree of tyre wear on different surfaces, the wear on the rough harsh surface being approximately three times as severe as that on the rough polished surface. In Lowne's context, rough pertains to macro-roughness of a road surface which constitutes individual stone chips. Typically these chips range in size from 6 mm to 20 mm. On the other hand, harshness of the surface refers to the micro-roughness of the exposed upper surface of the chip and typically has an amplitude ranging from 10 to 100 microns.

2. Measurement of weight loss provides a sensitive measurement of tyre wear.

3. Qualitative analysis showed that the harshness of the surface is of major importance in tyre wear, with surface roughness as a slightly modifying factor.

4. Quantitative analysis of various parameters indicating surface characteristics showed that the shape of the asperity tips (i.e. upper surface of the asperities) and the wet coefficient of friction at low speeds are major factors.

Lowne demonstrated that the best prediction of tyre wear, of the different predictive procedures which he considered, was given by an equation of the form:

$$W = A \, . \, N \, . \, \overline{\cot \alpha} + B \, . \, P + C$$

where W = the wear rating of the road surface

N = the number of wedge-shaped projections in the road surface microtexture, per unit length

α = the semi-angle of the apex of each microtexture asperity

P = the coefficient of wet friction

A, B and C = numerical constants

The results from our study, reported here, are generally in line with Lowne's conclusions. However, the range of tyre abrasion rates on different road surfaces measured in our study is more than six times the lowest measured rate, with a suggestion that a larger range of surface friction would produce an even larger range of tyre abrasion rates.

The abrasion measurements of the current study possibly could be predicted by Lowne's equation, but no attempt has been made to measure either N or α, and therefore this relationship cannot be confirmed. Lowne used a stereo-photogrammetry technique, measuring the height of the road surface at a spatial interval of 0.46 mm to obtain values of N and α.

5.2 Bergman and Crum (1973)

Bergman and Crum's (1973) conclusions included the following comments:

1. Abrasive tyre tread wear results primarily from the sliding of tread rubber on asperities of microtexture having the size range 0.1-0.4 mm.
2. Tyre tread wear results from severity of the test route which includes the total tangential force acting on the tyre and road surface abrasiveness, and from tyre characteristics composed of force slip characteristics and tread rubber properties.

The comments concerning microtexture are comparable to those of Lowne. From our current study, the harshness of the microtexture is likely to be the main cause of tyre abrasion, but no direct measurements of the harshness have been obtained to confirm this.

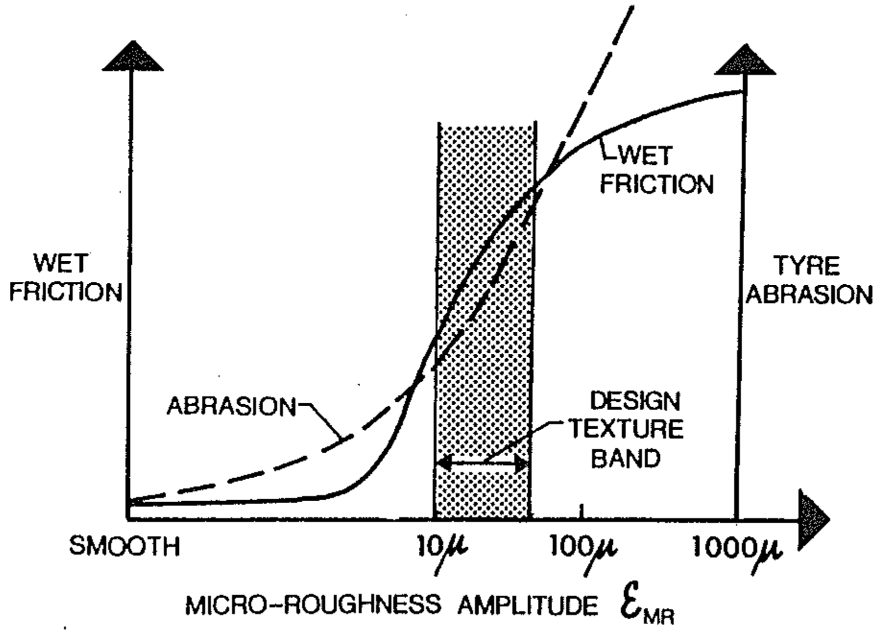
5.3 Moore (1975)

Moore (1975) comments that the effects of pavement micro-roughness, better known as microtexture, on both wet friction coefficient and tyre abrasion are clearly related (Figure 5.1). Both parameters increase non-linearly with increasing micro-roughness amplitude. Thus a compromise must be decided upon to maximise the friction while minimising abrasion losses.

A design microtexture ranging from about 10 µm to 70 µm appears to offer reasonably high coefficients of wet friction with a tolerable level of abrasion, as shown.

Indeed, the micro-roughness plays a fundamental role in counteracting and penetrating thin water films and, in establishing the magnitude required to minimise the likelihood of viscous hydroplaning, no account has been taken of the accompanying abrasion losses. Considerations of elastohydrodynamic interaction effects have suggested a range of microroughness from 3 µm to 10 µm, which is below the tolerable abrasion limit of 70 µm (indicated in Figure 5.1).

Figure 5.1 Tyre abrasion as function of pavement micro-roughness (i.e. microtexture) (reproduced from Moore 1975).



Moore's figure shows a complex relationship between wet friction and tyre abrasion. This relationship suggests that, for the current study, the observed relationship between dry tyre abrasion and wet Grip Number may not be readily extended beyond the range of the measured data. It also suggests that there is an important range of microtexture amplitude, up to about 100 µm, which produces an important benefit in terms of increasing wet friction. Above this range the wet friction reaches a plateau, whereas the tyre abrasion rate continues to increase steeply. This figure from Moore is an important diagram because it provides an insight into the relationship between friction and tyre abrasion.

5.4 Yandell and Gopalan (1976)

Yandell and Gopalan (1976) described experiments on artificial road surfaces, showing that tyre tread rubber abrasion increased as texture increased in fineness (i.e. a decrease in the size of surface asperities), and increased in ruggedness (i.e. an increase in the slope of the asperity profiles). Abrasion also increased as the damping factor of the rubber, and the load and speed of the rubber, all increased. The damping factor is defined as the area inside the stress-strain hysteresis loop divided by the area under the loading curve in the unconfined triaxial load-unload test on the tread rubber, with homogeneous stress conditions.

The test results showed that, at slip speeds occurring on roads, the removal of a certain range of fine texture can reduce tyre abrasion by 40%, but reduce friction by only 5%. These conclusions are therefore in broad agreement with those of Moore, and with the relationship between friction, tyre abrasion and microtexture amplitude indicated in his diagram (Figure 5.1).

6. DISCUSSION

6.1 Road Surface Abrasiveness

A procedure has been developed for the measurement of road surface abrasiveness, by measuring the weight loss on a test tyre fitted to a Findlay Irvine GripTester (see Section 2 in this report).

To obtain reliable tyre abrasion measurements using this machine, a minimum test length of 2 km of road is recommended to achieve typical dry abrasion rubber loss of at least 1 gram. This enables the weight loss caused by rubber abrasion to be satisfactorily distinguished from the natural variation in wheel weight caused by atmospheric conditions. However, the average test length used for this study was typically about 400 m, which is too short to achieve accurate tyre abrasion measurements using the GripTester. Therefore the current measurements include a significant degree of inconsistency related to the natural wheel weight variation.

Also the wisdom of using the GripTester in a dual role as an abrasion meter and a friction tester is questioned. This is because the GripTester has been designed to be used on wet pavements. Its operation on dry pavements results in increased loading of the sensitive measuring axle leading to possible over-ranging of the measuring system, and the need for more frequent replacement of the measuring tyre because of increased wear. Both effects have the potential to increase errors in the Grip Number measure of wet pavement friction.

6.2 Abrasion Rate to Grip Number Relationship

The test results show a large increase in tyre abrasion rate corresponding to a moderate increase in Grip Number. Therefore, in order to deduce the tyre abrasion rate through continuous measurements of the Grip Number, a very accurate measurement of the Grip Number is required. It is now known that variation occurs in the Grip Number measurement of road surfaces, for reasons which have not been fully determined but may include the influence of temperature and differences between test tyres. Therefore further work is required to ensure accurate Grip Number measurements.

