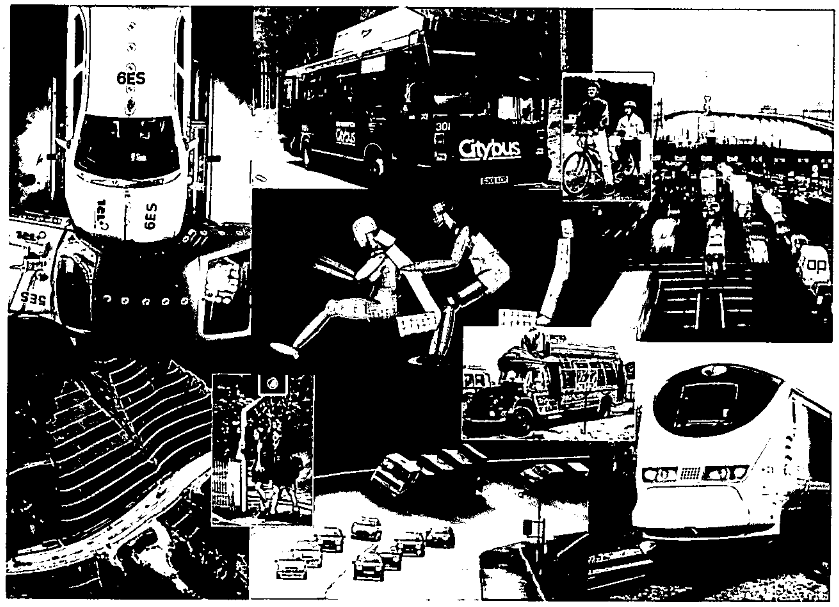

Laboratory testing of road-marking materials

by J C Nicholls

TRL Report 121

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TRANSPORT RESEARCH LABORATORY
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TRL REPORT 121

LABORATORY TESTING OF ROAD-MARKING MATERIALS

by J C Nicholls

Prepared for:	**Project Record:**	**N108**	**Accelerated Life Testing of Road-Marking Materials**
	Customer:	**Driver Information and Traffic Management Division, DOT (Mr B W Lyus)**	

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CONTENTS

EXECUTIVE SUMMARY

Currently, road-marking materials are assessed in the UK in terms of their performance on a trial site on the A1 near St. Neots. These trials, organised through the British Standards Institution, last for either one or two years, depending on category.

The need for a repeatable laboratory test that differentiates the quality of road-marking materials accurately to either supplement or replace these road trials is widely accepted. Not only should the use of a laboratory based accelerated trafficking regime be quicker, it should also be more reproducible than nature. The deterioration of the properties of the materials being monitored are likely to depend on the traffic level and the weather conditions (including the range and extremes of temperature and the extent of rainfall); these can vary from year to-year. Hence, work to develop such a regime is important both to the Department of Transport and to industry to give them assurance that the materials they specify and provide, respectively, are fit for purpose.

The results from a programme of laboratory tests show considerable differentiation between the materials for some of the properties measured, thus allowing the performance of the materials to be ranked. However, the rankings of the different road-marking materials from the St. Neots road trials for the various properties were found to be insufficiently definitive to be used to validate the laboratory rankings. Without such validation, there is no assurance that the differences found in the laboratory are reproduced on the road. Nevertheless, the trends from the results obtained at St. Neots have been used to identify the number of wheel-passes on the laboratory equipment that are equivalent to the standard one- and two-years wear on the site at St. Neots.

A general procedure for assessing the wear characteristics of road-marking materials using laboratory tests has been developed on the basis of the above work. This procedure could be used either as a screening process prior to road trials, thus allowing manufacturers to try out a wider range of products and hence encouraging innovation, or to replace road trials as the standard method of assessing road-marking materials. Given the limited correlation between the results from the laboratory tests and the road trials, the two approaches would need to be run in parallel for some time before the latter option could be considered. The comparison of a larger sample of materials, tested both at the road trial site and by the laboratory wear regime, should demonstrate whether or not the laboratory test does replicate the stresses applied to these materials on the road.

LABORATORY TESTING OF ROAD-MARKING MATERIALS

ABSTRACT

In the UK, road-marking materials are assessed using road trials, as is the case in most other countries. A programme of laboratory wear tests was carried out to try to replicate the performance achieved in road trials for a set of typical materials; the conditions of the test were adjusted to allow the maximum data to be derived in the minimum time. The tests have shown that the wear regime could be used to differentiate between materials, but the results do not replicate those obtained on the same materials from the standard road trials. However, part of this may be due to the relative harshness of the laboratory regime: little or no erosion was observed at the road trials, whilst all materials were eroded in the laboratory regime with some being almost totally removed. A standardised procedure has been derived from the tests, but further correlation with the performance on the road will be required to validate it fully.

1. INTRODUCTION

To be successful, road-marking materials obviously need to be clearly visible and not to be unsafe through low skid-resistance. These properties are relatively simple to measure initially, but the ability of the materials to retain these properties is less easy to ascertain. The deterioration of the serviceability of a material, such as its ability to retain appropriate luminance, retro-reflectivity and skid-resistance without spreading or being eroded, usually requires road trials to be undertaken, which take as long as the time for which durability needs to be demonstrated.

In the UK, the specification for road-marking materials is based on road trials to BS3262: Part 2 (BSI 1989) for which annual trials are organised by the British Standards Institution on the A1 near St. Neots. Each year, road-marking Contractors can apply their products as lines laid transverse to the direction of traffic on the nearside lane of the southbound carriageway. The relevant properties of these lines are measured when laid, one year later and, if a certificate as a class A rather than class B material to BS3262: Part 2 (BSI 1989) is required, again after two years. Other nations have similar schemes.

There are moves to harmonise these trial sites following the removal of trade barriers in Europe, originally planned for 1992. However, problems in reconciling the various European schemes have occurred because of differences in several factors, including:

1) the surfacings on which the road markings are laid, in particular their texture depths;
2) the (commercial) traffic flows; and
3) the climatic regimes.

The Bundesanstalt für Strassenwesen (BASt) (Federal Highway Research Institute), Germany, has been marketing their turntable test facility for assessing the durability of road-marking materials. Therefore, in addition to working to harmonise the road trial schemes, work is being undertaken by BASt and the Laboratoire Central des Ponts et Chaussées (LCPC), France, to correlate results obtained after laboratory ageing with site ageing (Bry et al 1992, Bry et al 1994). However, a suitable laboratory wear regime has yet to be developed which reproduces the same results for all properties as exposure on the road. It is found that the laboratory turntable test gives an extremely good indication of the wearing properties of a product under controlled conditions, but that its overall durability can only be assessed after road trials (Bry et al 1994).

The BASt facility is one of only two currently known to be available for such commercial testing. The second is a turntable test facility for tracking samples, Road Machine No.1 at the Transport Research Laboratory (TRL). Road Machine No.1 was developed for testing thin road surfacings but is capable of use with road-marking materials. To assist with the process of harmonising and rationalising the assessment of road-marking materials, the Driver Information & Traffic Management Division of the Department of Transport commissioned TRL to develop a wear regime for road-marking materials using Road Machine No.1.

2. TRL ROAD MACHINE NO.1

Road Machine No.1 was originally built in the 1930's for experiments on surfacing materials and comprises a 2.3m diameter table which is driven by an external motor and a separate tracking motor. Up to ten samples of nominal size 305mm x 305mm and 50mm thick can be accommodated on the circular table. Two standard car wheels, with Michelin XDX 195/70 VR 14 tyres, are mounted over the top surface of the samples which are installed on the driven table whilst the wheels run freely over the samples applying a dead load of approximately 5 kN each. The table speed is infinitely variable between 0 and 25 revolutions per minute which, with the wheels set at 0.9m from the centre, equates to a linear speed of up to 8.5km/h. The number of revolutions are automatically logged.

The wheels can be set in one of four positions with respect to the vertical plane. The set angles are 0, 7°, 14° and 21°. The lesser the angle, the greater the lateral stress that is induced on the test specimens. A separate tracking-motor is incorporated which allows the wheels to transversely track the width of the test specimens for speeds up to 10rev/min.

The machine has been enclosed in a temperature controlled chamber in which tests can be carried out at any set temperature within the range 0°C to 40°C. The machine, without its environmental chamber, is shown in Figure 1.

3. ASSESSMENT TESTS

3.1 GENERAL

In order to develop a regime which replicates exposure on site, the results of tests after each trial regime must be compared to those achieved after the standard time on the road. The tests to be carried out should be those usually carried out on the UK site, that is to say measurements of:

1) Erosion (Wear Index);
2) Spread;
3) Skid Resistance Value;
4) Luminance Factor; and
5) Retro-reflectivity.

