Submitted by the experts of TF on Tyres Abrasion

Informal document GRBP-78-17
(78th GRBP, August 30 – September 1, 2023,
agenda item 7(e))

Vehicle method for measurement of tyre-to-road abrasion rate in real driving environment

Contents

Introduction

This document gives specifications for a vehicle test method on public open roads. This document provides all necessary specifications and procedures to measure C1 tyres abrasion rate.

1 Scope

This document specifies methods for measuring tyre-to-road abrasion rate on open road circuit, in real driving environment.
This document is applicable to C1 tyres as defined in R117
Excluded tyres:
- Tyre not homologated for on road permanent usage (e.g. competition tyres)
- Free rolling tyres (trailers, caravan…) *to be checked*
- Temporary tyres (marked “temporary” only)
- Tyres designed for competitions;
- Tyres fitted with additional devices to improve traction properties (e.g. studded tyres);
- Tyres designed only to be fitted to vehicles registered for the first time before 1 October 2000;
- Professional off-road tyres.

2 References

- UN R117
- UN R154

3 Terms and definitions

3.1 Loop

Section of the circuit having the same starting and ending point.

3.2 Circuit

The roads which will be used for the abrasion test, can be run both way.
The circuit can consist of one or several loops, which can be run in any order.
If the same loop is run clockwise or anticlockwise, it has to be considered as 2 loops.

3.3 Shift

The time needed to run the circuit (including break time, rotation time between vehicle in convoy or drive in vehicle). By work regulation, a shift is often limited to 8 hours.

3.4 Total distance run by the test tyres during test

Total distance ran by a tyre during the test

3.5 Electric machine

Energy converter transforming between electrical and mechanical energy.

3.6 Category of propulsion energy converter

Internal combustion engine, or an electric machine.

3.7 Hybrid electric vehicle (HEV)

Hybrid vehicle where one of the propulsion energy converters is an electric machine.

3.8 Hybrid vehicle

Vehicle equipped with a powertrain containing at least two different categories of propulsion energy converters and at least two different categories of propulsion energy storage systems.

3.9 Not off-vehicle charging hybrid electric vehicle (NOVC-HEV)

Hybrid electric vehicle that cannot be charged from an external source. In this UN GTR, NOVC-HEV are categorised to “NOVC-HEV Category 1” and “NOVC-HEV Category 2” based on their traction REESS nominal voltage.

3.10 Off-vehicle charging hybrid electric vehicle" (OVC-HEV)

Hybrid electric vehicle that can be charged from an external source.

3.11 Pure electric vehicle (PEV)

Vehicle equipped with a powertrain containing exclusively electric machines as propulsion energy converters and exclusively rechargeable electric energy storage systems as propulsion energy storage systems.

3.12 Pure internal combustion engine vehicle (ICE)

Vehicle where all propulsion energy converters are internal combustion engines.

3.13 Rechargeable electric energy storage system – REESS

Rechargeable electric energy storage system that provides electric energy for electric propulsion.

3.14 FWD (Front Wheel Drive) vehicles

Vehicle where only the front axle delivers traction torque

3.15 RWD (Rear Wheel Drive) vehicles
Vehicle where only the rear axle delivers traction torque

3.16 4WD (4 Wheel Drive) vehicles
Vehicle where one of the axle traction torque can be switched off by the driver.

3.17 AWD (All Wheel Drive) vehicles
Vehicle with permanent or vehicle controlled 4 wheels drive.

3.18 Reference vehicle
This vehicle will be the vehicle fitted with the reference tyres

3.19 Test vehicle
This vehicle will be the vehicle fitted with the candidate tyres

3.20 Vehicle F2 coefficient
F2 coefficient may be found in vehicle certificate of conformity. It is determined according to UN R154.

3.21 Accelerations
Unit for accelerations is m/s^2
- Longitudinal acceleration: accelerations in the direction of vehicle movement:
  - positive sign for speed increase,
  - negative sign for speed decrease (e.g. braking)
- Lateral acceleration: accelerations perpendicular to the direction of vehicle movement
  - Positive sign turning left
  - Negative sign turning right

3.22 Classes of tyre
- as defined in R117

3.23 Category of tyres
- as defined in R117

3.24 LI (load index)
Numerical code associated with the maximum load a tyre can carry at the speed indicated by its speed symbol under the service conditions specified by the tyre manufacturer

3.25 Test tyre
Tyre that is used for an evaluation program, either candidate tyres or reference tyres

3.26 Reference tyre
Tyre which will be used in each convoy as a reference for abrasion rate performance of the candidate tyre(s).