The uncertainty in the Grip Number measurements is most pronounced when the GripTester is towed at speeds of 50 km/h typically used for road surveys. The current study was performed at 5 km/h, at which speed the Grip Number measurement is apparently more reliable because of less wheel bounce and reduced load transfer. The reliability of the Grip Number measurements at low speed needs to be proved, and the cause of the variation at high speed needs to be determined.

A substantial difference exists between the wet Grip Number measurements obtained at different speeds. This difference is not consistent for different road surface types. Consequently, any relationship between dry tyre abrasion rate and wet Grip Number measured at low speed is not clearly applicable to measurements made at high speed. At present, only Grip Number measurement at low speed seems likely to achieve the required accuracy to reasonably predict tyre abrasion rates.

6.3 Dry Abrasion Rate to Wet Grip Number Relationship

Despite the difficulties experienced in the measurement of both tyre abrasion rate and Grip Number, the results indicate a significant relationship between the dry tyre abrasion rate and the wet Grip Number measurement.

6.4 Range of Abrasion Rates and Test Surface Aggregates

A disadvantage of the study was that most of the measured data lay within a relatively narrow range of abrasion rates and Grip Numbers, with only one of the test road surfaces producing a considerably higher abrasion rate.

Additional data should be acquired for road surfaces specifically selected to demonstrate a range of Grip Numbers and abrasion rates wider than that used for this study. The road surfaces for the current study were selected to test a range of surface types and chipseal grades, but in many cases these produced similar Grip Numbers and tyre abrasion rates because of the common source of road aggregate.

Also only one data point has been obtained for each of the asphaltic concrete and friction course road surface types. This is insufficient to determine the influence of these surface types.

6.5 Dry Abrasion Rate to Dry Grip Number Relationship

No corresponding relationship between dry Grip Number and tyre abrasion rate was identified. In general, chipseal surfaces with small chip size had the highest dry Grip Numbers, the large size chipseal surfaces had the lowest dry Grip Numbers, and the other surface types produced intermediate Grip Number measurements.

6.6 Abrasion Rate, Chip Grade and Macrotexture Relationship

Chipseal grade determines the macrotexture of chipseal road surface. A range of tyre abrasion rates and wet Grip Numbers was measured for the chipseal surfaces, but no significant relationship between the chipseal grade and either of these measurements was identified.

6.7 Abrasion Rate to Road Roughness Relationship

There was no apparent correlation between road roughness (NAASRA measurements) and tyre abrasion, except that site 18 (SS/2) had NAASRA, tyre abrasion and wet Grip Number measurements which were all substantially greater than any of the other test sites.

6.8 Abrasion to Microtexture Relationship

Previous researchers (notably Lowne and Moore) have reported that tyre abrasion is primarily caused by road surface microtexture. Results from the current study suggest that this cause is correct, but do not confirm it, because the microtexture of the road surfaces was not measured directly.

The relationship between tyre abrasion and wet Grip Number may be generally applicable for a range of road surface materials, or may be applicable only to the greywacke material which was common to all of the test sites. This premise has yet to be verified.

Increased tyre abrasion could instead be caused by the scratching of the rubber tyre tread surface by road surface asperities that have a certain degree of sharpness or by angularity of the stone surface at a microscopic level. Both these types of microtexture may not necessarily produce good wet tyre grip. Thus very sharp asperities may tend to cut the rubber very easily, whereas more blunt asperities may contribute more to surface friction with less cutting of the tyre.

This issue can only be resolved by examining and measuring the microscopic characteristics of the surface microtexture, and comparing these characteristics with the tyre abrasion and Grip Number measurements.

6.9 Abrasion to Slurry Seal Surfaces Relationship

Site 18 (SS/2) produced substantially higher tyre abrasion rates than any other site. This slurry seal surface appears relatively smooth when viewed from above the pavement, but feels harsh to the hand, and has sand-like particles embedded in the surface matrix.

The slurry seal differs distinctly from the chipseal surfaces, which typically consist of stones of a regular size, of at least 5 mm ALD, with few smaller sand-like particles or asperities.

7. CONCLUSIONS & RECOMMENDATIONS

7.1 Measurement of Tyre Abrasion

A procedure was developed during the study for measuring the loss of tyre rubber from the GripTester test wheel by weighing the test wheel after it had traversed an abrasive surface. The rubber loss measured during the tests was insufficient to derive detailed conclusions from the measurements.

Recommendations

- For detailed analysis of tyre abrasion measurements, the rubber loss must be at least five times that achieved during this research project.

- For any future similar measurements the use of a purpose-built abrasion meter, operating independently of the GripTester, should be considered.

7.2 Relationship Between Wet Friction and Dry Abrasion Rate

The measurements of rubber loss indicate a general trend of dry abrasion rate increasing as Grip Number increases. The Grip Number is a measure of wet pavement friction as determined by the GripTester. Some of the data indicate that the abrasion rate may increase severely for only a moderate increase in wet pavement friction. However this increase must not be treated as conclusive evidence because large potential inaccuracies were recorded in the measurements.

Recommendation

- In order to confirm the true relationship between dry abrasion rate and wet pavement friction, as measured by Grip Number, a new set of measurements is required. The sites should be specifically selected to include surfaces covering a wide range of wet Grip Number.

7.3 Use of the GripTester for Determining Road Surface Abrasiveness

Measurement of pavement friction using the GripTester, or any other similar friction meter, is unlikely to be developed as the most appropriate method for on-road determination of pavement surface abrasiveness.

Recommendation

- To measure road surface abrasiveness, accurate procedures for measuring the abrasiveness more directly are required. These may include measurement of the abrasion of a test sample (e.g. a rubber block rubbed on the road surface, and weighed immediately before and after), or measurement by microscopic techniques of the size and shape of the surface asperities which cause the abrasion.

7.4 Validation of HDM III Micro-Tread Wear Model

The most commonly used model for predicting tyre tread wear as a function of vehicle and road characteristics is the micro-tread wear model employed in the World Bank's HDM III model. However, the rubber loss measurements do not fit well to the predictions of the micro-tread wear model but it is not known whether the observed discrepancy may be related to the inaccuracies of the rubber loss measurements.

Recommendations

- Considerably improved accuracy of rubber loss measurements is required so that the results can be compared with predictions of the HDM III micro-tread wear model.

- The GripTester is essentially intended for measurement of wet pavement friction. In order to apply the micro-tread wear model in the form proposed for application to the resulting Grip Number measurements, the current study has attempted to apply the dry Grip Number measurements. Careful consideration of the suitability of dry Grip Number measurements is therefore required for any future validation studies of the HDM III micro-tread wear model.

7.5 Road Aggregate Geometry Effects

The influence on rubber loss of macrotexture effects such as chip size, appears to be small from the results of this research. However, the influence of microtexture has not been examined. Previous researchers have suggested that asperities on the surface of the aggregate material do play a major role in determining road surface abrasiveness.

Recommendation

- Consideration of the microtexture geometry is essential for any future study of this type. This may include close-up photography of the road surface, laser profilometer measurements, and microscopic examination of the surface texture.

7.6 Influence of Microtexture Amplitude

All things being equal, the main increase in wet friction occurs if the microtexture (i.e. microscopic roughness on the surface of the roading aggregate) is in the amplitude range 0.01 to 0.1 mm. Aggregates with microtexture amplitude above this range afford relatively little additional increase in friction. In contrast, the tyre abrasion rate increases substantially for microtexture amplitude in the range 0.1 to 1 mm.

Control of microtexture amplitude therefore appears to have potential to reduce road user costs through reduced tyre wear while maintaining a reasonably high level of wet friction. This potential reduction in road user costs can be achieved by selecting pavement surfaces with microtexture amplitudes that are sufficiently large to maintain most of the benefits of high friction, but are not sufficiently large to cause excessive tyre wear.

On the other hand, as the most abrasive surfaces also produce the highest values of wet friction, their widespread use may possibly be justified because they contribute to improved road safety.

Recommendations

- The relative benefits of reduced tyre abrasion should be balanced with improved road safety, and also these benefits should be incorporated in the total road maintenance costs/road user costs equation.

- The combination of pavement surface characteristics which maximise the wet friction of a tyre should be identified. This will permit the most desirable surface characteristics which increase friction, and therefore safety, to be determined and differentiated from those characteristics which cause increased tyre abrasion.