These tests are described briefly below.

3.2 EROSION (WEAR INDEX)

The test method for erosion is given in Appendix D of BS3262: Part 2 (BSI 1989). A test grid of 20 squares, with an overall size 500mm x 100mm, is laid over a specified part of a test line. Each square is graded inversely according to the number of quartiles of thermoplastic remaining in terms of area (≥75% = 1 to <25% = 4) and the Wear Index is the sum of these grades. The requirement in clause 4.2.2 is that the Wear Index shall not exceed 35.

For use with specimens undergoing an accelerated wear regime, the test method is modified by using a grid of 10 squares, with an overall size 250mm x 100mm, because the specimens are only 300mm long. Therefore, ignoring any effects caused by the tyres running on a more consistent line than would be the case on the road, the Wear Indices derived from the grid of 10 squares are doubled to be equivalent to results from the standard test.

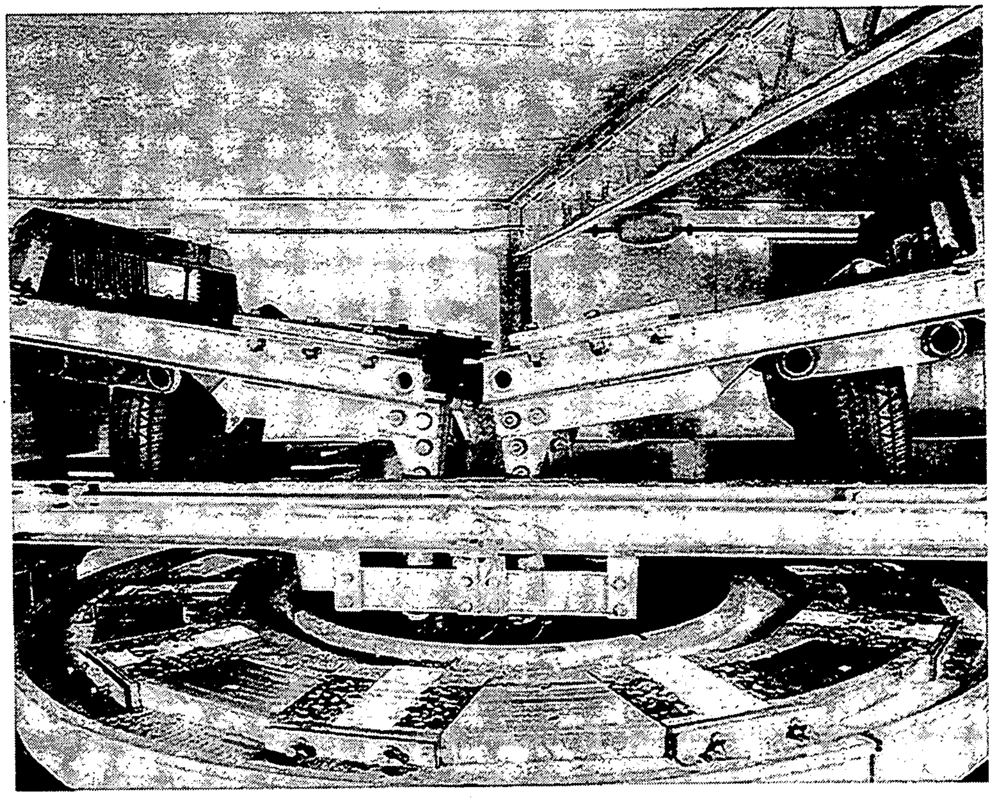

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Fig 1. TRL Road Machine No.1

3.3 SPREAD

Clause 4.2.3 of BS3262: Part 2 (BSI 1989) requires that the width of a test stripe at two specified points shall not have increased by more than 10 per cent of its initial value. On the slabs for the accelerated wear regime trials, the lines are a nominal 100mm width so that the maximum permitted spread is to a width of 110mm. The spread is measured at the mid-point and both third points on the slabs.

3.4 SKID RESISTANCE VALUE

Appendix J of BS3262: Part 1 (BSI 1989) defines the preparation of samples on which to test the skid resistance of road-marking materials using the TRL portable skid resistance tester in accordance with the manufacturer's instructions. The skid resistance is the mean result of three readings from each of two samples. Clause 8.5 of BS3262: Part1 requires that white and yellow marking materials shall have a skidding resistance of not less than 45 on site, both "as delivered" and after re-melting, although there is no requirement for the road trials in Part 2.

For the accelerated wear regime samples, the result are the mean result of three readings from the mid-point of the test length measured in accordance with Road Note No. 27 (RRL 1960).

3.5 LUMINANCE FACTOR

Appendix C of BS3262: Part 2 (BSI 1989) requires the Luminance Factor to be taken in accordance with Appendix F of Part 1 at five points on the trial lines. The method involves a light source arranged at an angle of 45° to the specimen and a photo-detector positioned to view the specimen at right angles. The Luminance Factor is the mean of three readings taken on different parts of the specimen. Clause 8.2.1 of Part 1 requires the Luminance Factor to be not less than 70% for "as delivered" materials and not less than 65% after re-melting for use, with Clause 4.2.1 of Part 2 requiring it to be not less than 50% when laid nor less than 45% at each subsequent inspection on the road trials.

For the trial materials, the luminance is measured at the same locations as the width (spread) measurements.

3.6 RETRO-REFLECTIVITY

Retro-reflectivity is a measure of the light reflected by a road marking from a source at an angle of 0.74° to the horizontal as observed at an angle of 1.37°. This geometry corresponds to a driver observing the road marking from a distance of 50m, which is considered to be optimal for describing reflectance properties of road markings and road surfaces illuminated by vehicle headlights. Neither the method for, nor any limits on, retro-reflectivity are given in BS3262 (BSI 1989), but it is measured on many of the lines at St. Neots by their manufacturer. This is because there are requirements for materials in use to have a minimum retro-reflectivity of 100mcd/m^2/lux in both TD26 of the Design Manual for Roads and Bridges (DMRB 8.2) and the Highway Authority Standard Tender Document (CSS 1994).

For the trial materials, the size of the marking on the test panels means that the retro-reflectivity are only measured at one location per sample.

4. TEST PROGRAMME

4.1 TEST SAMPLES

Samples of road-marking materials that had already been tested on the A1 at St. Neots were provided by members of the Road Safety Marking Association (RSMA), together with details of their road performance. The materials were given code letters to avoid any commercial embarrassment, particularly as the selected materials were chosen to cover as wide a range of performance as practical which meant using the "premium" material offered by one manufacturer and the "standard" from another.

Trial lines were applied to 305mm x305mm slabs. The slabs were made of rolled asphalt with pre-coated chippings applied before being compacted in moulds by roller-compactor. The slabs were subsequently grit-blasted to remove exposed binder and hence model a surfacing that is not new. The texture depths (sand patch to BS598: Part105 (BSI 1990)) of the surfacings were then measured at between 1.0mm and 1.5mm, and the slabs divided so that each road-marking material was applied to a representative selection of slabs with different texture depths.

The road markings were applied to the slabs by Prismo Ltd on two occasions, initially using five materials that were subsequently coded as *J*, *K*, *L*, *M* and *N* and subsequently to two repeat materials, *J* and *M*, and three new materials, *P*, *Q* and *R*. All the materials were applied in 100mm wide lines at a nominal thickness of 2.5mm at 170 ±5°C. Class B glass beads to BS6088 (BSI 1981) were applied to the lines at a nominal rate of 450g/m^2.

4.2 TEST REGIME

For each run with Road Machine No.1, pairs of samples using five different road-marking materials were trialled. The regime, in terms of the temperature of the room and the speed of rotation of Road Machine No.1, was varied between runs with some repeats to assess reproducibility. Sets of measurements were taken initially and at various measurement points through the runs. The details of each run are given in Table 1.

TABLE 1

Test Programme

Run No.	Temperature (°C)	Speed	Materials (rev/min)	Measurement Points (wheel-passes x 10^3)
1	20	20	*J, K, L, M & N*	0, 45
2	20	10	*J, K, L, M & N*	0, 3, 6, 25, 34, 110
3	5	10	*J, K, L, M & N*	0, 3, 8, 27, 53, 129
4	5	10	*J, K, L, M & N*	0, 6, 28, 58, 84, 218*, 262
5	10	10	*J, K, L, M & N*	0, 25, 52, 75
6	10	10	*J, K, L, M & N*	0, 5, 24, 71, 125, 204
7	10	10	*J, M, P, Q & R*	0, 5, 24, 70, 115
8	10	10	*J, M, P, Q & R*	0, 5, 24, 70, 115
9	15	10	*J, M, P, Q & R*	0, 5, 25, 76, 124, 147
10	15	10	*J, M, P, Q & R*	0, 5, 24, 70, 124

*A tracking failure occurred at 161,300 passes.

