

MIRIAM: AN INTERNATIONAL ROUND ROBIN TEST TO COMPARE ROLLING RESISTANCE MEASUREMENT METHODS

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ABSTRACT

The MIRIAM project (Models for rolling resistance in Road Infrastructure Asset Management Systems) was originally established by twelve partners from Europe and USA. It aims at developing methods for improved control of road transport carbon dioxide (CO₂) emissions in order to obtain a sustainable and environmentally friendly road infrastructure. The first phase of the project, taking place in 2010-2011, included a round robin test (RRT) to compare different rolling resistance (RR) measurement equipment. The RRT was organized in June 2011 on a test track in Nantes, France. Three institutes participated with their RR trailers. RR measurements were carried out on various surfaces, such as epoxy resin, surface dressings, thin layers, porous cement concrete, porous and dense asphalt concrete. Measurements were carried out at 50 and 80 km/h to assess the influence of speed on RR. A few tyres were used to study the impact of the tyre. Many runs were undertaken on the same surface to gain knowledge about repeatability and reproducibility of the test method. Texture measurements with laser profilometer were performed on the same test sections to investigate the homogeneity of the pavements and to study the relation between texture and RR. In this paper some results, analyses and conclusions of this pilot study are presented.

1. INTRODUCTION

The MIRIAM project, acronym for Models for rolling resistance in Road Infrastructure Asset Management Systems, was started in 2010 by twelve partners from Europe and USA. It aims at developing methods for improved control of road transport carbon dioxide (CO₂) emissions in order to obtain a sustainable and environmentally friendly road infrastructure. The focus is on the rolling resistance properties of pavements as it has been found that these properties influence energy consumption of road traffic substantially. In a first phase of the project, taking place in 2010-2011, measurement methods and equipment for rolling resistance were among the important subjects that were studied and as a major part of these activities, a round robin test (RRT) to compare different rolling resistance (RR) measurement equipment was conducted. The RRT was organized 6-10 June 2011 on a test track in Nantes, France. Three institutes participated with special trailers designed for measurement of rolling resistance properties of pavements.

This paper presents some of the results, analyses and conclusions of this pilot study with a focus on the comparison on the equipment.

2. NOTES

In this paper a comprehensive MIRIAM project report about the RRT [1] is the main reference for figures, data, and analyses. An earlier MIRIAM report presents a State-of-the-Art review of rolling resistance basic information and of measurement methods and equipment [2].

The order of co-authors on the first page, following main author Bergiers and second author Goubert, is chosen alphabetically and has nothing to do with the extent or importance of the contributions.

Abbreviations and acronyms that are used in this paper are explained in Table 1.

Table 1 – Abbreviations and acronyms used in this paper

Abbreviation /acronym	Explanation	Comment
AAV4	Test tyre Avon AV4	Specified in chapter 5
BASt	Bundesanstalt für Straßenwesen	Federal Highway Research Institute
BRRC	Belgian Road Research Centre	
C_r	Rolling Resistance Coefficient; dimensionless ratio of rolling resistance force to wheel load $C_r = F_r / F_z$ where the forces F_r and F_z are magnitudes and not vectors	Also abbreviated “RRC”
ES14	Michelin Energy Saver 14” tyre	Specified in chapter 5
ES16	Michelin Energy Saver 16” tyre	Specified in chapter 5
IFSTTAR	l’Institut Français des Sciences et Technologies des Transports, de l’Aménagement et des Réseaux	French institute of sciences and technology for transport, development and networks
R^2	Coefficient of determination (square of correlation coefficient R)	This is a measure of the variance explained by the tested regression
RR	Sometimes used as an abbreviation for Rolling Resistance	
RRT	Sometimes used as an abbreviation for Round Robin Test	Extensive test comparing a number of measuring devices or subjects; in this case rolling resistance trailers
SRTT	Standard Reference Test Tyre	Specified in chapter 5
TUG	Technical University of Gdansk, Poland	
VTI	Swedish National Road and Transport Research Institute	
XXXX/YYYY	Tyre type XXXX, owned by institute YYYY, measured by institute YYYY	
XXXX/YYYY_ZZZZ	Tyre type XXXX, owned by institute YYYY, measured by institute ZZZZ	

3. MEASUREMENT DEVICES

3.1. Rolling resistance trailers

The following organizations provided RR measuring devices in the form of towed trailers for comparison on the test track of IFSTTAR: BAST, BRRC and TUG.

Table 2 shows some essential features of the trailers that were used for the tests, with illustrations in Figures 1 - 4. A more detailed description of the trailers can be found in [2].

Table 2 – Essential features of trailers used during the round robin test in Nantes

Owner organization	BAST	BRRC	TUG
Test tyre size	14"-16"	14"	14"-16"
Test tyre protected from air flow?	yes	no	yes
Measurement principle	force	angle	angle
Number of supporting tyres	2	0 (test tyre also is supporting tyre)	2
Number of test tyres	1	1	1
Self-supporting construction	no	no	yes
Tyre load at testing	4000 N	2000 N	4000 N
Tyre inflation pressure	200 kPa	200 kPa	210 kPa
Exterior/Interior tyre temperature measurement	exterior	exterior/interior	exterior
Corrections made during measurement or afterwards?	afterwards	afterwards	during measurement
Measurement in wheel track or middle track?	middle track	middle track	middle track



Figure 1 – All participating trailers on the test track – BRRC (left), TUG (middle), BAST (right).



Figure 2 – The trailer from the Technical University of Gdansk (TUG) in Poland.



Figure 3 – The trailer from BAST in Germany.



Figure 4 – The trailer from BRRC in Belgium.

3.2. Dynamic laser profilometer for pavement texture measurements

Before performing the RR measurements, texture measurements were performed to verify the homogeneity of the test track surfaces. Texture was measured with a dynamic laser profilometer from BRRC. More details about this profilometer can be found in [3].

4. TEST LOCATIONS AND SURFACES

4.1. Test track and test surfaces

Figure 5 shows the outline of the test sections on the IFSTTAR test track in Nantes used in this study. The test track consists of a large half circle followed by test sections with various surfaces. The surfaces have been trafficked for several years only by test vehicles. See Table 3 regarding which of the test sections that were employed in the study. Figure 6 shows a compilation of close-up photos of the surfaces; with scales adjusted in order to make it possible to compare the textures. A more detailed description may be found in [1].