7.7 Bituminous Sealing Manual

Very little distinction in tyre abrasion rates was observed among the different types of pavement surfaces tested, apart from the slurry seals. This result was attributed to the road aggregates being sourced from only the Wellington region. The slurry seals, which incorporate a sandy aggregate mix rather than aggregate chips, can achieve high levels of wet friction but cause substantially increased tyre abrasion rates.

Recommendation

- Road aggregates produced by quarries in New Zealand should be assessed for their abrasiveness, in addition to their polished stone value and resistance to crushing, properties which are presently (1996) measured. This requirement will necessitate the development of an appropriate test method for determining the abrasiveness of aggregate samples that can be incorporated in the Transit New Zealand (1993) Bituminous Sealing Manual.

APPENDICES

A1. GENERAL DESCRIPTION OF THE GRIPTESTER

Opus Central Laboratories (formerly Works Central Laboratories, Lower Hutt) operates a surface measuring instrument known as a GripTester which is suitable for measuring the coefficient of friction on roads, airport runways and walkways. The GripTester is manufactured by Findlay Irvine Ltd of Scotland. Approximately 80 GripTesters are in use worldwide.

The GripTester (Figure A1.1) consists of a small trailer which is either pushed by hand or towed behind a vehicle. It can be used at normal traffic speed so that it does not impede traffic flows.

The GripTester has three wheels: two drive wheels and a third measuring wheel which is geared to rotate at a proportionally different rate, thereby producing 14.5% slip relative to the drive wheels. The drag force induced on the slipping wheel and the vertical force are monitored, and the calculated friction is logged on a computer file.

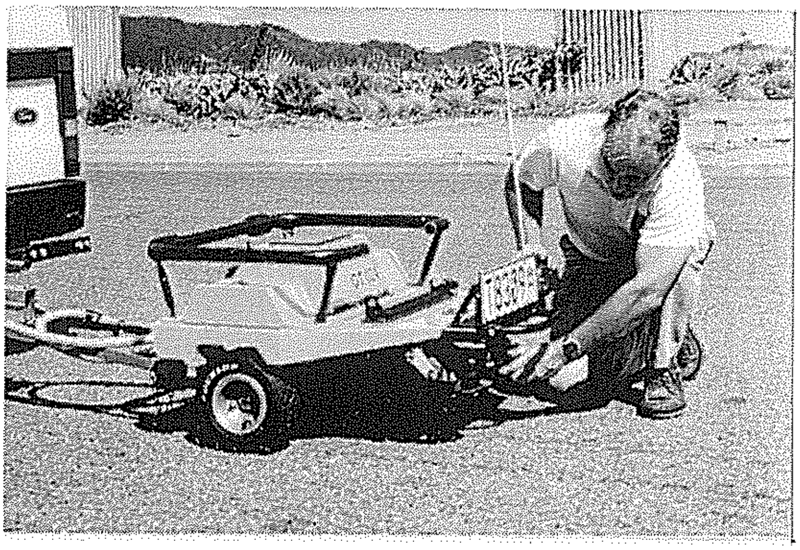
GripTester surveys are normally carried out on a wetted surface. Water is applied under the slipping wheel at a nominated rate which can be varied depending on requirements. A maximum water depth of 1 mm can be achieved at speeds up to 100 km/h with the water application system that is currently used.

The GripTester has undergone comprehensive evaluation in Europe in terms of its precision and correlation with other friction measuring devices (e.g. SCRIM and BPT). Authoritative relationships have been established between these instruments, and the UK Department of Transport has given the GripTester the same status as SCRIM for determining skid resistance levels of UK trunk roads and motorways. The resulting skid resistance data is in a format suitable for direct uplift into pavement management systems such as RAMM (Road Assessment and Maintenance Management system).

Central Laboratories have conducted several friction surveys as part of crash investigations on sections of roads where the lack of adequate friction is suspected to be a contributing factor. Because of its portability, the GripTester can be used for investigating the coefficient of friction in shopping malls and other pedestrian areas, e.g. railway platforms, large foyers in buildings, footpaths, etc. The British Civil Aviation Authority has recognised the GripTester for use on runways, and the Grip Tester has been accepted for inclusion in the ICAO (International Civil Aviation Organisation) Airport Services Manual (third edition). GripTesters are now in service at many international airports, including Auckland, New Zealand.

The GripTester is also easily able to determine the effect that vehicle speed has on friction for a particular surface. This is because the GripTester is capable of measuring friction over a speed range from 5 to 130 km/h, conditional on the towing vehicle being able to negotiate the route safely and within the law.

Figure A1.1 The GripTester, used for measuring friction of pavements.



A2. SITE SELECTION

Eight different surface types were used for the tyre wear study. These included chipseals ranging from grade 2 to grade 6 aggregates, friction course, asphaltic concrete and slurry seal. Two road sections were chosen for each surface type, and four sections of grade 3 chipseal. This gave a total of 18 test sections. The chosen sections were mostly on straight flat roads, 400 m or more in length, and within easy travelling distance of Wellington. The lengths as tested at some sites were less than 400 m because of the limited length of the particular surface or restrictions prescribed by traffic control requirements. The locations and Transit New Zealand estimated reference positions (ERPs) for the selected road sections are listed in Table A2.1.

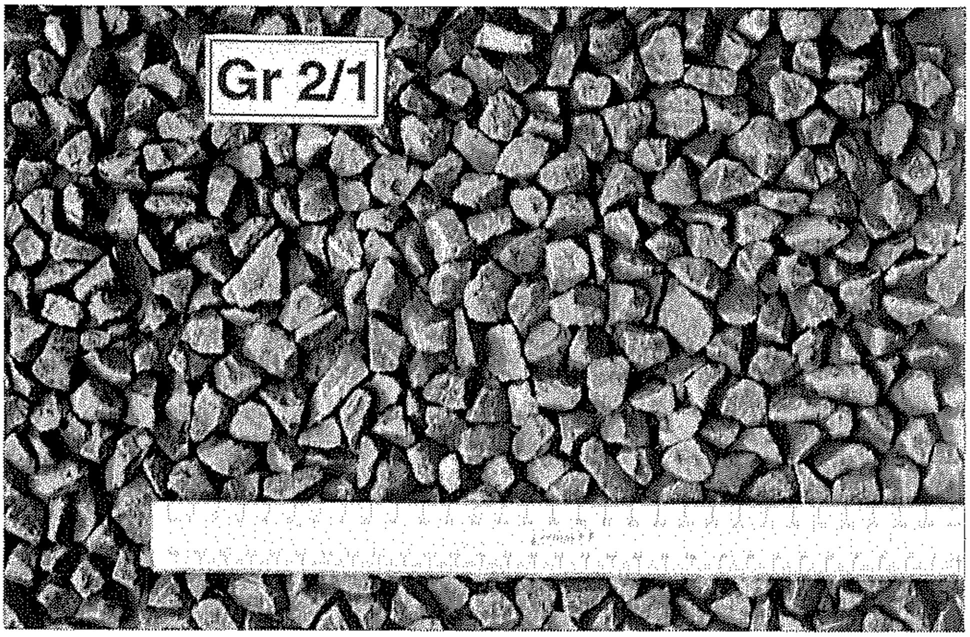
Table A2.1 Tyre abrasion at the 18 selected test sites.

Site no.	Designation	Location	Transit New Zealand ERP
1	Gr2/1	SH 1, Whitford Brown Bay to Paremata (NB)	969/1.0-2.0
2	Gr2/2	SH 58, Judgeford Straight (EB)	0/7.0-8.0
3	Gr3/1	SH 1, Te Horo passing lane (SB)	915/11.4-12.5
4	Gr3/2	SH 2, south of Mangaroa (SB)	946/0.0-1.0
5	Gr3/3	SH 2, north of Featherston (NB)	905/11.5-15.0
6	Gr3/4	SH 2, south of Greytown (SB)	905/5.8-11.4
7	Gr4/1	SH 53, east of Featherston (WB)	0/7.0-8.0
8	Gr4/2	SH 1, south of Otaki Bridge (SB)	915/7.7-8.3
9	Gr5/1	SH 53, east of Featherston (EB)	0/1.5-3.0
10	Gr5/2	SH 2, south of Carterton (SB)	883/18.5-19.5
11	Gr6/1	SH 1, Paremata to Whitford Brown (SB)	969/0.4-1.5
12	Gr6/2	SH 2, south of Silverstream (SB)	946/13.5-14.4
13	FC/1	SH1, Porirua off-ramp to Whitford Brown Bay(NB)	969/2.3-3.0
14	FC/2	SH 2, Dowse Drive to Melling (NB)	962/8.0-9.0
15	AC/1	SH 58, east of Pauatahanui Bridge (WB)	0/9.6-9.95
16	AC/2	SH 1, north of Paekakariki (SB)	942/9.0-9.4
17	SS/1	Moa Point Road, Lyall Bay (SB)	–
18	SS/2	Hatton Road, Karori (WB)	–

Gr1/ - Gr6/ = grades 1 to 6 chip; FC = friction course; AC = asphaltic concrete; SS = slurry seal;
/1 - /4 = site identifier
NB = northbound; SB = southbound; WB = westbound; EB = eastbound
ERP= Estimated Reference Position

Photographs of each of the eighteen road surfaces are shown on pp. 34-38.