The number of wheel-passes before a set of measurements was taken varied as the test programme was developed, the latter runs all having increasing gaps between measurement points. The Luminance Factor, retro-reflectivity, width and Wear Index were generally determined at each measurement point whilst the Skid Resistance Value was generally only determined at alternate measurement points because its measurement requires the specimens to be removed from Road Machine No.1 whilst the other properties could be measured with them in-situ.

The first run was carried at a speed of 20 rev/min, at which the tracking mechanism cannot be operated. Although the two wheels were offset so that the tracked area was nearly twice the width of the tyre, the localised erosion made it impossible to measure skid resistance and other measurements difficult. Therefore, all the remaining runs were carried out at 10 rev/min with tracking.

The first two runs showed that the wear regime cannot be carried out at a temperature of 20°C because the road markings blacked up with the tyre rubber, making it impossible to measure the Luminance Factor. The remaining runs provided results that could be analysed to develop the wear regime for road-marking materials.

5. RESULTS

5.1 ST. NEOTS SITE TRIAL

The initial intention was to use the results from the St. Neots trial site to validate the results of the tests on Road Machine No.1. The members of RSMA who provided sample materials also provided details of the test results initially, after one year and after two years in service, which are given in Table 2. There are some missing data (particularly for retro-reflectivity, which is not a standard test at St. Neots).

5.2 LABORATORY WEAR REGIME

5.2.1 Initial Values

The results of tests (other than Wear Index and spread, which require a comparison with previous values) carried out on the specimens prior to any tracking will give an indication of the variation inherent in both the sample preparation and the assessments tests rather than in the wear regime. The mean of each of the Luminance Factor, retro-reflectivity and Skid Resistance Value results were calculated separately for each set of samples with the same road-marking material (but treating repeat sets separately) and the ranges, means, standard deviations and coefficient of variations of those mean values were then calculated. The values, together with the mean of the standard deviations and coefficients of variation from the different sets of samples, are given in Table 3.

The range of mean values for different materials indicates the initial differences in the property between the different materials, these being 48 to 60 or 100 x (60 - 48)/(53 x 2)= approximately ±12 per cent for Luminance Factor, 128 to 255 or about ±37 per cent for retro-reflectivity and 53 to 65 or about ±10 per cent for Skid Resistance Value. However, the mean of the coefficients of variation for retro-reflectivity is 18 per cent, compared to 4 per cent for Luminance Factor and 6 per cent for Skid Resistance Value, indicating

TABLE 2

Results from St Neots Site

Material	Age (years)	Luminance Factor (%)	Retro-Reflectivity (mcd/m²/lux)	Width (mm)	Wear Index	Skid Resistance Value
J	0	82	304	Data	20	48
	1	53.5	134	not	20	58
	2	45.8	72	provided	20	63
K	0	75.1	62	99	20	45
	1	47.5	110	99	20	56
	2	51.3	89	101	20	67
L	0	79.6	183	104	20	46
	1	50.9	186	104	20	61
	2	49.3	96	105	20	68
M	0	72.7	138	98	20	50
	1	45.4	107	101	20	55
	2	42.9	104	103	20	63
N	0	67	Data	Data	20	32
	1	45	not	not	26	47
	2	39	provided	provided	40	46
P	0	83	282	100	20	47
	1	-	289	-	-	-
	2	44	264	101	20	56
Q	0	73.0	Data	104.5	20	56
	1	51.6	not	105	20	55
	2	48.2	provided	102	20	61
R	0	75.6	Data	100	20	47
	1	49.6	not	100	20	53
	2	42.6	provided	102	20	63

TABLE 3

Statistics from Average Initial Readings of Laboratory Samples for each Material

	Luminance Factor			Retro-reflectivity			Skid Resistance		
	Mean	St Dev	C of V	Mean	St Dev	C of V	Mean	St Dev	C of V
Min.	48			128			53		
Max.	60			255			65		
Mean	53	1.9	4 %	170	31.3	18 %	59	3.6	6 %
Std Dev	3.9			50.7			4.4		
Coeff of V	7%			30%			7%		

that there is a wider variation of results from the samples with the same line marking material for this test. The relatively limited range of mean values for the different materials results in there being little effective difference in the statistics for the standard deviations and coefficients of variation.

5.2.2 Results after Wear Regime

The average results for Luminance Factor, retro-reflectivity, Wear Index and Skid Resistance Value for each pair of samples from runs 3 to 10 are plotted separately in Figures 2 to 5 respectively, for each property/run combination. In addition, the proportional change from the initial value of Luminance Factor, retro-reflectivity and Skid Resistance Value for each sample tested in runs 3 to 10 are given in Figures 6 to 8, respectively, for each of the road-marking materials. The linear regression lines for all results, other than the initial set, for each test temperature are shown in Figures 6 to 8.

6. DISCUSSION OF RESULTS

6.1 ACTUAL VALUE AND PROPORTIONAL CHANGE

The properties measured on the samples during the wear regime have been used to assess the efficiency of the wear regime. However, either the actual value or the change from the initial value can be used for this purpose (other than for Wear Index and spread, which require a comparison with the initial value anyway). The results are likely to be very different for the two approaches, because a material that starts off with the 'best' value for a property can potentially have the value deteriorate the most and still remain the best overall if it starts with a sufficient 'lead'. Hence, it has the 'best' property but the 'worst' deterioration characteristics.

For this analysis, both the actual results at that stage in the wear regime and the proportional change from the initial values will be considered. In the following discussion, every effort is made to clarify which of these approaches is being considered.

6.2 LABORATORY TRIALS

6.2.1 Luminance Factor

The results in Figure 2 show an early drop (generally before the first set of readings) in the actual Luminance Factor, and then the values remain reasonably constant although with instances of both continuing falls (such as Materials *Q* and *R* in run 7) and recoveries (such as Material *J* and *M* in run 3). The ranking order for actual value of the different materials changes slightly both between and during runs, but with only Materials *R* and, in run 8, *Q* moving significantly relative to the others, with those materials becoming noticeably the weakest at the end of the regime. There is some overall ordering, with the ranking (starting with the highest or 'best') from runs 4, 5 and 6 being Materials *N, L, K, M* and *J* and from runs 7 to 10 being Materials *P, M, J* & *Q* and *R*; run 3 is ignored as it gave a conflicting ranking.

The plots of proportional change in Figure 6 show that the initial drop is between 25 and 45 per cent of the initial values. Thereafter, the values did not exhibit much change with increasing wheel-passes at 5°C, other than Material *M*, whilst there was a more consistent decrease with wheel-passes at 10°C and 15°C, although the regression lines for 15°C were, if anything, generally less steep than for 10°C. Hence, it appears that there is a critical temperature between 5°C and 10°C below which continued deterioration does not occur, whilst above that temperature there is no significant difference in the rate of deterioration. Nevertheless, it is assumed that the Luminance Factor will deteriorate with trafficking on the road, which implies that carrying out the test at 10°C or 15°C will model the expected in-situ behaviour more closely than at 5°C.

6.2.2 Retro-Reflectivity

Figure 3 shows that measurements of retro-reflectivity contain too many sudden and inexplicable changes in value, other than for runs 3 and 10, to allow any logical assessment to be carried out. This is consistent with the high variability found in the initial measurements (Section 5.2.1). The limited size of the specimen (100mm by 305mm) may be a contributory factor, and repeat determinations should be made in future work. Because the property cannot be made at different locations on such a small sample, it is proposed in future to take four readings, rotating the specimen through 180 degrees between each determination (i.e. duplicate readings from both ends of the line); the measurement would then be the mean of the four determinations.

Nevertheless, the regression lines through the proportional change in Figure 7 using the data available show no consistent difference for retro-reflectivity between carrying out the wear regime at 5°C, 10°C or 15°C.

6.2.3 Spread

The spread was small, possibly due to the relatively low temperatures at which the test regime is carried out. Given the experimental error inherent in measuring the line, it is not considered appropriate to analyse the results. Hence, neither the actual values nor the proportional changes have been plotted out. Nevertheless, the test should remain in any laboratory test regime to identify any "over-soft" road-marking materials.