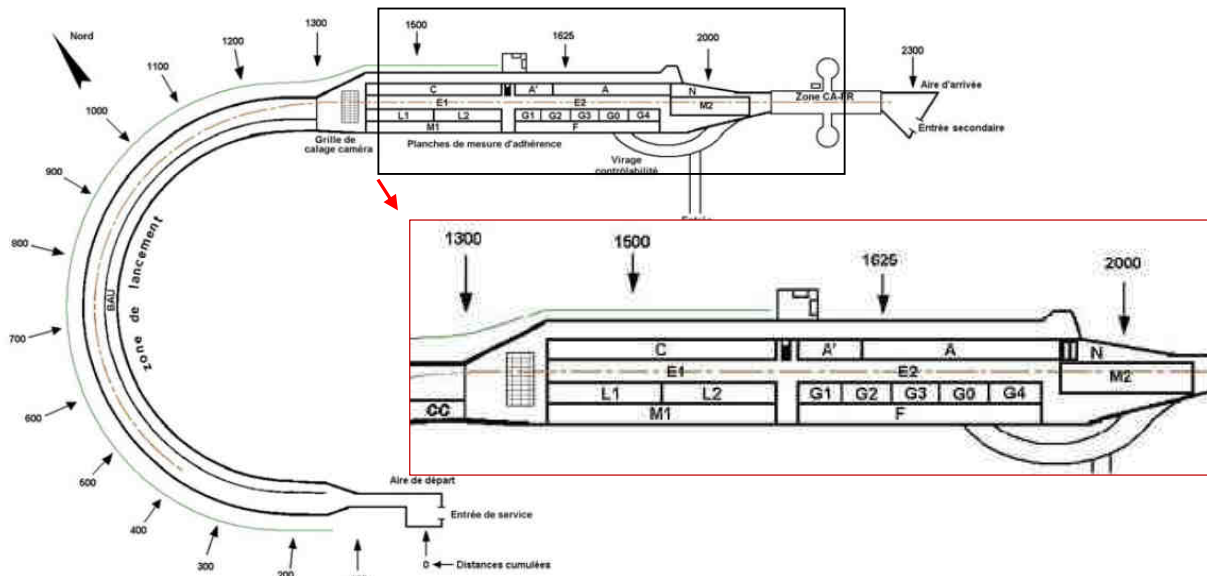


Figure 5 – The IFSTTAR test track at Nantes, France, used in this study (note that the sketch is not exactly to scale). The inset is an enlargement of the most essential part of the test track.

Table 3 – Summary of test sections

Pavement designation	Description
M1	Very thin asphalt concrete 0/10, class 1
F	Colgrip: Surface dressing, 1/3 bauxite (high skid resistance)
L1	Epoxy resin (smooth section)
L2	Sand asphalt 0/4
E1	Dense asphalt concrete 0/10 (new)
E2	Dense asphalt concrete (old)
M2	Very thin asphalt concrete 0/6, class 2
C	Surface dressing 0.8/1.5
A'	Surface dressing 8/10
A	Porous asphalt concrete 0/6
N	Porous cement concrete