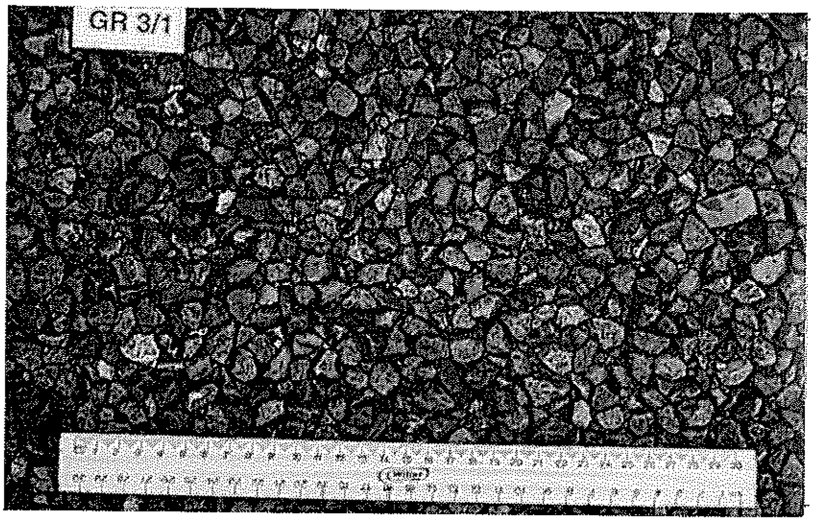
Appendix 2
Site 1, Gr2/1



Site 2, Gr2/2

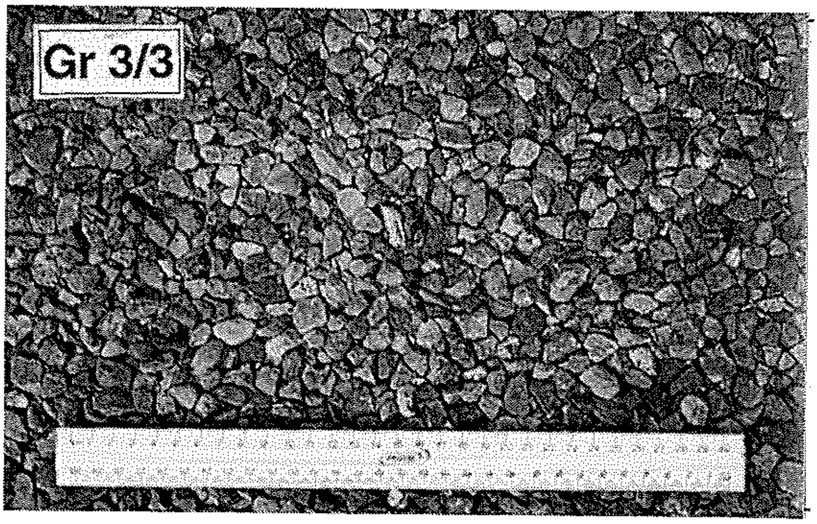
Scale marks are at 1 cm (10 mm) intervals on a 30cm ruler