Reference tyre to be used		*"Normal" reference tyre*	*"3PMSF" reference tyre*
Normal tyre		X	
Snow tyre		X	
	Snow tyre that is classified as tyre for use in severe snow conditions		X
Special use tyre		X	
	Special use tyre that is classified as tyre for use in severe snow conditions		X

3.27 Candidate tyre
Tyre which will be tested for abrasion rate performance.

4 Symbols and abbreviated terms
Table 1 Symbols used and corresponding paragraphs

Symbol	Unit	Clause	Designation
Q_{Ri}	kg	13.12	Test load for each reference tyre
Q_{Ti}	kg	13.12	Test load for each candidate tyre
$MRTS_i$	g	13.12	Reference tyre initial mass of tyre i
$MRTF_i$	g	13.12	Reference tyre finale mass of tyre i

$MCTS_i$	g	13.12	Candidate tyre initial mass of tyre i
$MCTF_i$	g	13.12	Candidate tyre finale mass of tyre i
S_S	Mg/km/t/°C	13.12, 8.6.2	Sensivity of summer reference tyre to temperature variation
S_W	Mg/km/t/°C	13.12	Sensivity of winter reference tyre to temperature variation
S1	Mg/km/t	13.12	Minimal abrasion rate @ 20°C of summer reference tyre during test
S2	Mg/km/t	13.12	Maximal abrasion rate @ 20°C of summer reference tyre during test
W1	Mg/km/t	13.12	Minimal abrasion rate @ 20°C of winter reference tyre during test
W2	Mg/km/t	13.12	Maximal abrasion rate @ 20°C of winter reference tyre during test
D_{Ti}	km	13.12	Actual total distance run by each test tyres during test
$ARRT$	mg/km/t	13.12	Abrasion rate of reference tyre, normalized to load in ton, at test temperature
$ARCT$	mg/km/t	13.12	Abrasion rate of candidate tyre, normalized to load in ton, at test temperature
$AICT$	No dimension	13.12	Abrasion rate index of the candidate tyre

5 Instrumentation

Calibration and check for weight scales shall be carried out according to annex B

5.1 Instruments for tyre mass measurement

Weight scale able to measure the tyre mass with accuracy of +/- 2 gramme

5.2 Instruments for alignment and camber measurement on vehicle

The device shall have accuracy of [+/- 0.033] +/- 2' (to be confirmed)

5.3 Instruments for vehicle mass measurement per position

Weight scale able to measure the load on each tyre with accuracy of +/- 0.1%

5.4 Instruments for acceleration, distance and speed measurements

During the test, a continuous evaluation of speed, lateral and longitudinal acceleration shall be done, with a sampling rate minimum and recommended 10 Hz. Technology to use is GNSS (Global Navigation Satellite System) measurement associated with numerical treatment of the positions. See numerical treatment for GNSS (Global Navigation Satellite System) data in annex 1.

Distance run by a tyre = GNSS distance + distance without GNSS signal, unless this distance is estimated by the GNSS itself.

Accelerometers usage has been considered in this document and should be avoided as no numerical treatment available.

5.5 Tyre pressure measurement device

The device shall have accuracy +/- 3 kPa

5.6 Instruments for weather (rain, snow, ice) measurement

For rain, test drivers to record mileage with wipers in function (actually wiping the windshield) for each shift.
For snow/ice, test drivers to record mileage driven with snow or ice on the road for each shift.

5.7 Instruments for temperature measurement

The vehicle external thermometer can be used, and data recorded with time and location on paper or file.
Any thermometer, positioned to measure external air temperature is acceptable as well.
Continuous measurement device recording the temperature acceptable as well.
Initial and final measurement should be done using a calibrated thermometer.

5.8 Instruments for tyre and wheel assembly mass measurement

Weight scale able to measure the tyre mass with accuracy of +/- 2 grammes

6 Tyre, tyre and wheel assembly and vehicle measurement procedure

6.1 Tyre mass measurement

The tyre should be cleaned and dried before mass measurement, with device or product not removing any rubber from the tyre (e.g. water based non abrasive cleaner). Any visible stone should be removed from the pattern before mass measurement. The measurement shall be repeated 3 times and averaged.

6.2 Tyre and wheel assembly mass measurement

The tyre assembly should be cleaned and dried before mass measurement, with device or product not removing any rubber from the tyre (e.g. water based non abrasive cleaner). Any visible stone should be removed from the pattern before mass measurement, without air pressure, and without valve core.
The mass measurement should be performed after checking that the balancing masses are all present on the assembly.

6.3 Vehicle mass measurement procedure

The vehicle should be cleaned and dried before measurement, with full fuel tank (ICE vehicle), test ballast, equipped with the tyres to be tested and wheels used for the test with drivers average weight. Load on each wheel shall be measured.

6.4 Vehicle alignment measurement procedure

To confirm with measurement experts

7 Vehicle requirements

7.1 General requirements

Alignments setting shall be performed as following:
- With empty or loaded vehicles with full tanks, measurement and setting of the alignments respecting conditions in clauses 7.1.1 to 7.1.4 (depending on the vehicle type)
- Measure and record the alignment values with vehicles in loaded conditions
- These values measured with loaded conditions will be monitored during the test, and will the reference values to respect during the tests.