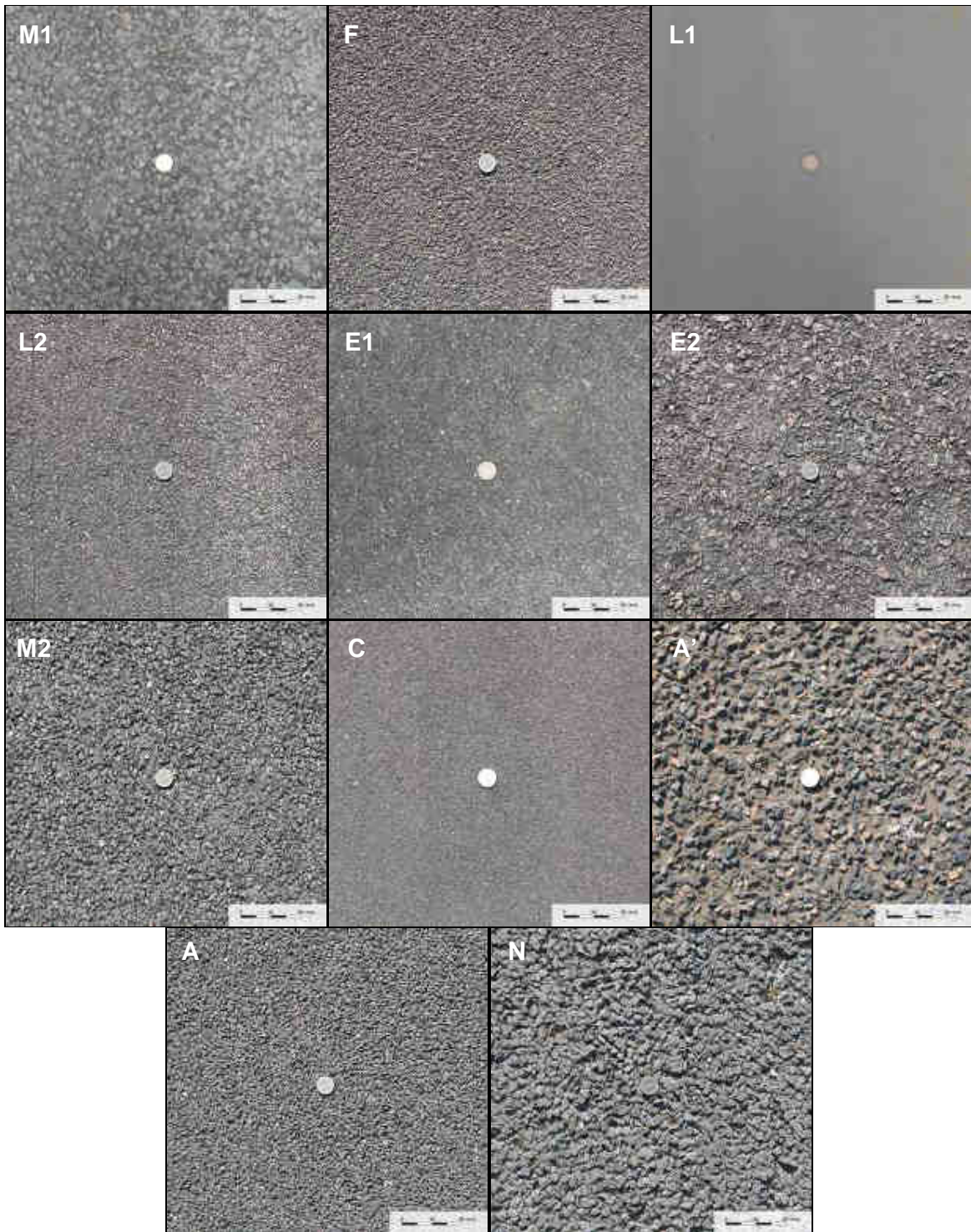


Figure 6 – Photos of the various test sections – the coin in the pictures has a diameter of 23 mm

4.2. Texture and homogeneity of test sections

A compilation of the texture spectra of all test sections is shown in Figure 7. For L1, which is a very smooth epoxy surface, the part of the spectrum with texture wavelength below 30 mm shall be neglected as it is caused by the internal noise of the laser profilometer.

Since the width of the test sections ranges between 2.5 and 3.9 m, the various trailers might have measured in different wheel tracks. All trailers have test tyres mounted in the

middle of the vehicle; however, a different positioning of the trailers might cause different RR measurement results, as texture may vary laterally. Therefore the transversal homogeneity was verified by texture measurements which were performed in the middle, left and right wheel tracks. Comparison of the results showed that only test sections N and L1 had a minor variation between wheel tracks (middle and right tracks in this case). This was estimated to be negligible in relation to other errors.

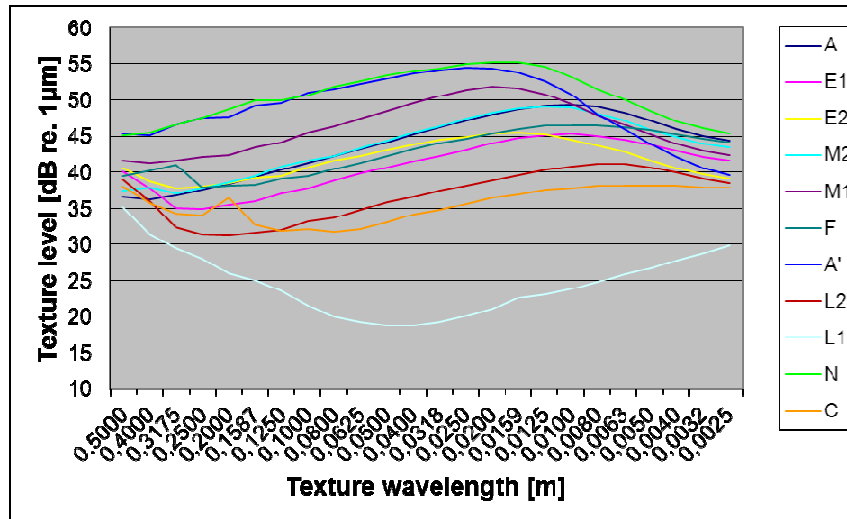


Figure 7 – Compilation of the texture spectra of all tested sections.

5. TEST TYRES

5.1. Characteristics

Pictures of all test tyre types used in the study are shown in Figure 8; more detailed information is compiled in Table 4. Each institute used its own set of tyres.



Figure 8 – Tread patterns of the test tyres; from left to right: SRTT, AAV4, ES14 and ES16.

Table 4 – Overview of test tyres and their symbols used in the RRT.

Symbol	Manufacturer	Tyre type	Tyre size	Load Index	DOT marking
AAV4/BASt	Avon	Supervan AV4	195 R14 C	106/104N	ATJ8 PC2810
AAV4/TUG	Avon	Supervan AV4	195 R14 C	106/104N	ATJ8 PC2810
ES16/BASt	Michelin	Energy Saver	225/60 R16	98V	HC 3V 00KX1511
ES16/TUG	Michelin	Energy Saver	225/60 R16	98V	HC 3V 00KX1511
ES14/BRRC	Michelin	Energy Saver	195/70 R14	91T	F1 J9 681X3010
ES14/TUG	Michelin	Energy Saver	195/70 R14	91T	F1 J9 681X3010
SRTT/BASt	Uniroyal	Tiger paw M+S	P225/60 R16	97S	ANX0 EVUU4608
SRTT/TUG	Uniroyal	Tiger paw M+S	P225/60 R16	97S	...0404

To minimize measurement differences due to the tyres, an effort was made to use tyres from the same batch (defined by their DOT markings). Only the SRTT tyres were originating from a different batch (see the right column of Table 4). Additional measurements were performed on the laboratory drums of the TUG on all sets of tyres, with a view to detect differences between tyres of the same type.

5.2. Tyre inflation and load

BAS_t and BRRC applied a tyre inflation of 200 kPa, while TUG used a tyre inflation of 210 kPa (after warm-up). In the Artesis project the influence of tyre inflation was investigated. A difference of 10 kPa was found to correspond to a C_r difference of 1.6 % [3].

The BAS_t and TUG trailers used a load of 4000 N, while the BRRC trailer used a load of 2000 N because of restrictions related to the trailer suspension.

5.3. Rims/wheels

The SRTT and ES16 tyres were mounted on wheels with a rim width of 6.5". The wheels used for the ES14 and AAV4 tyres had a rim width of 6 and 5.5", respectively.

6. MEASUREMENT PROCEDURE

By driving 15 minutes at 80 km/h a sufficient tyre warm-up was achieved. All teams performed their measurements individually as handling of the trailers differed too much to do it consecutively. For safety reasons communication with other teams was done through walkie-talkies.

The IFSTTAR weather station situated on the test track registered all data about air temperature, wind direction, and wind speed. Thereby, weather conditions could be linked to the measurements afterwards. However, eventually no wind or temperature corrections were applied as it was concluded (based on the data) that their influence would remain small [1].