Appendix 2 (continued)
Site 3, Gr3/1

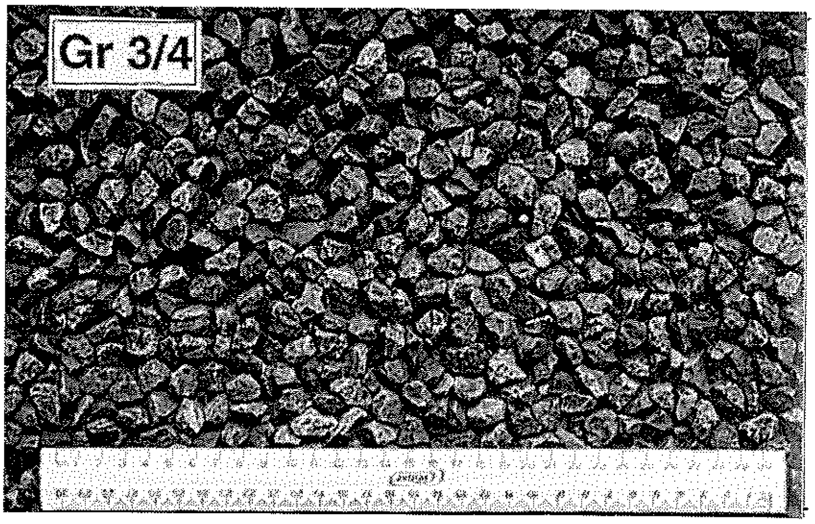


Site 4, Gr3/2

Site 5, Gr3/3

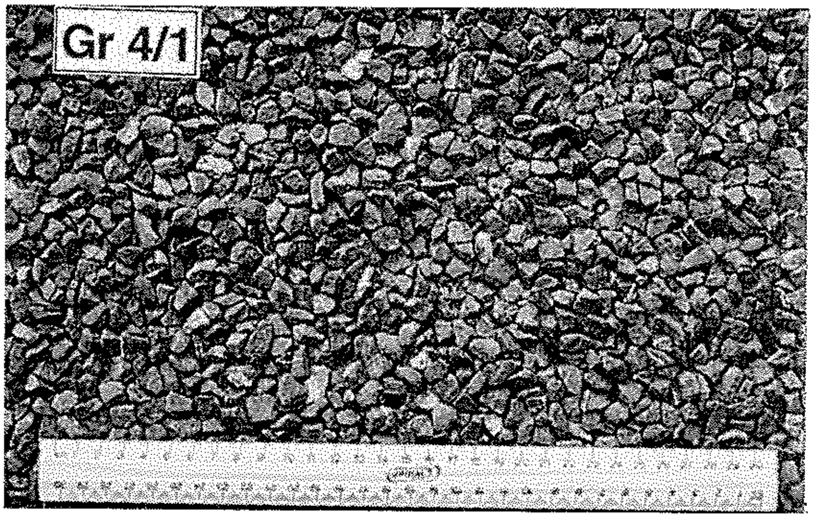


Site 6, Gr3/4

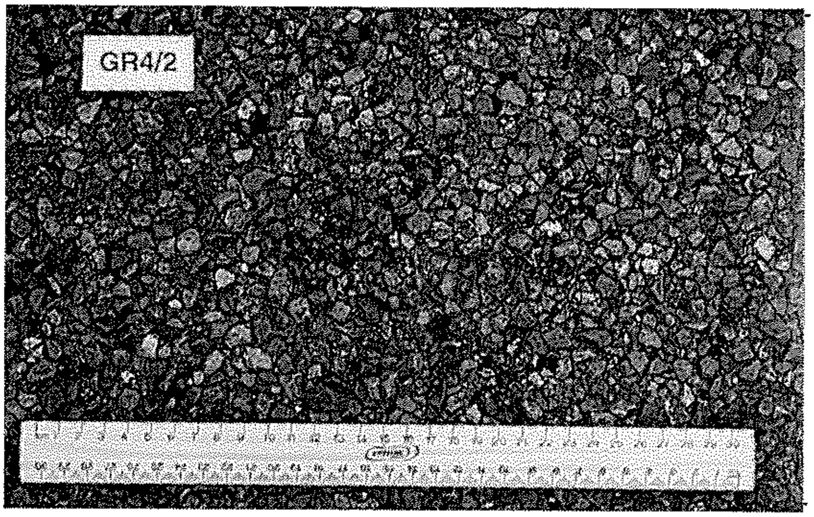


Scale marks are at 1 cm (10 mm) intervals on a 30cm ruler

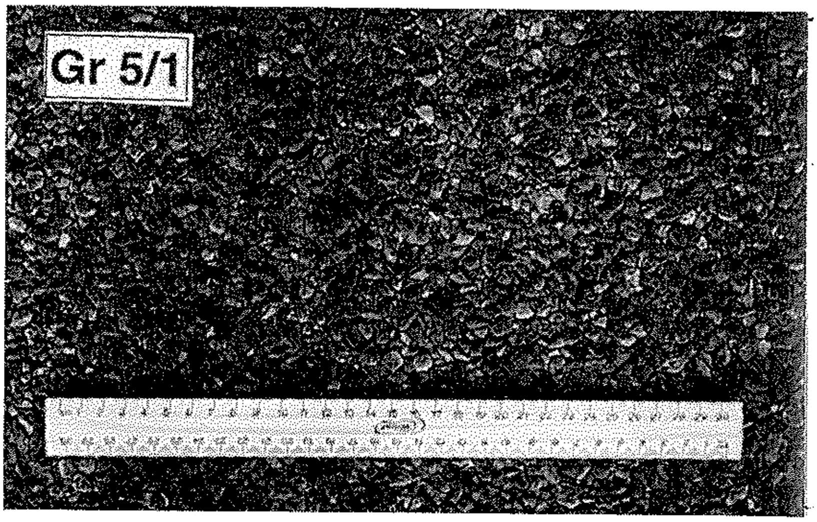
Appendix 2 (continued)
Site 7, Gr4/1



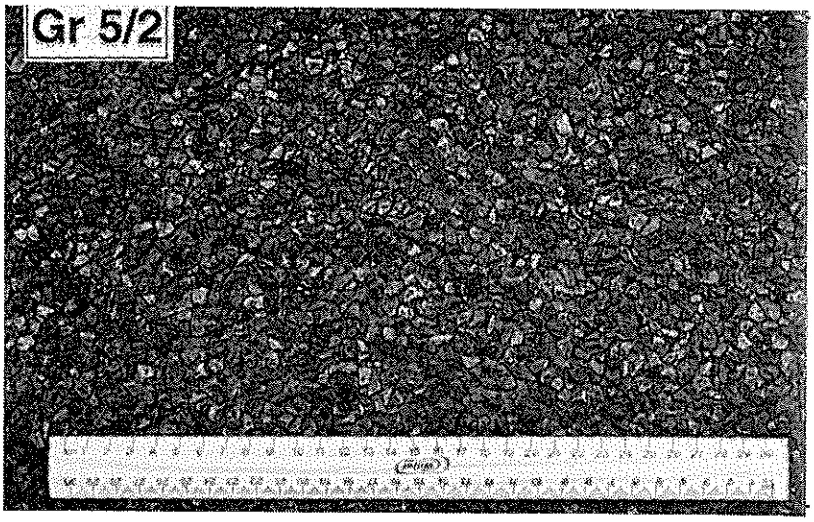
Site 8, Gr4/2



Site 9, Gr5/1



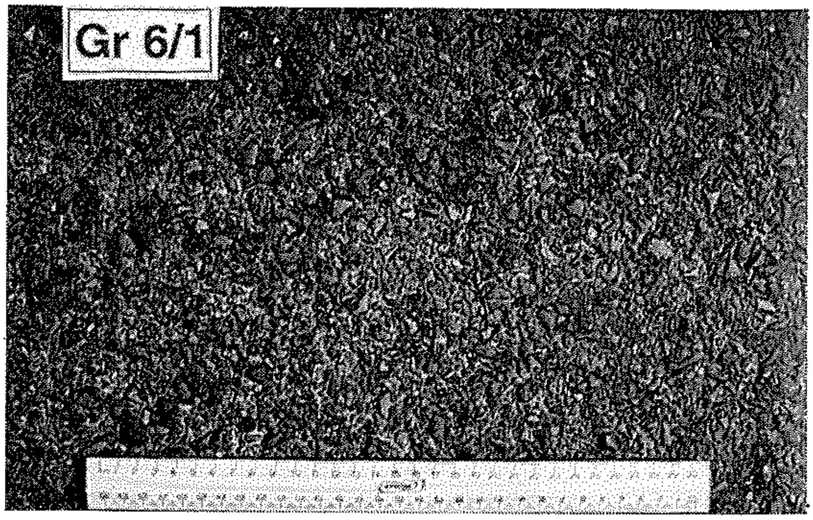
Site 10, Gr5/2



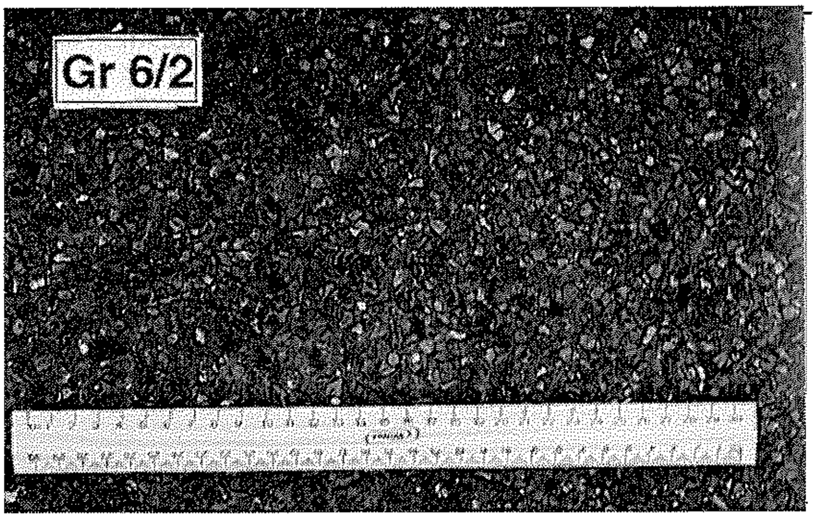
Scale marks are at 1 cm (10 mm) intervals on a 30cm ruler

Appendix 2 (continued)