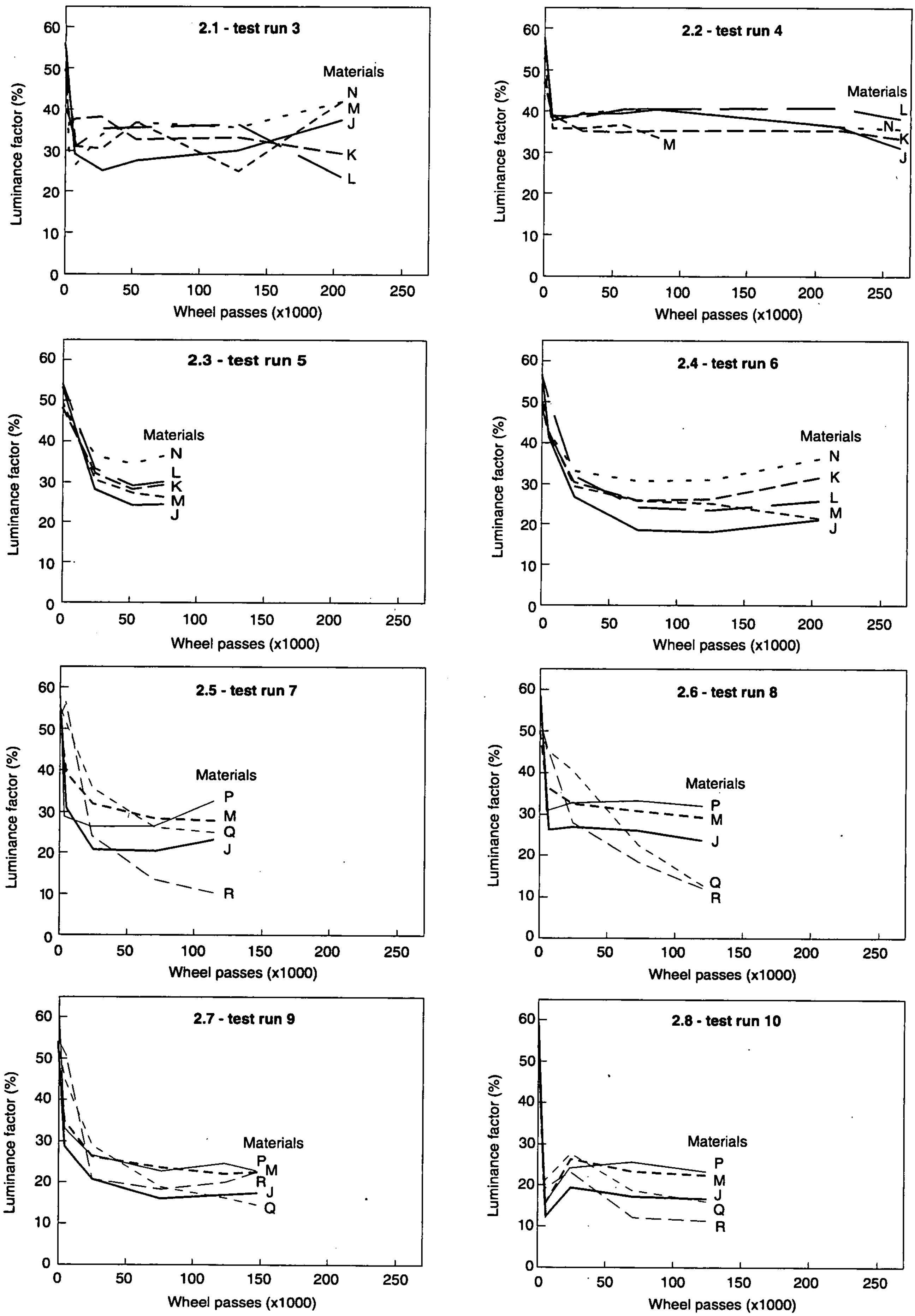

Fig 2. Luminance Factor Values

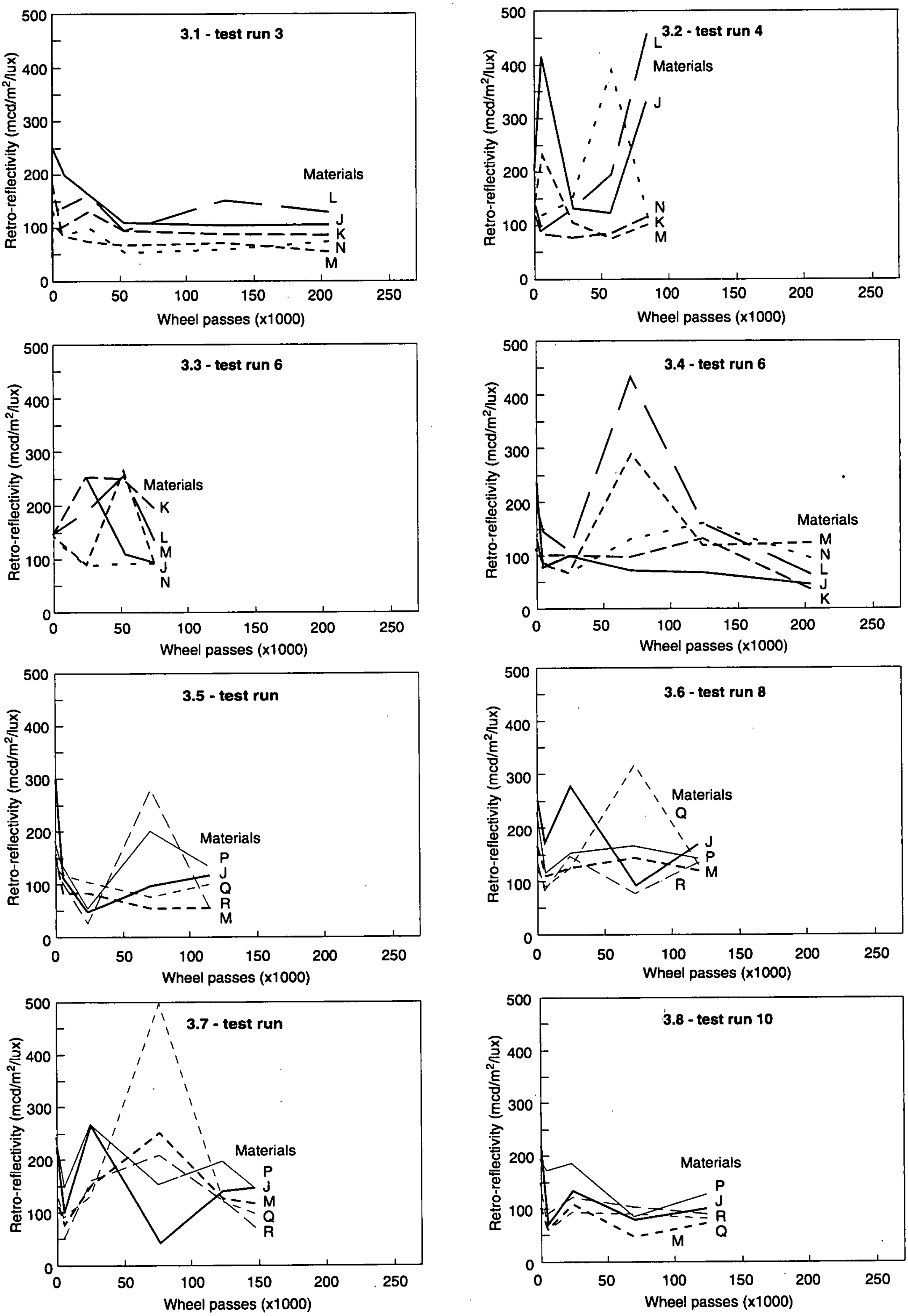

Fig 3. Retro-reflectivity Values

6.2.4 Erosion (Wear Index)

Figure 4 shows that the Wear Index clearly differentiates between the materials, with Materials *K*, *P* and, to a lesser extent, *N* showing little or no wear while Materials *Q* and *R* show considerable wear almost immediately and Material *M* after 50,000 wheel-passes. Other materials show intermediate behaviour. The overall ranking for erosion of these materials from the laboratory tests (starting with the lowest or 'worst') is materials *K* & *P*, *N*, *L*, *J*, *M*, *Q* and then *R*. The ranking is consistent for all the runs, irrespective of temperature.