7. MEASUREMENT RESULTS

7.1. Short term repeatability

In this section measurement runs performed one after the other on the same test section are analyzed.

7.1.1 BAS_t

BAS_t repeated measurements on test sections M1 and L2 with the AAV4, ES16 and SRTT tyres at 50 and 80 km/h. For each combination of tyre/speed/direction, several measurements of C_r were carried out and the average and the standard deviation were calculated. The standard deviation was divided by the mean value and expressed as a percentage. The mean value of these percentages is then calculated; see the results in Table 5, which are expressed:

- for all combinations
- for each direction
- for test sections M1 and L2
- for speeds 50 and 80 km/h
- for each tyre

Table 5 – Average value of the relative standard deviations for various combinations (BAST trailer).

Direction	east	2.3 %
	west	3.0 %
Test section	M1	2.6 %
	L2	2.6 %
Speed	50 km/h	2.2 %
	80 km/h	3.1 %
Tyre	AAV4	2.6 %
	ES16	2.3 %
	SRTT	2.9 %
All		2.6 %

The overall short-term repeatability of the BAST trailer was found to be 2.6 %, which appears to be independent of tyre and surface.

7.1.2 BRRC

Measurements on test sections M1 and L2 were repeated by BRRC with the ES14 tyre at 50 and 80 km/h. Eight runs were made for each direction (west and east). The same average value as in section 7.1.1 is calculated for all cases; see results in Table 6.

Table 6 – Average value of the relative standard deviations for various combinations (BRRC trailer).

Direction	east	3.5 %
	west	2.0 %
Test section	M1	3.1 %
	L2	2.3 %
Speed	50 km/h	2.1 %
	80 km/h	3.3 %
All		2.7 %

The overall short-term repeatability of the BRRC trailer was found to be 2.7 %. There appears to be some speed and direction dependency, which may be related to the wind as the BRRC trailer does not have much wind shielding.

7.1.3 TUG

TUG performed several runs on ten test sections with all tyre types at 50 and 80 km/h. The same average value as in section 7.1.1 is calculated for all cases; see results in Table 7.

Table 7 – Average value of the relative standard deviations for various combinations (TUG trailer).

Direction	east	1.2 %
	west	1.0 %
Test section	M1	1.2 %
	L2	1.1 %
Speed	50 km/h	1.0 %
	80 km/h	1.2 %
Tyre	AAV4	0.5 %
	ES14	0.7 %
	ES16	1.1 %
	SRTT	1.8 %
All		1.1 %

The overall short-term repeatability of the TUG trailer was found to be 1.1 %. There is no significant influence due to speed, test section or direction. However, the tyre type seems to influence the repeatability.

7.2. Day-to-day repeatability

In this section measurements performed on different days on the same test section are analyzed.

7.2.1 BAST

Measurements were performed on various test sections with the SRTT tyre at 50 and 80 km/h on 6 and 9 June 2011. Results at 50 km/h are shown in Figure 9 (also in Figure 10).

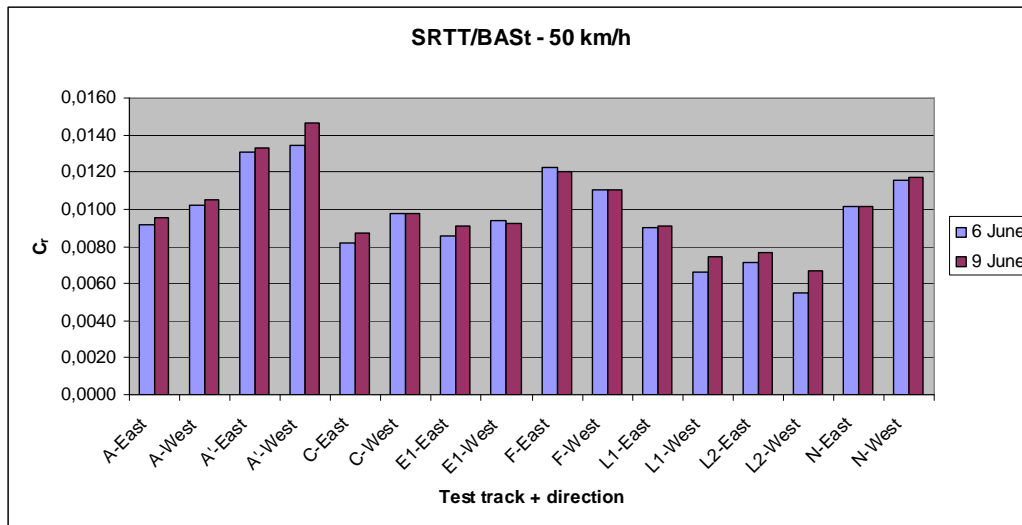


Figure 9 – SRTT/BAST measurements 6 and 9 June 2011 at 50 km/h.

The overall relative RMS variation σ was found to be 7 % for both speeds, which is calculated as follows:

$$\sigma^2 = \sum [(C_{r,i,6 \text{ June}} - C_{r,i,9 \text{ June}}) / C_{r,i,6 \text{ June}}]^2 / N$$

for all tracks i , where

- N is the number of test tracks
- $C_{r,i,x}$ is the rolling resistance coefficient measured on track i on day x

7.2.2 BRRC

BRRC performed measurements on several test sections on 6 and 9 June 2011. Since the trailer hit an object on the 9th, partly damaging the device, only part of the results are relevant. As can be seen in Table 8 there appears to be a systematic increase of 10 up to 25 %, probably due to a calibration error. More information about calibration procedures may be found in [4].

7.2.3 TUG

No measurements were repeated by TUG on different days.

Table 8 – Day-to-day repeatability measurements with tyre ES14/BRRC on 6 June (blue colour) and 9 June 2011 (no colour), at 80 km/h.