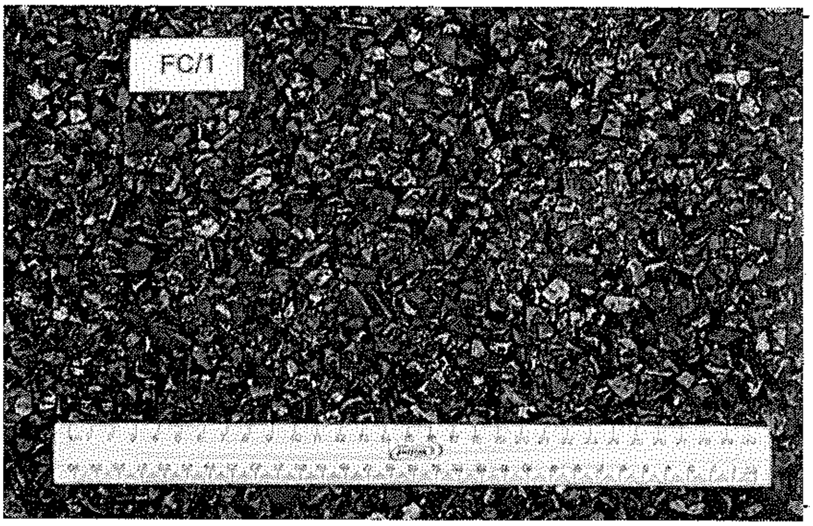
Site 11, Gr6/1



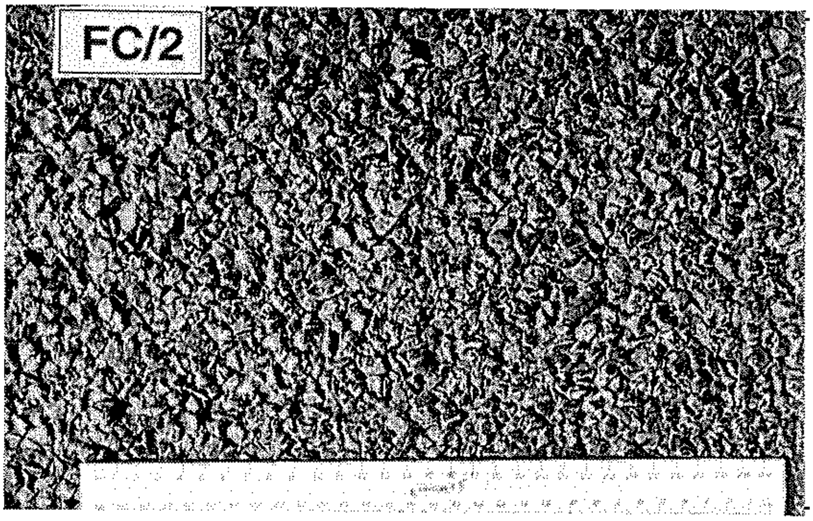
Site 12, Gr6/2



Site 13, FC/1

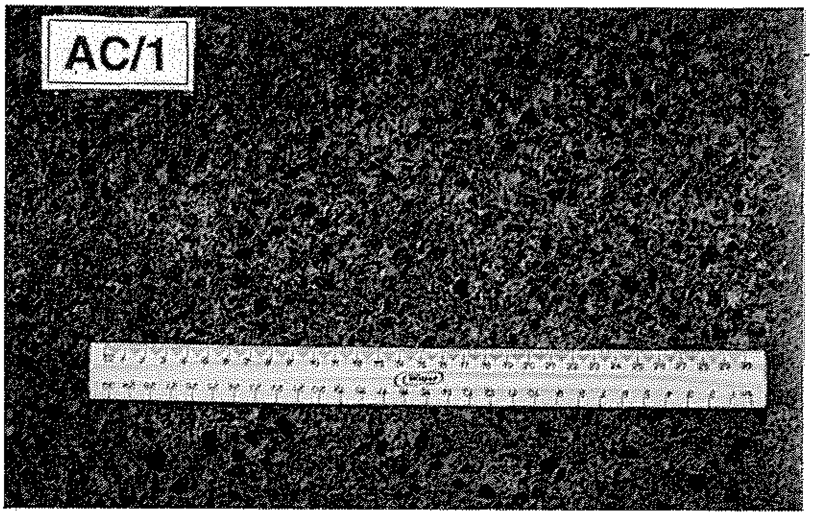


Site 14, FC/2

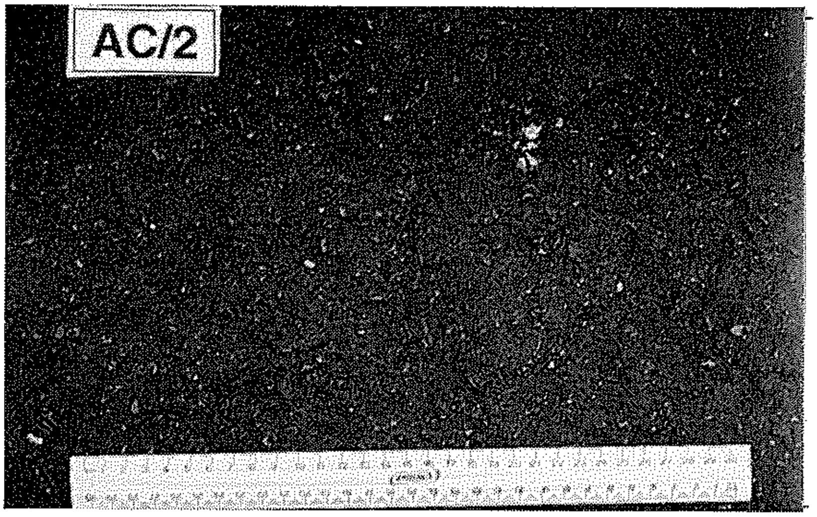


Scale marks are at 1 cm (10 mm) intervals on a 30cm ruler

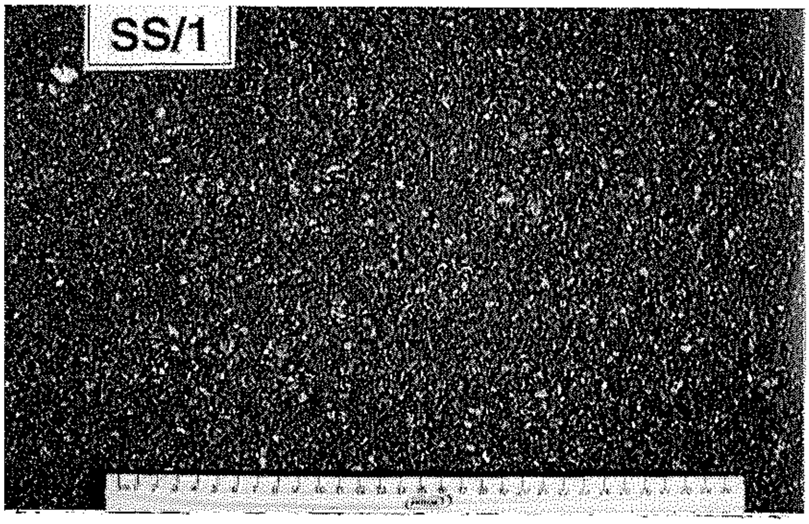
Appendix 2 (continued)
Site 15, AC/1



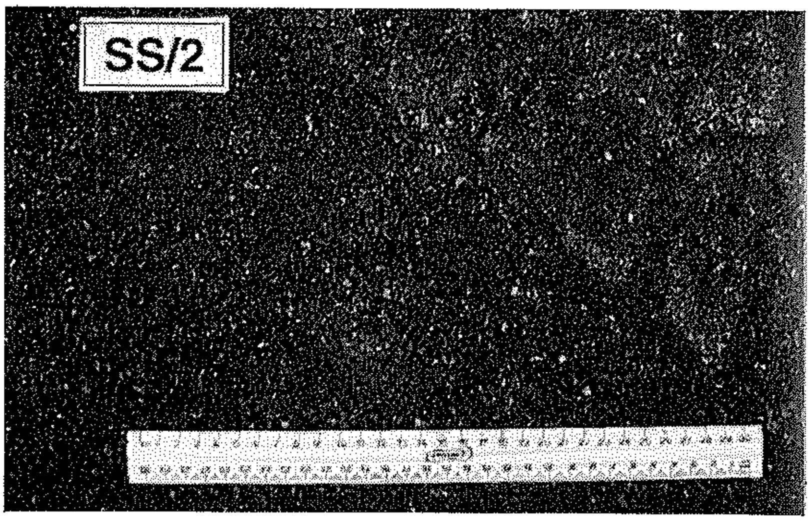
Site 16, AC/2



Site 17, SS/1



Site 18, SS/2



Scale marks are at 1 cm (10 mm) intervals on a 30cm ruler

A3. USE OF THE GRIPTESTER TO MEASURE TYRE ABRASION

Opus Central Laboratories operates a Findlay Irvine GripTester to measure road surface friction. This machine incorporates a smooth test tyre which slips at a steady rate over the road surface. This slipping causes abrasion of the tyre rubber. The overall design of the GripTester is quite similar to an abrasion meter described by Bergman and Crum (1973), which was a push-mode device specifically designed to measure tyre abrasion caused by road surfaces. The decision was taken to use the GripTester in the push mode rather than vehicle-tow mode to measure the road surface Grip Number and tyre abrasion simultaneously. Therefore the procedure adopted was similar to that described by Bergman and Crum.

The GripTester measuring wheel is 243 mm in diameter, and has a smooth rubber surface which is 55 mm wide. The wheel carries a steady load of approximately 23 kg. Variable loads caused by the change in weight of the water tanks, and the force on the push bar, are designed to be carried mostly on the two main drive wheels. The circumference of the measuring wheel rotates at a speed of 0.855 of that of the drive wheels. Therefore the rubber of the measuring wheel effectively slips forward over the road surface at a speed of 0.145 of the forward speed of the machine. At a push speed of 5 km/h, the typical tyre abrasion rate on a dry road surface is about 0.8 g/km.

The nominal density of the test tyre rubber (manufactured to ASTM standard) is 0.00113 g/mm^3. Consequently an abrasion rate of 1 g/km for the test wheel corresponds to a tread wear rate of 1 mm per 47.4 km, or a volumetric tread wear rate of 0.885 dm^3/1000 km.

$$1 \text{ mm tread} = 1 \times 55 \times 243 \times \pi \text{ mm}^3 \text{ rubber} = 41{,}987 \text{ mm}^3 \text{ rubber}$$

and

$$1 \text{ g/km abrasion rate} = \frac{1}{0.00113} \text{ mm}^3\text{/km} = 885 \text{ mm}^3\text{/km} \qquad (= 0.885 \text{ dm}^3\text{/1000 km})$$

$$\therefore \quad 1 \text{ mm tread} = \frac{41{,}987}{885} = 47.4 \text{ km}$$

In the push mode used for the abrasion tests, the GripTester carries water tanks which can apply a film of water to the road surface in front of the test wheel. Grip Number and tyre abrasion measurements were performed with the water supply switched on (for the "wet" measurements) and switched off (for the "dry" measurements).