Alignments (TOE and camber) on both axles of reference vehicle and of each test vehicle shall be checked at least:
- At the beginning of the test, max 50 km of distance run before starting the test,
- Optionally at half distance,
- In case of an impact (e.g. curbstone contact, etc)
- At the end of the test, max 50 km of distance run after finishing the test,
- Any additional distance to go to geometry measurement facility shall not be driven with reference or test tyres.

At the end of the test, the alignments shall not vary by more than +/-0.15 degree for toe and +/- 0.3 degree for camber from initial measurement under the same condition.

Optionally alignments can be checked at half distance.

7.1.1 Vehicles acceptable suspension and static tuning for FWD vehicles

7.1.1.1 Vehicles used for candidate tyres:

- Loaded vehicle (including full tank, ballast and drivers average weight):
  - Toe IN/OUT angle per wheel on the front axle set to 0 ± 0.1 degree (0 degree ±6’),
- Unloaded vehicle with full tank:
  - Camber angle on the front axle set in the interval [-0.8;0] degree,
  - Targeted values for toe per wheel for rear axle: [0.05;0.2] degree,
  - Targeted values for camber per wheel for rear axle: [-1.6; -0.6] degree.

7.1.1.2 Vehicle used for reference tyres,

- Loaded vehicle (including full tank, ballast and drivers average weight):
  - Toe IN/OUT angle per wheel on the front axle set to 0 ± 0.05 degree (0 degree ±3’),
- Unloaded vehicle with full tank:
  - Camber angle on the front axle set in the interval [-0.8;0] degree,
  - Targeted values for toe per wheel for rear axle: [0.05;0.15] degree,
  - Targeted values for camber per wheel for rear axle: [-1.6; -0.6] degree.

In addition, for reference vehicle, toe IN/OUT in absolute value shall be lower than the values used for test vehicles for front axle.

7.1.2 Vehicles acceptable suspension and static tuning for RWD vehicles

7.1.2.1 Vehicles used for candidate tyres, loaded including full tank, ballast and drivers average weight

- Toe IN/OUT angle per wheel on the front axle set to 0 ± 0.1 degree (0 degree ±6’),
- Camber angle on the front axle set to 0 ± 0.1 degree,
- Toe IN/OUT angle per wheel on the rear axle set to 0 ± 0.1 degree (0 degree ±6’),
- Camber angle on the rear axle set to 0 ± 0.1 degree.

7.1.2.2 Vehicle used for reference tyres loaded including full tank, ballast and drivers average weight

- Toe IN/OUT angle per wheel on the front axle set 0 ± 0.05 degree (0 degree ±3’),
- Camber angle on the front axle set to 0 ± 0.1 degree,
- Toe IN/OUT angle per wheel on the rear axle set to 0 ± 0.1 degree (0 degree ±6’),
- Camber angle on the rear axle set to 0 ± 0.1 degree.

In addition, for reference vehicle, toe IN/OUT in absolute value shall be lower than the values used for test vehicles for front axle.

7.1.3 Vehicle acceptable suspension and statice tuning for 4 wheels drive vehicles

4 WD vehicles can be used using only one axle as drive axle, then are considered as FWD or RWD depending on the configuration.

7.1.4 Vehicles acceptable suspension and static tuning for All wheel drive vehicles

Vehicle with permanent 4 wheel drive are to respect the RWD vehicles settings described in clause 7.1.1.1

7.1.5 Vehicle acceptable propulsion energy convertor

All the propulsion energy convertor are allowed, as long as they are homogeneous in the convoy.

7.1.6 Vehicle acceptable transmission system

Front wheel drive vehicle shall be used if available for the tyre size to be tested.

If the tyre size can only be fitted on rear wheel drive vehicle, a rear wheel drive vehicle shall be used, and the reference tyres shall as well be fitted on rear wheel drive vehicle

If the tyre size can only be fitted on all wheels drive vehicle, an all wheels drive vehicle shall be used, and the reference tyre shall as well be fitted on all wheels drive vehicle. If available, vehicle with similar torque distribution shall be used for both reference tyre and candidate tyre. If not available, the default mode shall be used for both reference vehicle and test vehicle.

Automatic or manual gear box are possible in the same convoy.

7.1.7 Vehicle driving mode

If several driving mode are available, the default driving mode shall be selected.

7.1.8 Regenerative braking

It is allowed to use vehicles with similar regenerative capabilities for all the tires in the convoy (reference and test tyre).