Test track	Direction	Date	C _r	Change between 6 and 9 June
F	E	6 June	0.0197	
F	W	6 June	0.0205	
F	E	9 June	0.0232	17.8 %
F	W	9 June	0.0242	18.0 %
L1	E	6 June	0.0160	
L1	W	6 June	0.0169	
L1	E	9 June	0.0188	17.5 %
L1	W	9 June	0.0196	16.0 %
L2	E	6 June	0.0169	
L2	W	6 June	0.0183	
L2	E	9 June	0.0189	11.8 %
L2	W	9 June	0.0202	10,4 %
A	E	6 June	0.0170	
A	E	9 June	0.0206	21.2 %
C	E	6 June	0.0174	
C	E	9 June	0.0217	24.7 %
A'	E	6 June	0.0203	
A'	E	9 June	0.0240	18.2 %

7.3. Reproducibility

7.3.1 BAST-TUG

Measurements performed by BAST and TUG with the SRTT, AAV4 and ES16 tyres at 80 km/h are shown in Figure 10. Graphs representing BAST measurements are drawn with a full line, while the TUG graphs are drawn with a dashed line. All graphs show similar patterns with respect to the effect of road surface.

BAST carried out measurements with the SRTT on two days, namely 6 and 9 June 2011 (see also section 7.2.1). These results are plotted in the graph (compare the results for SRTT/BAST_0606 and SRTT/BAST_0906).

Except for two inconsistent BAST values, the graphs representing AAV4/BAST and AAV4/TUG lie rather close together at 80 km/h (approximately 10 % difference). However, this is not the case at 50 km/h. This speed dependency is difficult to explain.

The C_r values with for the ES16 and SRTT tyres are much higher for BAST than for TUG at both speeds.

TUG did measurements with AAV4/TUG and AAV4/BAST, SRTT/TUG and SRTT/BAST in order to investigate the differences related to the tyres. The largest differences were found for the SRTT tyres which is probably due to the fact that they came from different batches (see Table 4) and have different rubber hardness. However, hardness can only explain a part of the large difference; there must be also some other factor; such as possibly some undetected tyre manufacturing problem. Applying a tyre correction to the SRTT results improves the comparison significantly, although the relative difference remains quite high. Applying a tyre correction to the AAV4 results does not improve the comparison much [1].

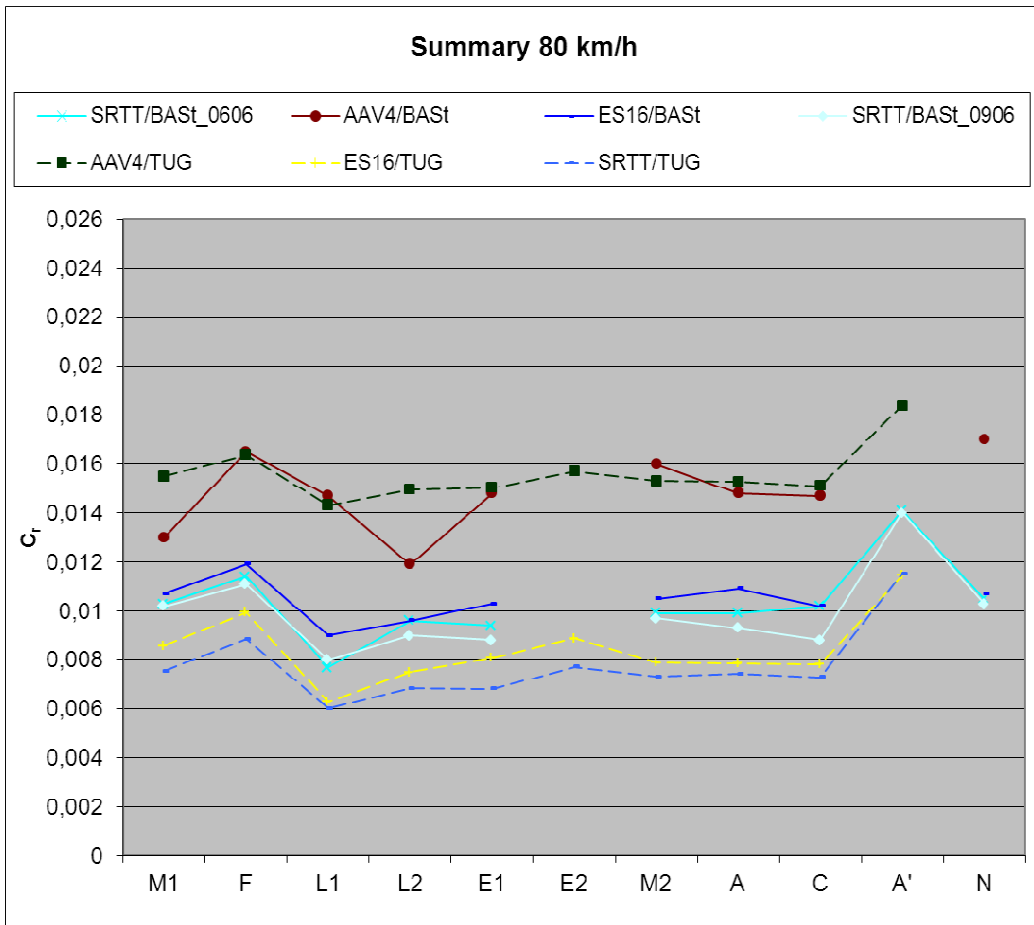


Figure 10 – Measurements performed by BASt and TUG with SRTT, AAV4 and ES16 tyres at 80 km/h.

Very good correlations are found between the results of the ES16/BASt and ES16/TUG tyres at both speeds (see Figure 11). However, some difference between the regression line and an assumed 1:1 relation (red colour) can be seen, indicating a poor reproducibility.