6.2.5 Skid Resistance Value

It can be seen from Figure 5 that there is usually an immediate initial increase in Skid Resistance value, although it is not as marked as the initial drop in Luminance Factor. Thereafter, there is a trend for the Skid Resistance Value to reduce with wheel-passes, although this trend is not conclusive. It is assumed that the initial increase is caused by the relatively smooth 'skin' formed when laying being disturbed, exposing 'rough' particles, while any subsequent decrease is due to the micro-texture of those particles being worn smooth.

The overall ranking for Skid Resistance Value (starting with the highest or 'best') from runs 4, 5 and 6 is Materials *N*, *L*, *J* & *K* and *M* and from runs 7 to 10 is Materials *Q*, *R*, *J* & *M* and *P*, although the final measurement for Material *R* in run 9 may indicate that its ranking should be dropped.

The plots of proportional change in Figure 8 show that the initial change is between a decrease of 5 per cent and an increase of 15 per cent, and that there is no consistent difference for Skid Resistance Value between carrying out the wear regime at 5°C, 10°C or 15°C. The ranking for Skid Resistance Value in terms of proportional change (starting with the greatest improvement) at a test temperature of 10°C was Materials *K*, *L* & *M*, *J*, *N*, *R* and then *Q* & *P* initially changing slightly to *Q*, *K*, *L* & *M* & *J*, *N*, *R* and then *P* after about 10,000 wheel-passes. It should be noted that the results for material *Q* for that temperature, which are limited in number, appear to be atypical in that there is an initial decrease and an increase with tracking.

6.3 VALIDATION WITH ROAD TRIALS

6.3.1 Properties Available

The results from the St. Neots trials in Table 2 indicate that the Wear Index cannot be used for validation because only Material N showed any erosion (although it is understood that the result was obtained from a site other than St. Neots) whilst the change in width was minimal and therefore also of limited potential use. Furthermore, there is not likely to be much spread in the laboratory trials because these test runs are carried out at relatively low temperatures.

The values of retro-reflectivity from the St. Neots trial are more limited than for the other properties, with only 5 sets of results. The initial results vary considerably (from 62 to 304, which may be due to different techniques used to apply the glass beads, which provide most of the initial retro-reflectivity), as do the changes thereafter (one staying reasonably constant; one increasing and then decreasing; and three dropping more or less consistently). This, together with the high variability found in the initial laboratory measurements of retro-reflectivity (Section 5.2.1), make that measure difficult for use in validation. Therefore, the validation against road trials must be based primarily on Luminance Factor and Skid Resistance Value.

6.3.2 Luminance Factor Ranking

The ranking (starting with the highest or 'best') of materials for Luminance Factor values after application at St. Neots is Materials *P*, *J*, *L*, *R*, *K*, *Q*, *M* and then *N*; the ranking after two years at St. Neots is Materials *K*, *L*, *Q*, *J*, *P*, *M* & *R* and then *N*, although some of the differences between materials are within the experimental error of the measurement. The ranking is reasonably similar to that found from the laboratory tests (Section 6.2.1), but with some notable exceptions such as Material *N*, with the lowest value in the road trials and highest from runs 4 to 6.

After one year's wear, the average Luminance Factor results from the St. Neots trial reduced to between 62 and 71 per cent of their original value and to between 53 and 68 per cent after 2 years. The latter range of 15 per cent is relatively small, showing that there was no significant variation between the materials in terms of the change from their initial values.

6.3.3 Skid Resistance Value Rankings

The ranking (starting with the highest or 'best') of materials for Skid Resistance Value after application at St. Neots is Materials *Q*, *M*, *J*, *R* & *P*, *L*, *K* and then *N*, with Material *N* significantly the worst. The final values after two years were all in the range 63 to 68 except for Material *N* which, at 46, was very much the worst. The ranking after 1 year is Materials *L*, *J*, *K*, *M* & *Q*, *R* and then *N* and *L*, *K*, *J* & *M* & *R*, *Q*, *P* and then *N* after 2 years. This is in reasonable agreement with the ranking from the laboratory trials (Section 6.2.5) except for Material *N*, which performed best in the laboratory trials but worst at St. Neots. However, it should be noted that the initial, poor result for Material *N* with a skid resistance value of 32 at St. Neots was only half the average value of 65 (standard deviation 3.5) obtained on laboratory samples prior to testing. Therefore, the initial reading at St. Neots should be treated with caution.