- If regenerative braking can be switched off, the vehicle can be used for any tire, regenerative braking shall be switched off during the test,
- If regenerative braking cannot be switched off:
  - It is allowed to use the vehicle if similar regenerative capabilities vehicles are used for all the tires in the convoy (reference and test tyre), with same regenerative settings,
  - If different vehicle in the convoy, the reference tire shall be tested on a vehicle without regenerative braking (to avoid increasing the abrasion of ref tire, while not increasing for the test tires)

7.1.9 Vehicle acceptable aerodynamical performances

Aerodynamical performance of the vehicle fitted with reference tyres shall respect the following condition:

F2 of vehicle with reference tyres <=1.2*F2 of vehicles of measured tyres

7.1.10 Vehicle acceptable mass (depending on the tyre size and tyre load index)

- The total vehicle mass shall allow to load the tyre with a total load of 67% +/- 7% of the total nominal tyre load capacity for 4 tyres. Example of calculation: the reference tyres load index is 94, which corresponds to a maximum load of 670 kg. The total load nominal load of the 4 tyres is then 670*4 = 2680 kg. The loaded vehicle mass shall then be 2680*67% = 1796 kg with a tolerance of 2680*7% then +/- 188 kg.
- Load distribution between front and rear axle shall be as following:
- For FWD vehicles: Front axle load 56% +/- 7%, Rear axle 44% +/- 7% of total vehicle load
- For AWD/RWD vehicles: Front axle load 50% +/- 7%, Rear axle 50% +/- 7% of total vehicle load

Ballast allowing to reach above load is authorized, under the condition that it does not exceed 85% of the vehicle maximal payload. A minimal ballast of 1.5 passengers including driver shall be included.

8 Circuit, acceleration and speed requirements

The circuit shall be a closed loop, with car coming back to the departure point, without being transported on a car carrier.

8.1 Circuit minimal length

Circuit shall be made of one or several closed loops, with car coming back to the departure point. The minimal length shall be 300 km of different roads. Vehicle shall not be transported on a car carrier, except in case of vehicle/tyre failure.
Circuit can be run both ways. Equal distance to be run each way if both ways are used.

8.2 Driving style distribution

The circuit shall respect the following distribution of acceleration/distance:

- Roads representative highway driving style:
  - 40% +/- 5% of the total distance
  - Longitudinal acceleration standard deviation in range [0.18;0.53] m/s^2
  - Lateral acceleration standard deviation in range [0.32;0.78] m/s^2
- Roads representative of regional driving style:
  - 30% +/- 5% of the total distance
  - Longitudinal acceleration standard deviation in range [0.34;0.78] m/s^2
  - Lateral acceleration standard deviation in range [0.52;1.46] m/s^2
- Roads representative of urban driving style:
  - 30% +/- 5% of the total distance
  - Longitudinal acceleration standard deviation in range [0.42;0.80] m/s^2
  - Lateral acceleration standard deviation in range [0.54;1.27] m/s^2

8.3 Global accelerations level

8.3.1 Standard deviation

- Longitudinal acceleration standard deviation: 0.45 m/s^2 +/- 10%
- Lateral acceleration standard deviation: 0.93 m/s^2 +/- 10%

Longitudinal and lateral accelerations standard deviations during the test shall not deviate by more than 5% from one vehicle to another vehicle of the same convoy

8.3.2 Maximal acceleration

- Maximal longitudinal acceleration: +/- 5 m/s^2 for a distance representing at least 99.8% of the total distance
- Maximal lateral acceleration: +/- 5 m/s^2 for a distance representing at least 99.8% of the total distance

8.4 Speed requirements

Speed shall not excess applicable legal limits, nor the speed of 140 kph

8.5 Acceleration and speed monitoring during the test

Acceleration and speed shall be constantly monitored during the test for each car in the convoy.
Acceleration and speed calculation are explained in Annex A