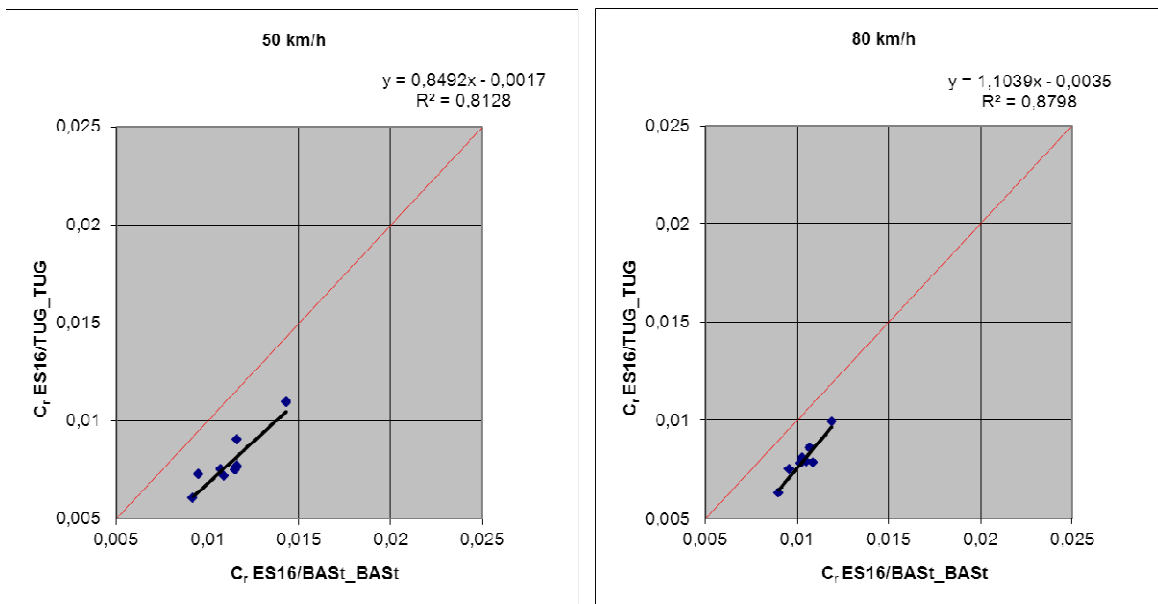


Figure 11 – Correlation between ES16/BASt and ES16/TUG at 50 km/h (left) and 80 km/h (right).

Very good correlations were found between the SRTT/BASt and SRTT/TUG tyres for both speeds (see Figure 12). The correlation at 80 km/h is even excellent (0.984). However, the difference to the 1:1 line (red colour) is again substantial, especially at 50 km/h, indicating a poor reproducibility.

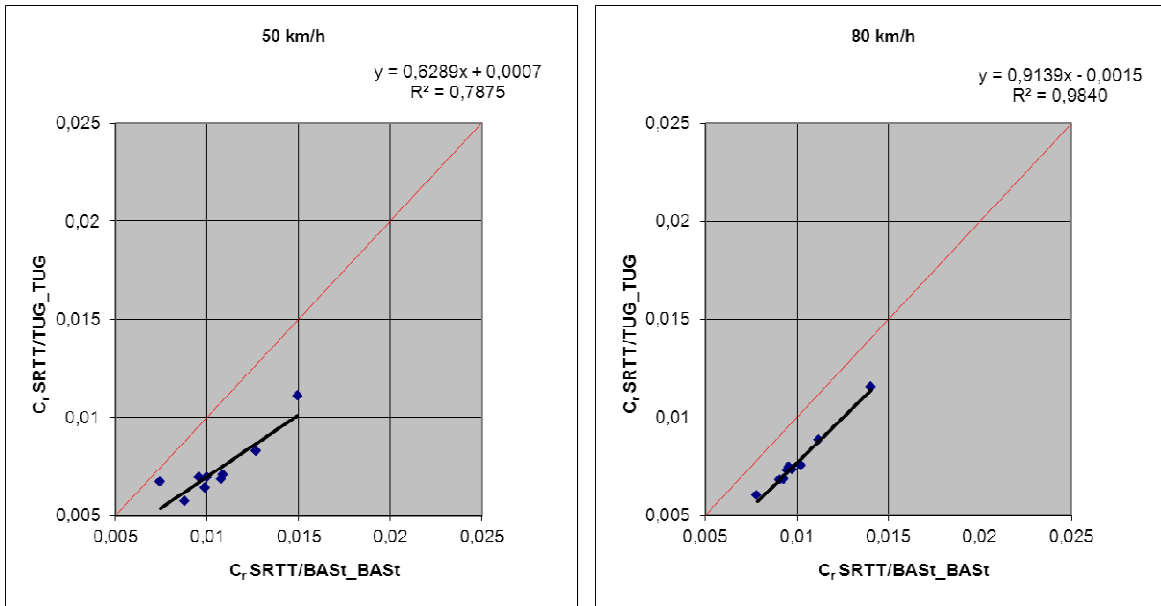


Figure 12 – Correlation between SRTT/BASt and SRTT/TUG at 50 km/h (left) and 80 km/h (right)

Measurements with AAV4/TUG and AAV4/BASt at 50 km/h show a very good correlation, while those at 80 km/h fail to show any correlation (Figure 13). This is mainly due to two inconsistent BASt values (see Figure 10). Also, there appears to be a poor reproducibility.