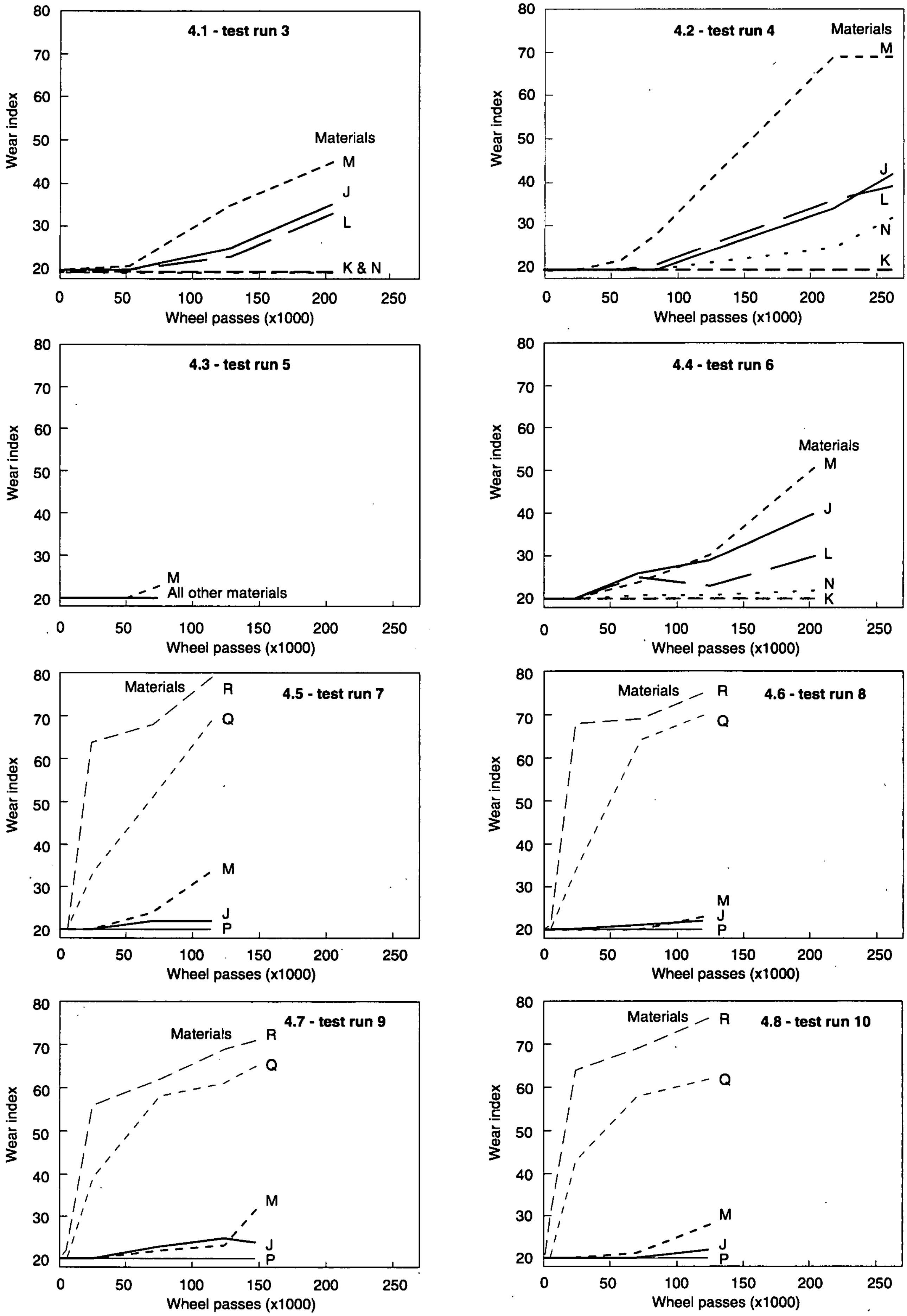

Fig 4. Wear Index Values

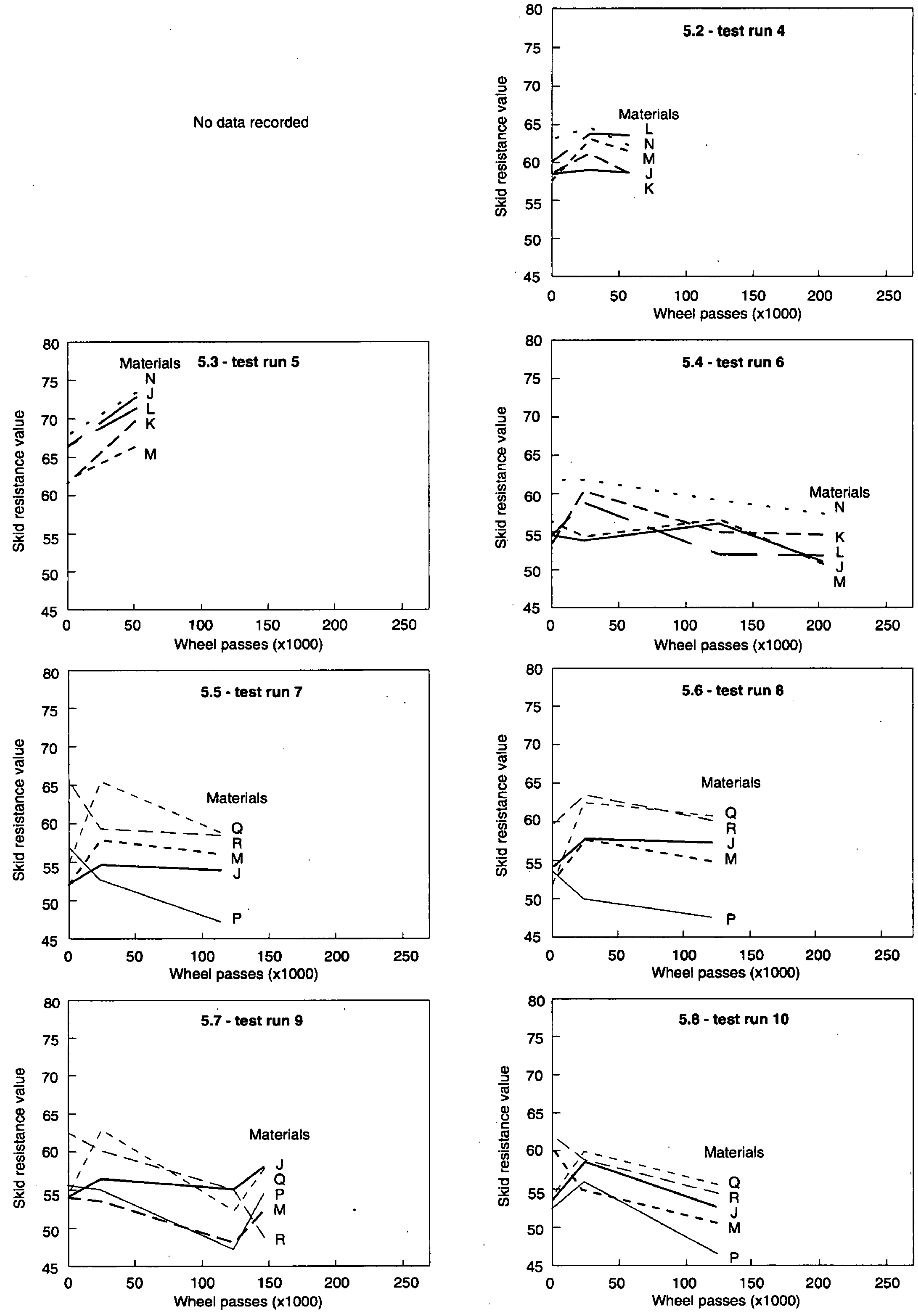

Fig 5. Skid Resistance Values

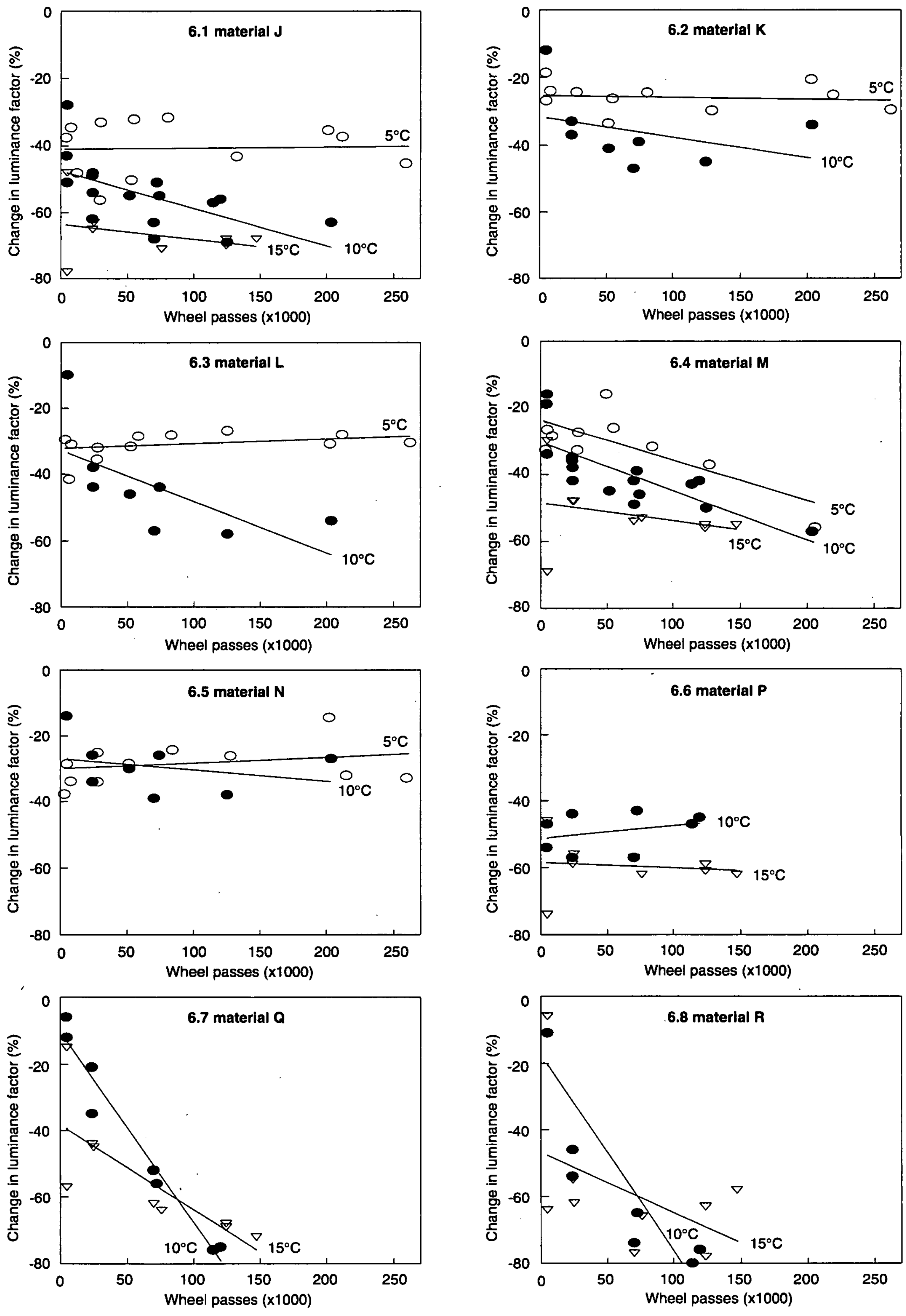

Fig 6. Proportional Changes in Luminance Factor

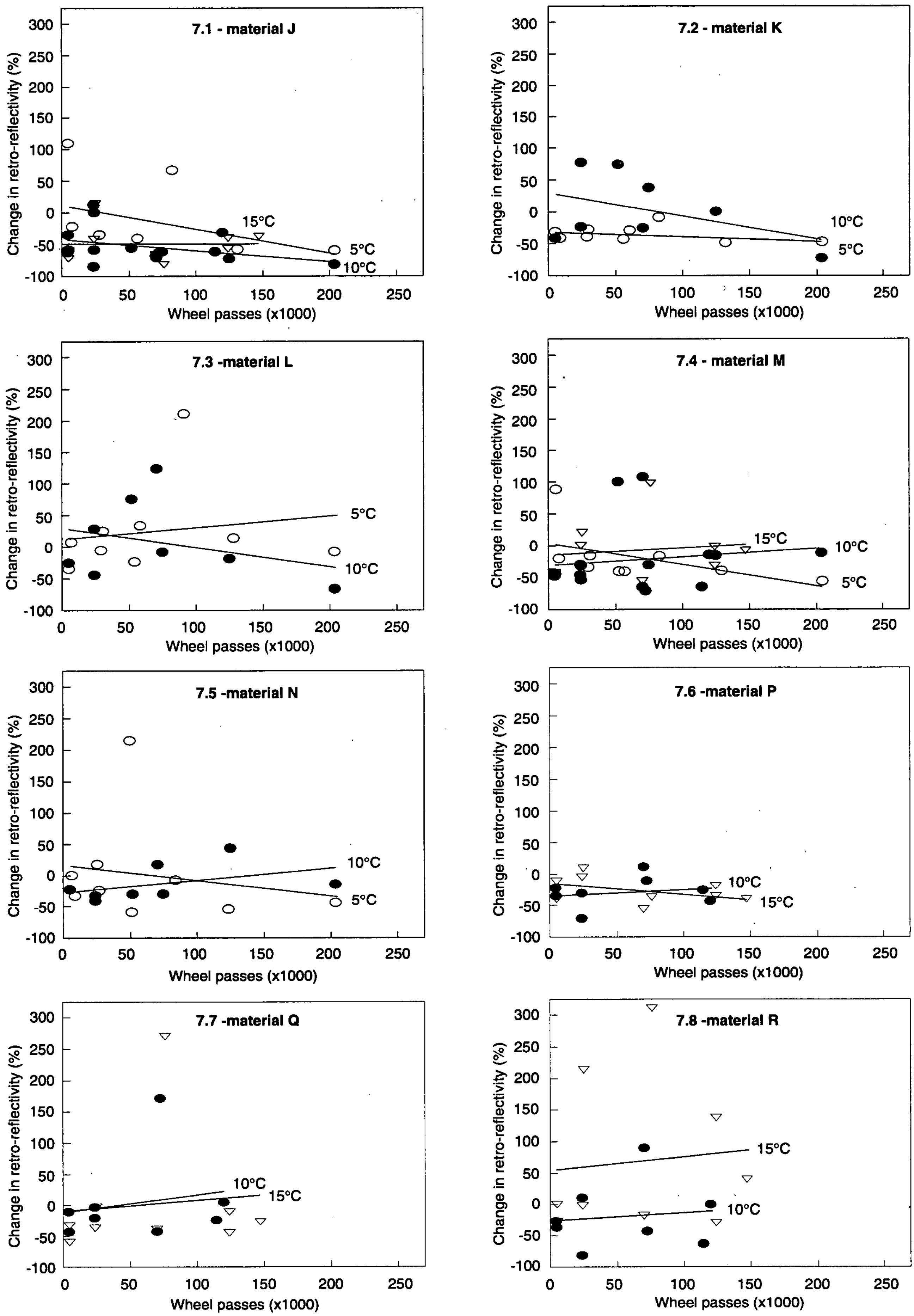

Fig 7. Proportional Changes in Retro-reflectivity

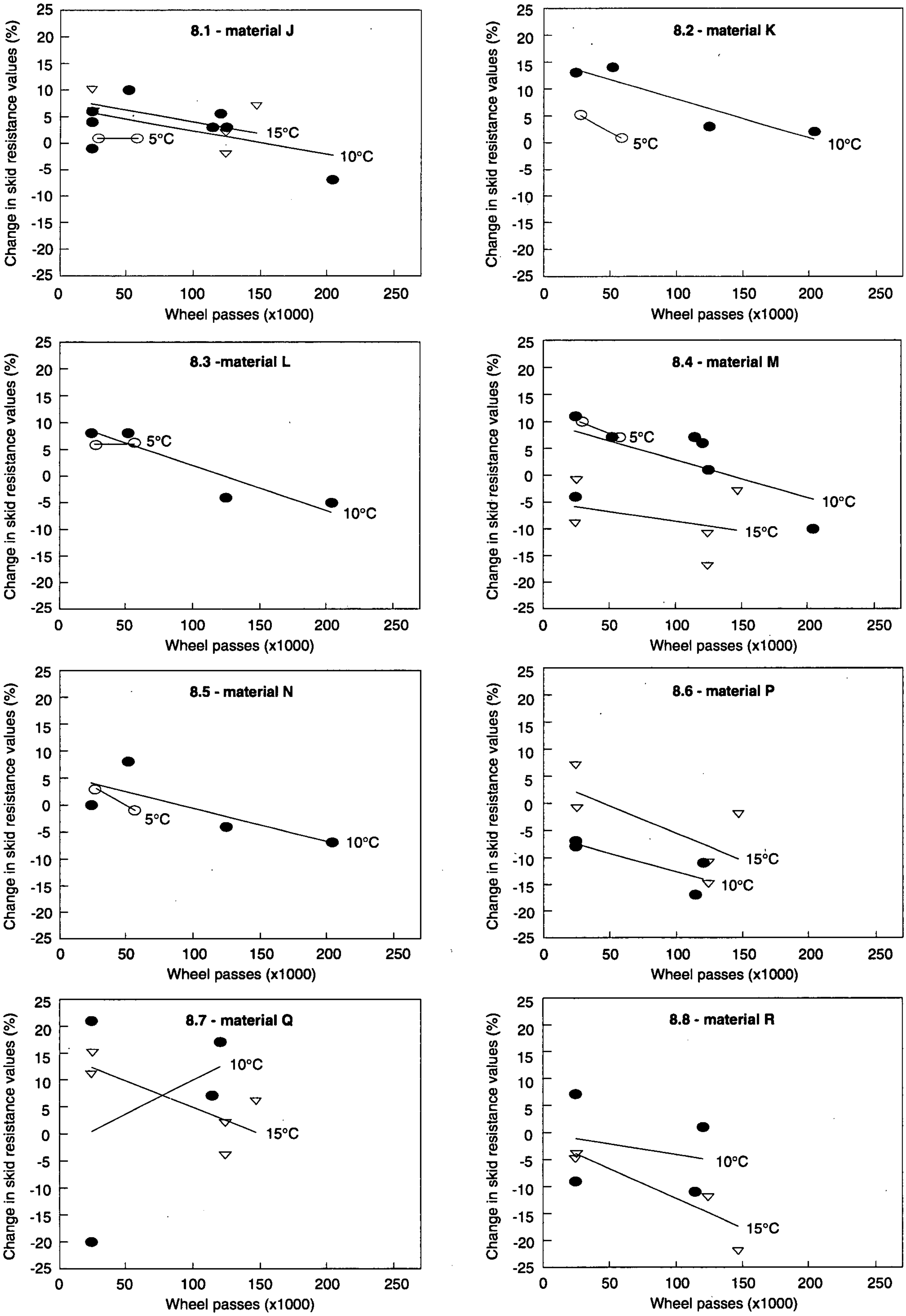

Fig 8. Proportional Changes in Skid Reistance Value

After one year's wear, the average Skid Resistance Value results from the St. Neots trial increased to between 98 and 147 per cent of their original value and to between 109 and 149 per cent after 2 years. The ranking in terms of proportional change (starting with the greatest change) is Materials *N, L, K, J, R, M* and then *Q* after 1 year and *K, L, N, R, J, M, P* and then *Q* after 2 years, with Material *Q* significantly the worst. Hence, the laboratory ranking after 10,000 wheel-passes (Section 6.2.5) is not inconsistent with the ranking from the road trials except for Material *N* (whose low initial result at St. Neots is suspect), which goes from one of the best on the road to one of the worst in the laboratory for least improvement in value, and Material *Q*.

However, at St. Neots the value of Skid Resistance Value increased by about 20 per cent from the initial level after one year and by about 35 per cent after two years whereas only Material *Q* reached anything like this increase in the laboratory trials. This difference in performance must devalue the similarity found in the ranking orders.

6.3.4 Overall Validation

Overall, the data from the St. Neots trials have limited ability to validate the laboratory results because there is so little consistent variation in their performance. All the materials passed those trials for Class A materials. This limited ability to validate laboratory tests is also consistent with the BASt/LCPC comparison of results from the BASt turntable facility with road trials in both Germany and France, where it was found that the overall durability of road-marking materials can only be assessed after road trials, although the laboratory turntable test was found in that research programme to give an extremely good indication of the wearing properties of a product under controlled conditions (Bry et al 1994).

6.4 CALIBRATION AGAINST ROAD TRIALS

6.4.1 Possible Properties

Although the data from St. Neots are difficult to use to validate the ranking order because of the limited difference between the materials, the average value can also be used for calibrating the number of wheel-passes that are equivalent to one- and two-years exposure on the St. Neots site.