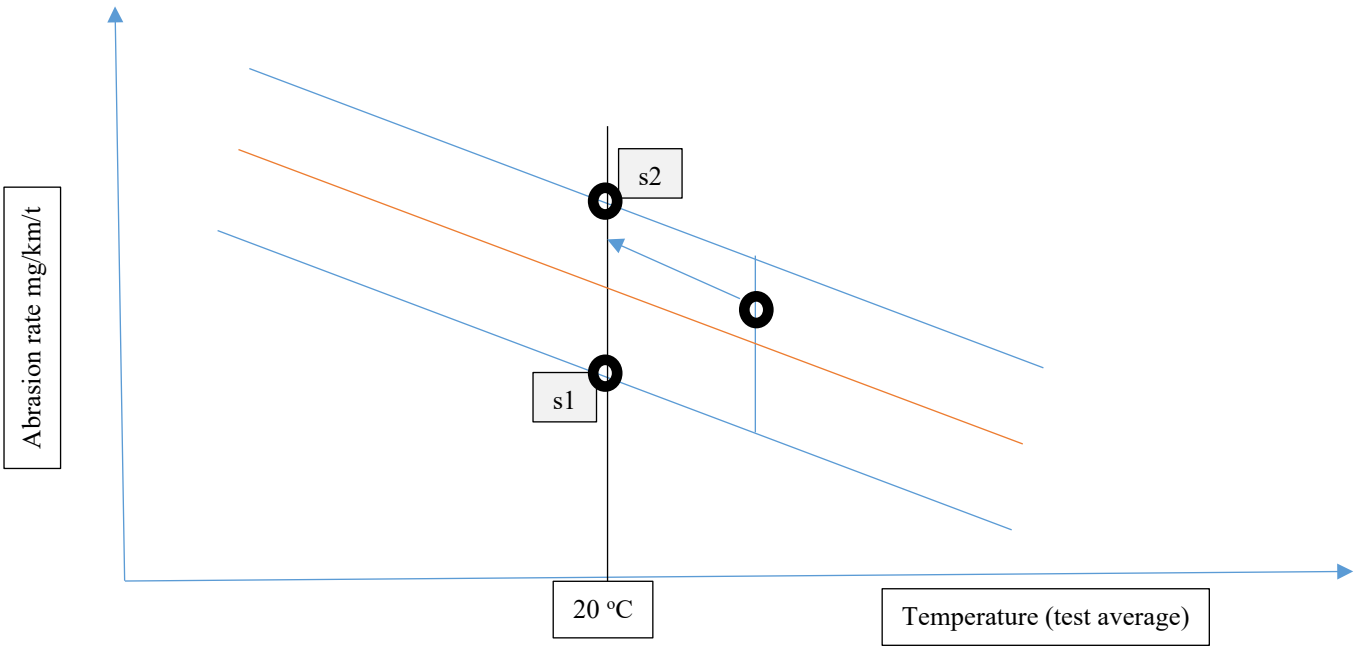
8.6 Circuit abrasion level

To be usable for test, the circuit shall respect at least one of the below abrasion value for reference tyres:

8.6.1 Abrasion level specification

- Summer reference tyre: circuit abrasion level @ 20 °C should be in the range [s1,s2]*mg/km/T
- Winter reference tyre: circuit abrasion level @ 10 °C should be in the range [w1,w2]* mg/km/T

* still to be fixed



Calculation shall be made according to paragraph 8.6.2

8.6.2 Reference tyre abrasion level calculation at 20°C

- At least one reference tyres (summer or winter) shall be measured at least 3 times in total at different temperatures differing by more than 5 degrees C, with at least 2 different vehicles in each repetition.
- A linear regression will give the value of abrasion rate for references tyres at 20 degrees (summer) or 10 degrees (winter). The final value will be the average of the 2 vehicles.
- For summer reference tyres, at least one measurement shall be done between 15 and 25 °C.
- For winter reference tyres, at least one measurement shall be done between 5 and 15 °C.

For each of the 6 sets of reference tyres tested, an $ARRT_i$ abrasion rate in mg/km/t at a temperature T_i is available

S, the slope of the regression line of the reference tyre abrasion rate to the average test temperature during the test is by the following calculation

$$S = \frac{\sum_{i=1}^{6}(ARRT_i - \overline{ARRT_i}) \times (T_i - \overline{T_i})}{\sum_{i=1}^{6}(T_i - \overline{T_i})^2}$$

If the circuits is utilized to test both 3PMSF tyres and non 3PMSF tyres, the S calculation shall be done for each reference tyre, giving S_S and S_W values

9 Weather and climate requirements

9.1 Climate requirement for tyres not for severe Snow (no 3PMSF) usage

Tyres from Normal, Special use categories and Snow tyres not intended for severe snow usage (without 3PMSF):

- Temperature average during the test: range = [7°C ;35°C]
- Temperature minimal/maximal during the test: range = [2°C ;40°C] for 90% of test distance.
- No driving if Snow or Ice
- Maximum % of wet mileage = 20 %

9.2 Climate requirement for Severe Snow (3PMSF) tyres abrasion test:

- Temperature average during the test: range = [-3°C ;20°C]
- Temperature minimal/maximal the test: range = [-7°C ;25°C] for 90% of test distance.
- No driving if snow or ice distance for more than 5% of the distance
- Maximum % of wet mileage = 20 %

9.3 Weather data recording

9.3.1 Wet distance measurement:

Wet%: measurement by % of distance with wipers on. These can be manually collected on one vehicle of the convoy, or data can be collected from vehicle information (as CAN bus) if available.

9.3.2 Average temperature:

Minimum 5 measurements per shift on the circuit, including starting and arrival point, and highest altitude reached on the circuit, made on at least one vehicle of the convoy.

The temperature measuring devices shall be accurate within ±1 °C. At least at starting and arrival point, the measurement shall be done with a fixed device respecting requested precision, with a temperature sensor positioned outside in an unobstructed location, exposed to the airflow and protected from direct solar radiation. The latter may be achieved by any shading screen or similar device.

For measurements on the road, a weather station installed in the vehicle with external temperature sensor can be used.