The decision to use the GripTester as an abrasion meter is of debatable benefit. Variation is known to occur in the Grip Number measurement for road surfaces, for reasons which have not been fully determined but may include the influence of temperature and differences between test tyres. Therefore, the additional measurement of tyre abrasion rates using the GripTester, involving repeated changes of test tyres, is likely to increase the variation in Grip Number measurements. Unfortunately, five test tyres had to be employed to keep the duration of testing to an acceptable length of time. If only one measuring tyre has been used, only one measurement every three days could have been executed due to the required conditioning of the measuring tyre.

The essential features of the abrasion measurements in the study are that a test tyre is operated at a fixed slip rate under approximately constant load. This could be reasonably achieved using a purpose-built abrasion meter operating independently of the GripTester.

The main advantages of using the GripTester for the abrasion measurements are:

- It is available, and operates quite satisfactorily as an abrasion meter;
- It is a device with known operating characteristics, and the results could be compared with similar tests using other GripTesters (used overseas, for example);
- The wet abrasion and wet Grip Number are measured simultaneously, which is advantageous because the water supply rate is controlled, and no potential for variation in measurements related to the water supply is likely. However, detailed knowledge of the wet tyre abrasion rate is of limited value, as it contributes little to total vehicle tyre wear. For the current study, the wet tyre abrasion measurements were largely unsuccessful as the rubber weight loss was too small to be measured reliably.

The disadvantages of using the GripTester for the abrasion measurements are:

- The potential for increased errors in the Grip Number measurements;
- The rate of abrasion of the GripTester tyre is relatively small, and therefore requires a fairly long test section. A purpose-built abrasion meter would probably be designed to abrade the tyre at a faster rate being with a fixed slip that is greater than 14.5%.

A4. GRIPTESTER OPERATION PROCEDURE

A4.1 GripTester Calibration and Test Configuration

Full calibrations, according to the manufacturer's instructions, were conducted on a regular basis during the test programme. Spot calibration checks were also performed before and after each day's testing. As one aim of this project was to compare the wear rates of different surfaces under dry and wet conditions, the GripTester was set up so that the test configurations were as identical as possible. Consequently, the self-watering system was installed on the GripTester for all runs, including dry runs, and the water tanks were filled to the same level before each test run. This self-watering system was calibrated to provide a surface water film of 0.25 mm at the proposed push test speed of 5 km/h.

As the GripTester was not supplied with a device to measure the speed, a Cateye Mity 2, model CC-MT200, bicycle computer was fitted to the left hand treaded drive tyre on the GripTester. This device, which uses a non-contact magnetic sensor, can be programmed to display the instantaneous speed and the distance travelled. These readings are updated once a second.

A4.2 Preparation for Push Test Runs

On arrival at the test strip the GripTester was unloaded, switched on, and left for 5 minutes to allow it to warm up, according to the manufacturer's instructions. The calibration was checked and switches on the signal processing unit were also checked to ensure that they were on "Friction", "Push" and "Roads".

The output from the GripTester was connected via a cable to the RS 232 port on a laptop PC. This PC sat on top of the GripTester. Power for the PC was provided by a sealed 12V lead acid battery. The self-watering system was clipped in place and the water tank levels checked. The pushing handle was installed and clipped in place.

Before commencing any test runs, readings were taken of atmospheric pressure (Baromec barometer), dry and wet bulb temperatures (rotating thermometers), and road and tyre temperatures (contact thermometer). The GripTester, with one of the test tyres in place, was shifted to the centre of the lane at the start of the test strip. The test tyre was kept up, off the ground, by using the transport buggy.

A4.3 Dry Test Runs

The transport buggy was removed and the survey was started by triggering the PANELS software and pushing the GripTester over the test strip. The speed was increased to 5 km/h as quickly as possible, and then maintained at this rate for the rest of the test strip. At the end of the test strip, the measuring system was stopped and the acquired data analysed to provide values of the total length and the average Grip Number. The tyre and road temperatures were measured, the dry test tyre was removed, and the next test tyre was put on. The transport buggy was clipped in place to keep the next test tyre up off the ground, and the GripTester was pulled back to the start of the test strip.

At sites where the available distance was significantly less than 400 m, the test runs were repeated with the same test tyre, as many times as were necessary to give a total distance of about 400-500 m.

A4.4 Wet Test Runs

The wet test runs were carried out following exactly the same procedure as the dry test runs, apart from turning on the water supply before measurements were taken. As with the dry test runs, the tyre and road temperatures were taken before and after the test runs.

A4.5 Grip Number

The Grip Number measured by the GripTester is similar to but not the same as road surface friction μ. Friction is usually defined as the horizontal force divided by the vertical force. In the use of the GripTester, the Grip Number is the measured horizontal drag divided by the measured vertical load on the test wheel. However, because of the mechanisms involved in these measurements, the measured load and drag forces are not necessarily the true vertical and horizontal forces. Consequently, the Grip Number should simply be regarded as a measurement produced by the GripTester which is analogous to friction. The measured Grip Number is known to be influenced by road slope and curvature, but for this study these effects were minimised by testing straight horizontal road surfaces wherever possible.

Since the measurements for this study were performed, additional tests with the GripTester have found that the Grip Number measured on individual stretches of road changed by up to 0.12 within a period of 2 hours (tests performed at 50 km/h using different test tyres). The reasons for these changes are not understood at the time of writing (1996): they may include differences between the nominally identical test tyres, other measurement errors, or real changes in the friction of the road surfaces, possibly related to the surface temperature.

This variation of Grip Number measurements is a serious concern for the current study, as this potential difference of up to 0.12 between consecutive Grip Number measurements is essentially the same as the range of wet Grip Number measurements which were recorded during the study (all but one of the measurements were within a range of 0.13). The use of different measuring tyres is one of the suspected causes of variability in the results.

Nevertheless the Grip Number measurements recorded for this current study are essentially correct, and repeatable to within ±0.03. Push mode measurements at low speed are expected to be more repeatable than the towed tests at 50 km/h, because at the higher speed there is a large oscillation of the measured load and drag signals, which is caused by the GripTester bouncing and rocking on its suspension.

A5. RUBBER WEIGHT LOSS MEASUREMENTS

The principle of the tyre abrasion measurement procedure is that the measurement wheel was weighed before and after a test, and the difference between the two weights can be ascribed to loss of tyre rubber caused by abrasion. In practice, considerable attention to detail is required to eliminate other potential causes of wheel weight change such as absorption of moisture or accumulation of road debris, and changes in rubber weight related to atmospheric conditions. Therefore all these factors must be accounted for by the measurement procedure.

Five wheels with new tyres, designated R1, R2, R3, R8 and R9, were used during the study. The tyres came from the same manufacturer's batch, and therefore the abrasion rate of the rubber in each tyre should in theory be identical.

A5.1 Tyre Weighing Before Abrasion Tests

After initial operational tests with the GripTester, the tyres were placed in a controlled environment room at a nominally constant temperature of 21 °C and relative humidity of 50%. They were left in this room for the weights to stabilise under controlled and repeatable conditions. The tyre weights were measured using a Sartorius 5500.00 g balance. All tyres were brushed to remove any dirt and the valves were removed when weighing was conducted. A standard 2 kg reference weight was used to check the balance's repeatability each time it was used.

A5.2 Tyre Weighing Before and After Abrasion Tests

Immediately before each of the GripTester surveys on the 18 test sites, all the tyres were weighed, and those intended for use were lightly sanded to ensure that the tyre surfaces were essentially the same for each test. The tyres to be used were then weighed again and inflated with dry nitrogen to the specified pressure of 137.9 kPa (20 psi).

After each GripTester survey the tyres were dried to remove any excess water, brushed to remove any dirt or grime, deflated, valves removed, and weighed. They were placed in an oven at a temperature of 21 °C or 30 °C for a period of 16 hours (see Section A5.3 following). They were then weighed several times each day to monitor the process of tyre weight stabilisation. The aim was to achieve the same stable tyre conditions before and after each test, so that the measured weight difference was only that caused by road surface abrasion. At least two days were allowed between successive site tests.