6.4.2 Erosion (Wear Index)

There is effectively no erosion at St. Neots, yet beyond 25,000 to 50,000 wheel-passes, most of the laboratory specimens showed signs of wear. On this basis, a tentative estimate of calibration can be made, namely that 50,000 wheel-passes at 5°C, 25,000 wheel-passes at 10°C and 15,000 wheel-passes at 15°C are equivalent to at least 2-years exposure to traffic at the St. Neots site.

6.4.3 Luminance Factor

The one-year equivalent number of wheel-passes should reduce the value of Luminance Factor by 35 per cent and the 2-year by 40 per cent of the original value (Section 6.3.2) based on the St. Neots' results. These levels can be used with the regression lines shown in Figure 6 to establish the approximate equivalent number of wheel-passes in the laboratory trials. At 5°C, the Luminance Factor for Material *J* is reduced by 40 per cent and those for Materials *K, L* and *N* are reduced by about 30 per cent soon after tracking starts and remain at about that value thereafter. The exception is Material *M*, which reaches the one-year level after about 100,000 wheel-passes and the two-year level after 150,000 passes. At 10°C, Material *N* has a relatively flat regression curve after about an initial 30 per cent reduction; the other materials drop to the equivalent of the one- and two-year levels after approximately the number of wheel-passes given in Table 4.

The table indicates that, for Luminance Factor, approximately 25,000 wheel-passes is equivalent to one year exposure to traffic on the road trial site at St. Neots and 75,000 to two years if the wear regime is carried out at 10°C whilst less than 10,000 wheel-passes are required to equate to 2 years at St. Neots if the wear regime is carried out at 15°C.

Although the increase in the temperature at which the wear regime is carried out from 10°C to 15°C does increase the change for Luminance Factor, as for other properties, it would appear that the lower temperature is preferable if estimates of the one and two year performances at the St. Neots trial site are required because the wear exceeds the relevant values at that temperature before the first set of readings.

6.4.4 Skid Resistance Value

The one-year equivalent number of wheel-passes should increase the value of Skid Resistance Value by about 20 per cent and the 2-year by about 35 per cent of the original value (Section 6.3.3) based on the St. Neots' results. However, the laboratory results tend to increase by 5 to 10 per cent initially and then start to reduce. Therefore, the Skid Resistance Value results cannot be used to calibrate the wear regime.

6.5 STANDARDISED TEST REGIME

The results from St. Neots do not indicate a great differentiation between the materials being tested, from which it could be surmised that the road trials are ineffective. However, the reason for the limited differentiation is that the time and cost involved with trialling materials means that a material is only entered in the trial by manufacturers when they feel assured that it will pass. Hence, it is probable that the lack of differentiation is due to the materials being

TABLE 4

Equivalent Number of Wheel-Passes for Luminance Factor at 10°C and 15°C

St Neots Age	Wear Regime at 10°C 1 year	Wear Regime at 10°C 2 years	Wear Regime at 15°C 1 year	Wear Regime at 15°C 2 years
Material *J*	0*	0*	0*	0*
Material *K*	50,000	150,000	n/a	n/a
Material *L*	25,000	50,000	n/a	n/a
Material *M*	25,000	75,000	0*	0*
Material *P*	0*	0*	0*	0*
Material *Q*	40,000	50,000	0*	10,000
Material *R*	30,000	40,000	0*	0*

0* = Reduces to less than the relevant level with initial tracking

biased towards compliance with the trials rather than the trials necessarily being unable to differentiate between 'good' and 'bad' materials.

The results from the laboratory trials do indicate a greater differentiation for some properties. The comparison of these properties with the results from St. Neots have been used to develop a proposal for a standard laboratory test wear regime for the road-marking materials, as given in the Appendix to this report. This proposal has been based on assessments of only some of the properties that are measured; either there is no clear agreement between the laboratory and site results or the laboratory results are unclear for the other measured properties. Therefore, there is no assurance that the use of this regime on significantly different materials from those tested here will behave in a similar manner.

The results showed some variability between the results from nominally identical specimens on the same run. One method of reducing the influence of between-specimen variability is to increase the number of repeat specimens, with the test result being the mean of these determinations. For these tests, it would be beneficial to carry out future testing in triplicate rather than duplicate. This will also help in identifying when a sample is an outlier - with two results, if they are significantly different there is no indication as to which is the outlier while, with three results, the outlier is the one different from the other two.

7. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the trials carried out to date:

1) The laboratory wear regime can discriminate between different road-marking materials to a greater extent that the road trials held at St. Neots. The discrimination is clearest with the Wear Index with rankings also being available from Luminance Factor and Skid Resistance Factor. Spread varies so little that it cannot be ranked whilst there are some anomalies in the measurements of retro-reflectivity; the measurement of retro-reflectivity should be the mean of several determinations to minimise the errors inherent in carrying them out on relatively small samples.

2) The results provided from the St. Neots trial did not discriminate sufficiently to validate the rankings derived from the laboratory trials. However, they can be used to calibrate the regime in terms of determining the number of wheel-passes roughly equivalent to time on the St. Neots trial.

3) A procedure for a laboratory wear regime for road-marking materials can been derived.

Based on those conclusions, the following recommendations are made:

4) Laboratory testing of road-marking materials to the procedure outline in the Appendix to this report is carried out alongside road trials as at St. Neots.

5) Comparisons of results from both the road and laboratory testing regimes on materials with a wider ranger of properties are used to validate the laboratory procedure.

8. ACKNOWLEDGEMENTS

The work described in this report was carried out in the Civil Engineering Resource Centre of TRL (Resource Centre Manager Mr P G Jordan) with Mr J C Nicholls as Project Manager and Mr B W Ferne as Quality Audit and

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APPENDIX A: PROPOSED LABORATORY TEST PROCEDURE

NOTE: The proposal has been developed around TRL Road Machine No.1. Other, similar, road machines could be used, but some values may need to be adjusted.

A.1 SAMPLES

Apply the road-marking material(s) to be tested as 100mm wide lines at a nominal thickness of 2.5mm with Class B glass beads to BS 6088 at 450g/m^2 on slabs of nominal size 305mm x 305mm and 50mm thick. The slabs shall be of the type of road surfacing(s) on which the material is intended to be used. The standard slab material for comparison of the different road-marking materials will be rolled asphalt with pre-coated chippings having a sand-patch texture depth of 1.3 ±0.1mm.

A.2 INITIAL MEASUREMENTS

Measure the Luminance Factor, retro-reflectivity, width and Skid Resistance Value of each specimen. Install sets of three similar slabs in the road machine with the test lines perpendicular to the perimeter.

NOTE 1: The measurements to be carried out using the methods described in the main report but with the measurement of retro-reflectivity being the mean of four determinations.

NOTE 2: The number of samples of a particular road-marking material on a particular substrate to be tested in the standardised procedure will be three because the variation that can occur between specimens for some of the properties measured. This will allow outliers to be identified more easily and, should they not be identified, will reduce their influence on the result. However, this will also have the effect of reducing the number of materials that can be tested at one time on TRL Road Machine No.1 from five to three.

A.3 TEST CONDITIONS

Set the temperature of the chamber in which the road machine with test specimens loaded is housed to 10°C and allow the conditions to stabilise. Once stabilised, rotate the table of the road machine at 10 revolutions per minute with the wheels laterally tracking back and forth across the samples. The wheels shall apply a load on the samples of approximately 5kN.

NOTE 1: 10 rpm is the maximum speed at which the wheels can be tracked on TRL Road Machine No1, which is required in order to avoid localised rutting and hence inhibit taking some of the measurements.

NOTE 2: The self-weight of the wheels in TRL Road Machine No.1 results in a load of approximately 5kN on the table.

A.4 MEASUREMENTS AND MEASUREMENT POINTS

Measure the Luminance Factor, retro-reflectivity, spread, Wear Index and Skid Resistance Value after 25,000 wheel-passes, 75,000 wheel-passes and 150,000 wheel-passes.

NOTE: The measurements to be carried out using the methods described in the main report but with the measurement of retro-reflectivity being the mean of four determinations.

A.5 INTERPRETATION OF RESULTS

Report the average result for each property:

- after 25,000 wheel-passes as equivalent to one year on the St. Neots trial site (Class B);
- after 75,000 wheel-passes as equivalent to two years on the St. Neots trial site (Class A); and
- after 150,000 wheel-passes. as equivalent to extended trafficking.

NOTE: This equivalence should be used until better evidence becomes available.

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