Continuous measurement is acceptable. In this case, average, minimum and maximum measurement should be reported in the report, for the full test. The 10 first minutes after departure and after each driver's break shall be discarded from the minimum, maximum and average calculation. Time based average for temperature is acceptable.

10 Reference tyre requirements

Reference tyres shall be stored in condition recommended by ASTM.

10.1 Normal reference tyre requirements

Normal reference tyre (225/45R17 94 XL ASTM …) shall be used for tyres not for severe snow condition, means normal, snow and special use tyres as defined in UN R117.

10.2 3PMSF reference tyre requirements

3PMSF reference tyre (225/45R17 94 XL ASTM …) shall be used for tyres for severe snow conditions as defined in UN R117

11 Preparation and adjustments with respect to tyres

11.1 Tyre fitment on rim and vehicle

New candidate tyres shall be mounted and balanced on any rim requested and authorized by the tyre manufacturer.

New Reference tyres for each test shall be fitted on a 7.5" rim width.

The rim width of candidate tyre shall be recorded. Tyres with special fitment requirements, such as asymmetric or directional design, shall also be mounted in accordance with these requirements: direction of rotation shall be respected and the side of the tire intended to face vehicle outside shall be outside.

11.2 Tyre weight measurement (without rim)

Measurement done following procedure described in paragraph 6.1

No rubber (e.g. vents) shall be removed from any tyre (test or reference) before starting the test.

Each tyre weight shall be measured:
- Before being fitted on the wheel, to get the initial tyre masses M_{RTSi} for reference tyres and M_{CTSi} for candidate tyres
- After finishing the test and dismounting the tyre from the tyre wheel assembly, to get the final tyre masses M_{RTFi} for reference tyres and M_{CTFi} for candidate tyres

11.3 Tyre and wheel assembly mass measurement

Measurement done following procedure described in paragraph 6.2

Intermediate measurement of tyre and wheel mass assembly are optional.

11.4 Tyre inflation pressure

Reference tyres pressure is 290 kPa.

Candidate tyres shall be inflated (cold) at their nominal pressure determined by the standard they belongs to:
- For standard load tyres, the pressure shall be 250 kPa,
- For reinforced load tyres (XL) and high load capacity tyres (HL), the pressure shall be 290 kPa,
- Nominal pressure for nominal load determined by the relevant standard if different (e.g. 240 kPa or 280 kPa for some TRA tyres).

12 Preparation and adjustments with respect to vehicles

Vehicles for test and reference tyres shall be selected following the constraints of paragraph 7.

12.1 Vehicle mass measurement

Measurement done following procedure described in paragraph 6.3
The vehicle shall be ballasted following prescription of paragraph 7.1.10
Measurements of each wheel load Q_{Ti} and Q_{Ri} are required.

12.2 Vehicle tuning

Vehicle alignments to be tuned following prescription of paragraph 7.1.1 to 7.1.4

13 Test method and measurements

13.1 General

- The tyre abrasion test is run on open roads, using up to 4 vehicles in a convoy, driven about 8000 km along selected circuits having a given driving severity, exposing each candidate tyre to the same condition (severity, drivers, position in convoy, weather…)
- The tyres are evaluated relatively to a reference tyre, fitted on one convoy's vehicle, in order to absorb mainly temperature variation, but other varying parameters as well.
- Measured performances: new tyres mass losses for a given service (distance and/or load carried), averaging vehicle 4 tyres. Unit: mg/km and/or mg/km/ton, giving an index relative to reference tyre.

13.2 Test total distance

8000 -300/+1200 km.

13.3 Convoy composition and management

Convoy should be homogeneous for:
- Number and position of driven wheels (see paragraph 7.1)
  - FWD only in the convoy
  - RWD only in the convoy
  - AWD (4 permanent driven wheels) only in the convoy.
- Propulsion energy converters (e.g. Pure internal combustion engine vehicle" (ICE), NOVC-HEVCs only, OVC-HEVs only, or PEVs only) in the same convoy. See for hybrid vehicle on paragraph 7.1.8

If the candidate tyre size can be fitted on the same model of vehicle that the reference tyre, the same model and same settings of vehicles shall be used for both reference tyre and candidate tyre, if parameters allowed for candidate tyre (especially loading).

Maximal distance between vehicle in the convoy: each driver shall be able to have visual contact with the vehicle preceding and following him.

Each vehicle shall drive on the right lane (or left lane for left driving countries) when free.

13.4 Vehicle rotation in the convoy, driver rotation on vehicles

Each candidate tyre, including tested and reference tyres, shall be exposed for the same distance with a tolerance of 10% to:
- all drivers,
- all positions in the convoy.

13.5 Data measured before, during and after the test

13.5.1 Before and after the test:

Before and after the test, the following measure shall be done:
- Each tyre mass,
- Load on each tyre,
- Vehicle alignments (unloaded vehicle then loaded vehicle),
- Tyre pressure after tyre fitment and before dismounting tyres.