A5.3 Difficulties Experienced with Rubber Weight Loss Measurement

A5.3.1 Effects of Atmospheric Conditions

The weight of a piece of rubber fluctuates with time because of changes in atmospheric conditions including temperature, humidity and atmospheric pressure. The Central Laboratories' controlled environment room was used to provide steady temperature and humidity conditions in which to stabilise the rubber weight before and after an abrasion test.

The weight of a wheel at any given time could be measured with a repeatability of better than ±0.01 g (each wheel, including tyre, weighed about 2 kg). However, even in the controlled environment room, it was difficult to achieve a stable weight which did not vary with time. In nominally stable conditions, after the initial three days stabilisation period, the wheel weight after an abrasion test typically fluctuated by about ±0.03 g, with wheel weight changes of up to 0.1 g being measured on occasions. Therefore the tyre weight loss caused by abrasion during a test could only be measured to within about ±0.06 g, allowing for the potential weight fluctuation before and after the test. This fluctuation over time was not consistent for each wheel; it was possible for the weights of some wheels to increase while others decreased, even though they were stored together in the same controlled environment room.

The median measured tyre abrasion for dry tests was 0.29 g, and for wet tests was only 0.16 g. Therefore the possible error, for the wet tests in particular, is large compared to the measured tyre abrasion. For this reason, discussion of the individual wet tyre abrasion measurements has been avoided in this report. Also, the wet abrasion measurements suggested some additional variation, possibly because the tyres had been wetted during the test process.

At least one test (at Site 9) produced an unusually large and unexpected measured weight loss. The reason for this has not been explained, but is probably not related to tyre abrasion alone. The wet tyre measurement for site 9 has been omitted from the results for this reason.

The procedure used for tyre abrasion measurements went to considerable lengths to minimise sources of error, but even so the final errors were relatively large compared to the measured tyre abrasion. For any future tyre wear study, the amount of tyre wear for each test should be increased by a factor of at least 5, and preferably by a factor of 10. This increase probably therefore requires a proportional increase in the length of the measured road surface, or else the use of a purpose-built abrasion meter which achieves the required weight loss in a shorter length of road.

A5.3.2 Effects of Drying on Tyre Weights

Efforts to optimise the weight measurement procedure were made during the course of the tyre abrasion study, and therefore the tyre weight stabilisation procedure was not identical for each test.

For the initial tests, the drying oven temperature was set to 40 °C. The drying process at this temperature was found to produce an initial weight loss substantially greater than the tyre abrasion loss, and up to a month in the controlled environment room was required for this weight loss (due to moisture loss from the tyre) to be recovered. This was unsatisfactory, and therefore the measurements from sites 2, 13 and 15 have been omitted from the results.

On another occasion the use of the drying oven was omitted from the test procedure, and this also produced unsatisfactory effects. Therefore the measurements from site 7 have been omitted from the results.

Of the remaining tests, the first half were dried at 30 °C and the second half were dried at the ambient room temperature of about 21 °C. No difference was apparent between the effects of drying at these two different temperatures.

A5.3.3 Conclusions

The optimum procedure for stabilisation of the wheel weight before and after an abrasion test should therefore include:

- drying in the oven at 25 °C for 16 hours;
- stabilising wheel weight in the controlled environment room for at least three days;
- using a more stable controlled environment than is currently available in the Central Laboratories' controlled environment room, to achieve more accurate weight loss measurements.

Bergman and Crum (1973) used a control tyre during their study which was treated in the same way as their other test tyres except that it was not abraded. In this way, weight changes related to temperature and humidity, etc. could be monitored and separated from the weight loss caused by abrasion. The use of a control tyre is likely to be a worthwhile addition to the test procedure.

A6. COMPARISON BETWEEN TYRE ABRASION RATES USING DIFFERENT TEST TYRES

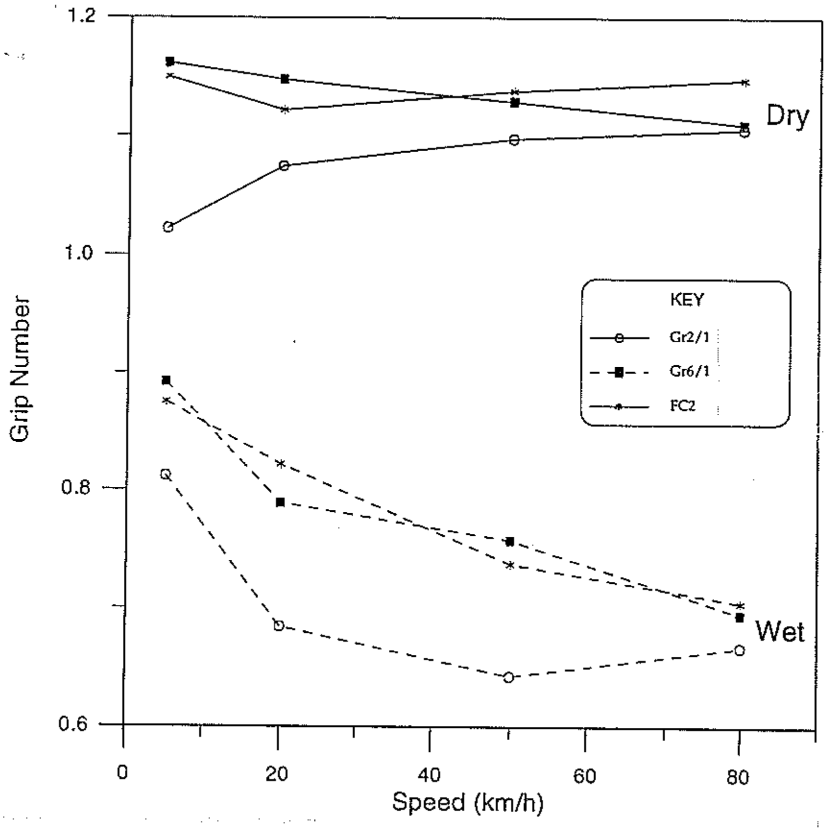
Five nominally identical test tyres (R1, R2, R3, R8, R9) from the same manufacturer's batch were used for the tyre abrasion study. To compare the relative abrasion rates for these five tyres, they were each tested on the same 1 km length of representative chipseal surface during a single day (21 September 1994). These measurements were additional to the measurements on the 18 test sites. The measured dry abrasion weight loss for each wheel is:

R1	0.76 g
R2	1.05 g
R3	0.67 g
R8	0.73 g
R9	0.68 g

The weight losses for four of the wheels are similar, and are within the range of weight measurement variability. The other wheel, R2, recorded a substantially greater abrasion rate.

However, when the weight loss measurements for the 18 test sites are examined, the results for wheel R2 are not significantly different to those of the other wheels. Therefore no attempt has been made to modify the site test results, based on the different abrasion rates measured above. Nevertheless, there is the possibility of different abrasion rates between different tyres. Further evidence is required to determine whether the different abrasion rates measured on the test sites are repeatable.

Figure A7.1 Variation of Grip Number with test speeds (of 5, 20, 50, 80 km/h).



A7. VARIATION OF GRIP NUMBER WITH TEST SPEED

To determine how the Grip Number, measured by the GripTester, varied with speed, three different surface types were selected for study. These consisted of a grade 2 chipseal, a grade 6 chipseal, and a friction course surface. For the speed study the GripTester was set up in "tow" mode for which:

(a) the GripTester was fitted with a tow bar on its front end so that it can be towed by a vehicle; and

(b) the signal processing unit was switched to "tow" mode.

As for the push tests, the watering system remained in place for the speed tests. Three vehicle speeds of 20 km/h, 50 km/h and 80 km/h were used for the tests. The towing vehicle accelerated up to the test speed and the survey was started as soon as that speed was achieved. The survey was terminated at the end of the test strip. The tyre and road temperatures likewise were taken before and after each speed run.

Two "dry" runs were carried out at each test speed. Single "wet" runs were also performed at each of the three speeds. For these, the watering rate was set at maximum. This is equivalent to producing a surface water film of about 0.25 mm at 80 km/h and thicker film depths at the slower speeds of 20 km/h and 50 km/h. After each wet run the water tanks were topped up to the set level. The results are shown in Figure A7.1 (on facing page).

The push-mode measurements at 5 km/h are also included. It should be recognised that the measurements at 5 km/h involved a different procedure which is therefore likely to contribute to the observed differences in measured Grip Numbers.

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