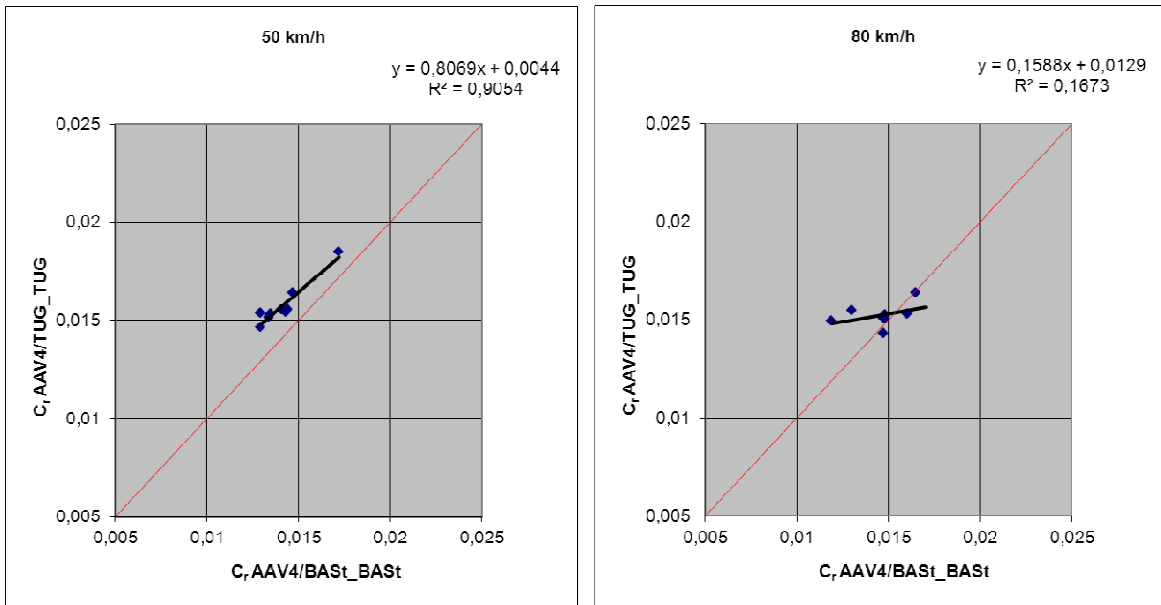


Figure 13 – Correlation between AAV4/BASt and AAV4/TUG at 50 km/h (left) and 80 km/h (right).

7.3.2 BRRC – TUG

Results of measurements made with the ES14 by BRRC and TUG are shown in Figure 14 for both speeds. Graphs representing BRRC measurements are drawn with a full line, while the TUG graphs are drawn with a dashed line. A large difference appears between the TUG and BRRC results at 80 km/h. This is due to the lack of wind shielding of the BRRC trailer.

Figure 14 reveals an outlier for M2. The C_r values measured by BRRC are too high. This surface was measured separately after turning the vehicle with a small turning radius and after a high acceleration over small distance. At a certain time these manipulations even caused an impact between vehicle and trailer. The acceleration may have caused higher C_r values for M2. This problem will be verified by BRRC in the near future.

When discarding the outlier M2, all graphs show a similar shape. The results at 50 km/h are situated closely together, although a larger difference was expected, as TUG uses a higher load (4000 N). Drum measurements in the TUG laboratory also revealed differences between the ES14/TUG and ES14/BRRC tyres, which are speed and surface dependent (C_r is influenced by 0.001 – 0.003) [1].

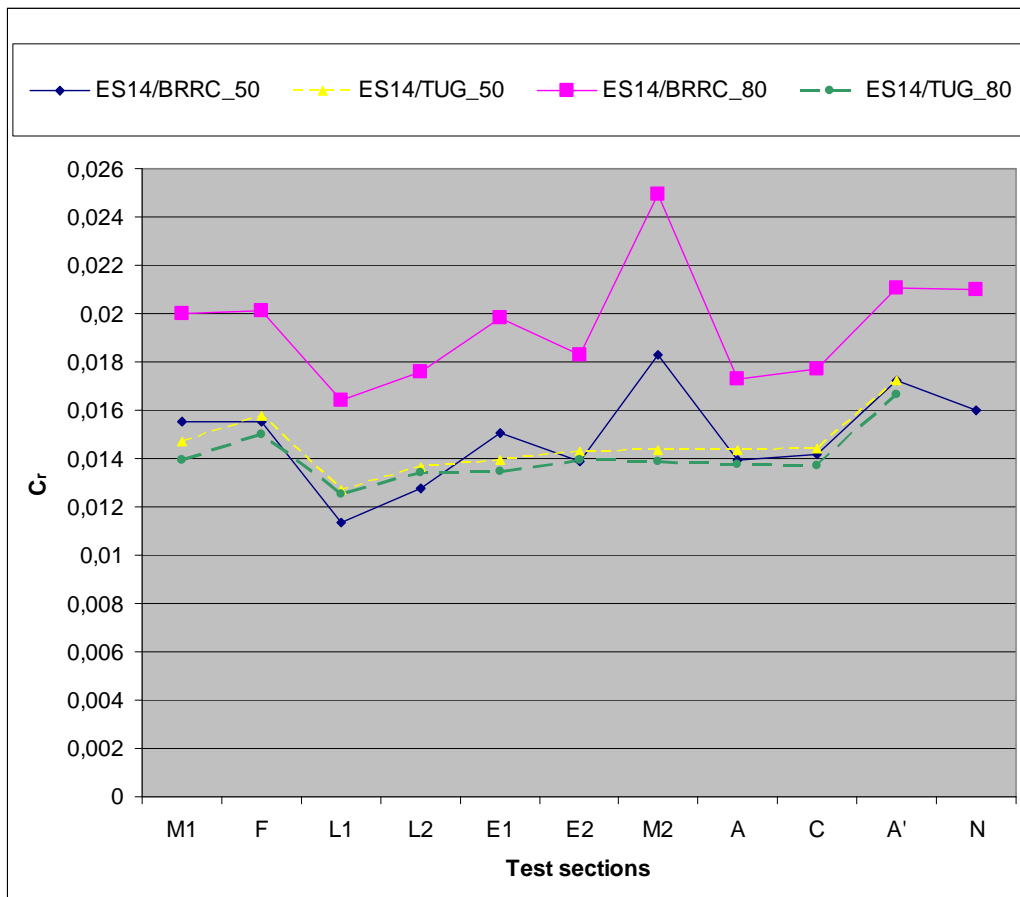


Figure 14 – ES14/BRRC and ES14/TUG measurements at 50 and 80 km/h.

A fair correlation can be seen in Figure 15 at 50 km/h while almost no correlation is shown at 80 km/h (probably due to the influence of wind). However, if M2 would have been discarded, better correlations would be found ($R^2 = 0.818$ at 50 km/h and $R^2 = 0.612$ at 80 km/h). Again, a poor reproducibility is found as the BRRC values are consistently higher.