13.5.2 During the test

During the test, following measurements shall be performed:
- Continuous measurement of longitudinal and lateral accelerations on each vehicle,
- Continuous speed measurement on each vehicle,
- Temperature measurement (as requested in paragraph 9.3),
- Tyre pressure each day, cold condition.
- Vehicle alignment, in loaded condition, accompanied by correction to initial value if relevant for vehicle used for reference tyres, 4 times during the test, at roughly a quarter of the test distance.

At intermediate stops, it is recommended but not compulsory to measure:
- Tyre and Wheel assembly mass,
- Vehicle alignment, in loaded condition, accompanied by correction to initial value if relevant for vehicle used for candidate tyres

13.6 Data processing for average temperature

Temperature measurement during the test:

During each shift, temperature shall be measured and recorded at the beginning of test, intermediate 1, intermediate 2, intermediate 3 and end of test. At least one point should be located at the maximal altitude of the test, and one point shall be located at minimal altitude of the circuit.

Average temperature is the average of all the measured temperature.

In case of continuous measurement, average temperature should preferably be calculated distance based, but time based average for temperature is acceptable.

13.7 Data processing for test longitudinal and lateral accelerations standard deviation

During each shift, a continuous evaluation of speed, lateral and longitudinal acceleration is compulsory, with a sampling rate minimum and recommended 10 Hz. Most common technology is GNSS (global Navigation Satellite System) measurement associated with numerical treatment of the positions

Acceleration data processing is defined in Annex A

13.8 Test validation

The test is validated if following conditions are met:
- Temperatures: minimal, maximal and average temperatures as calculated in paragraph 13.6 shall respect specifications of paragraph 9
- Accelerations: lateral and longitudinal acceleration should respect maximal, standard deviation values as calculated in paragraph 13.7 shall respect specifications of paragraph 8.3
- Vehicle alignments at the beginning and end of test shall respect the specification of paragraph 7.1
- For 3PMSF candidate tyres, abrasion rate of the winter reference tyre normalized at 10C ($ARRT_{20}$) is in the range defined in paragraph 8.6.1
- For other candidate tyres, abrasion rate of the summer reference tyre normalized at 20C ($ARRT_{20}$) is in the range defined in paragraph 8.6.1
- A visual inspection of reference tyres shall show no damage on reference tyres. Tyre sidewall marking shall still be readable. If a reference tyre was loosing more than 1 cm^2 of tread chunking area, the tyre shall be considered as destroyed, and tyre destroyed process to be used.

13.9 Deviation from nominal circuit

If the circuit is modified by less than 10 km for the full test and the total driven distance remains in the 8000 -300/+1200 km and the abrasion rate of reference tyre @ 20C and the accelerations limits are in the authorized ranges, the circuit is still valid, and the distance considered for calculation has to be corrected accordingly.

If the circuit is modified by more than 10 km and less than 30 km, for less than 8 shifts and the total driven distance remains in the 8000 -300/+1200 km, and the abrasion rate of reference tyre @ 20C and the accelerations limits are in the authorized ranges, the circuit is still valid and the distance considered for calculation has to be corrected accordingly.

Accidental deviation(s) are acceptable if representing less than 20% of circuit distance or less than 100 km (whichever is lower) under the condition that reference tyre abrasion rate @ 20C stays in authorized limits and acceleration standard deviations are respected

In other cases, the circuits has to be revalidated.

13.10 Vehicle trouble handling

- If a vehicle used in the convoy is damaged and cannot be used anymore (major mechanical failure or accident), it shall be replaced by an identical vehicle, identically loaded and tuned. The replacement vehicle, equipped with the same tyres having started the test, shall run without other vehicles of the convoy the distance lost due to vehicle failure, on the lost segment of the circuit.
- If a vehicle used in the convoy is broken down and can be repaired, the lost distance shall be ran without other convoy vehicle on the lost segment of the test circuit.

Alternately, if the failure happens on a test vehicle and not on the reference vehicle, the convoy can continue the test, and the failing vehicle/tyre withdrawn from the convoy. A new set of candidate tyres shall then be used for a new test, starting from scratch.

13.11 Tyre trouble handling

- If a tyre used during the test on the reference vehicle or one of the test vehicles is damaged by reparable puncture and if the tyre can be repaired without running without pressure, the added repair mass shall be recorded and taken into account in the final calculation. The use of a spare tyre is authorized for a maximal distance of one loop ~~7.5%~~ of the test. The mileage ran with the spare tyre shall be recorded and taken into account for the tyre abrasion rate.
- If a tyre used during the test is destroyed (or non-repairable puncture or ran without pressure), the mass loss of the other tyre tested on the same axle is used twice to perform the final calculation. The spare tyre used to replace the destroyed tyre should have the same size and same pattern as the replaced tyre.