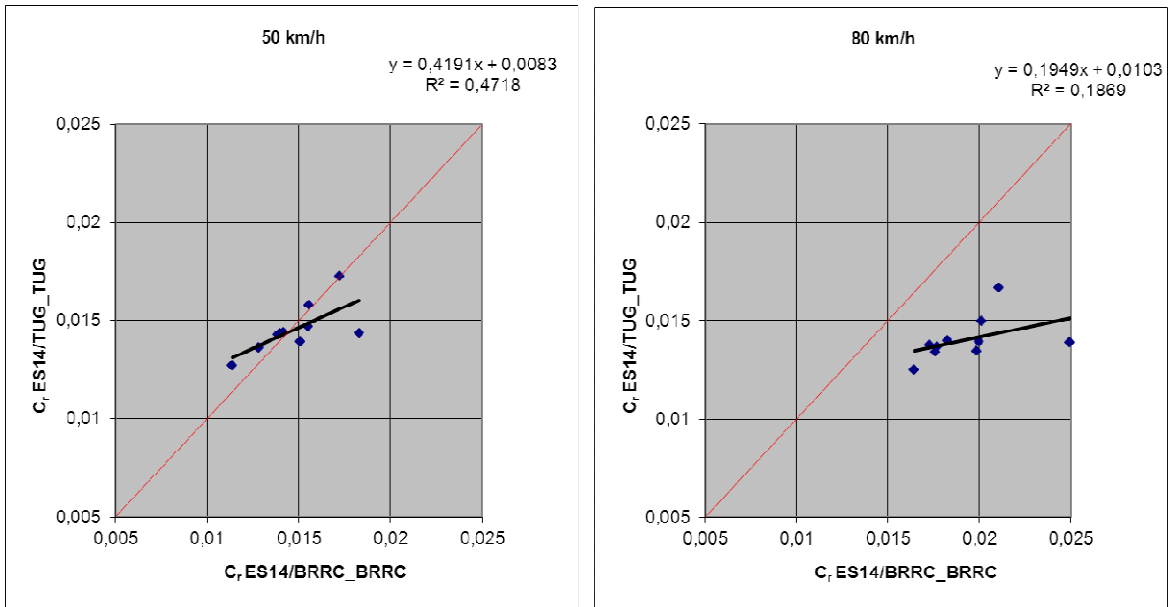


Figure 15 – Correlation between ES14/BRRc and ES14/TUG at 50 km/h (left) and 80 km/h (right).

7.3.3 Trailer-related differences

Measurements were performed by BAsT and TUG with exactly the same tyres (see Figure 16: AAV4/BAsT and SRTT/BAsT). At 50 km/h there appears to be a certain offset. For the AAV4 graphs the difference should have been the opposite, as TUG measured with a higher tyre inflation pressure. The offset is opposite for the SRTT graphs. This offset does not appear at 80 km/h. The results are inconsistent as the differences depend on tyre and speed, which is difficult to explain. It may be an indication of a different speed dependency of the two trailers.

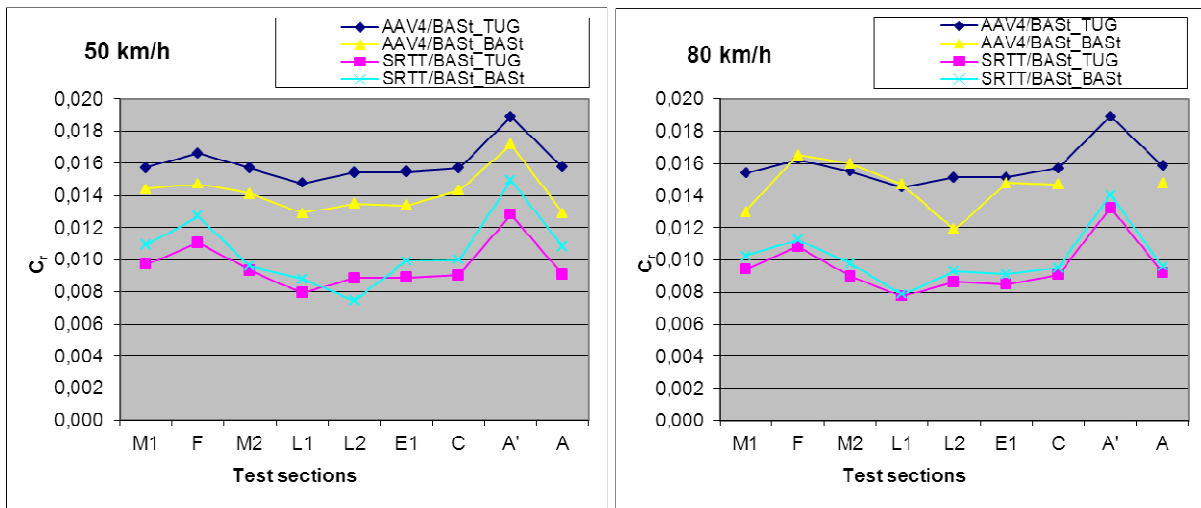


Figure 16 – C_r measured by TUG and BAsT measured for various test sections with AAV4/BAsT and SRTT/BAsT tyre at 50 (left) and 80 km/h (right)

8. CONCLUSIONS

The short term repeatability of the BRRC and BAST measurements were approximately 3 % of the average rolling resistance (C_r) values, which one can consider as just acceptable. The short term repeatability of the TUG trailer measurements was as low as 1 %, which is excellent.

The variability of the measurements from day to day was approximately 7 % for BAST, which was considered as not acceptable as it is as high as the differences one wishes to detect. For the BRRC trailer, it was even higher, indicating that there is a calibration problem which needs a follow up. Corresponding tests for the TUG trailer were not made.

The correlation between the values of C_r measured by the trailers of BAST and TUG, using different samples of tyres of the same type, were generally very good, except for the Avon AV4 tyre at 80 km/h (probably due to some temporary disturbing effect). In general, reproducibility appeared to be rather poor; following what is written in the previous paragraph.

Measurements were made with different Michelin Energy Saver 14" tyre samples on the BRRC and TUG trailers. The correlation between the BRRC and TUG measurements over the test sections is rather poor at 50 km/h and almost non-existent at 80 km/h. The poor correlation at 50 km/h is due to one outlying value measured with the BRRC trailer, which is probably erroneous due to an acceleration effect. When discarding this outlier, the correlation becomes very good. Some differences between the two tyres were revealed by the TUG drum measurements, which might have influenced the measurements on the test track. The lack of correlation at 80 km/h is most likely due to the absence of wind shielding of the test tyre on the BRRC trailer, allowing air drag to play a significant role.

9. ACKNOWLEDGEMENTS

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