13.12 Data processing for abrasion rate calculation

13.12.1 Reference tyre abrasion rate normalized to distance and load at average test temperature (mg/km/t)

Average abrasion rate at test average temperature of the reference tyre during the test is calculated as following, and expressed in mg/km/T:

$$ARRT = \frac{1000 * \sum_{i=1}^{4} (MRTS_i - MRTF_i)/D_{Ti}}{\sum_{i=1}^{4} Q_{Ri}/1000} \quad \text{At average test temperature}$$

13.12.2 Normal Reference tyre abrasion rate calculation at 20°C

Apply the temperature correction determined in clause 8.6.2 to the normal reference tyre abrasion rate

$$ARRT_{20} = ARRT_{Tm} + S_S \times (T_m - 20)$$

13.12.3 Winter Reference tyre abrasion rate calculation at 10°C

Apply the temperature correction determined in clause 8.6.2 to the Winter reference tyre abrasion rate

$$ARRT_{10} = ARRT_{Tm} + S_W \times (T_m - 10)$$

13.12.4 Candidate tyre abrasion rate normalized to distance and load at average test temperature (mg/km/t)

The average abrasion rate at test average temperature of the candidate tyre during the test is calculated as following, and expressed in mg/km/T:

$$ARCT = \frac{1000 * \sum_{i=1}^{4} (MTTS_i - MTTF_i)/D_{Ti}}{\sum_{i=1}^{4} Q_{Ti}/1000} \quad \text{At average test temperature}$$

13.12.5 Abrasion index of candidate tyre independent from temperature

$$AICT = \frac{ARCT}{ARRT}$$

14 Measurement uncertainty

The measurement procedure described in paragraph 13 is affected by several parameters (e.g. temperature variations, vehicle impact, road and environmental conditions, measurement system uncertainty) that lead to variation in the resulting abrasion level observed for the same tyre. The source and nature of these perturbations are not completely known and sometimes affect the end result in a non-predictable way.

The uncertainties so determined are grouped as follows:

a) variations expected on the same test circuit using the same vehicle with similar temperatures in consecutive tests (run-to-run);

b) variations expected on the same circuit using different vehicles and different temperatures with variations in ambient conditions and equipment properties that can normally be expected during the year, e.g. circuit surfaces variations;

c) variations between on different circuits, using different vehicles where, apart from ambient conditions, equipment, staff, and road surfaces conditions also are different (site-to-site).

Uncertainty data are given in Table 2 for all tyre class of this document. The variability is given for a coverage probability of 95 %. The data express the variability of results for a certain tested tyre and do not cover product variation.
Until more specific knowledge is available, the data for site-to-site variability may be used in test reports to state the expanded measurement uncertainty for a coverage probability of 95 %.

Tyre category	Run-to-run	Month to month	Site-to-site
C1 abrasion index	[X]	[Y]	[Z]
[a] The actual measurement uncertainty for the month-to-month situation is dependent on			

Table 2 Variability of measurement results for a coverage probability of 95%

An ongoing experimental plan will allow to determine X, Y and Z before formal document for GRBP

15 Test report

15.1 The test report shall include the following information:

a) reference to this document;

b) average, minimal and maximal temperature during the test;

c) % of distance covered on wet roads;

d) Reference of the circuit used for the test, including the circuit length, driving style distribution, location,

e) Total deviation distance to the nominal distance in km

f) Start and end date of the test.

15.2 For each reference tyre, the following information shall be reported:

g) model of vehicle used for reference tyre;

h) tyre data, including manufacturer, brand name, trade name, size, LI and load capacity, speed symbol, reference pressure, and serial number of the tyres;

i) vehicle tuning at the beginning of the test (Front axle TOE and camber, rear axle TOE and camber), unloaded condition, for the vehicle fitted with reference tyre;

j) vehicle tuning at the beginning of the test (Front axle TOE and camber, rear axle TOE and camber), loaded condition, for the vehicle fitted with reference tyre;

k) vehicle tuning at each intermediate measurement of the test (Front axle TOE and camber, rear axle TOE and camber), loaded condition, for the vehicle fitted with reference tyre;

l) vehicle tuning at the end of the test (Front axle TOE and camber, rear axle TOE and camber), loaded condition for the vehicle fitted with reference tyre;

m) rim width (7.5”);

n) cold inflation pressure at the fitment;

o) cold inflation pressure at 50% of the test;

p) cold inflation pressure at the end to the test;

q) balancing mass at the beginning of the test;

r) balancing mass at the end of the test;

s) initial tyre mass $MRTS_i$ for each reference tyre;

t) final tyre mass $MRTF_i$ for each reference tyre;

u) abrasion rate in mg/km/t normalized at 20°C

v) ran distance for each reference tyre;

w) standard deviation of longitudinal acceleration for the vehicle fitted with reference tyre;

x) standard deviation of lateral acceleration for the vehicle fitted with reference tyre;

y) % of distance covered over the maximal longitudinal acceleration for the vehicle fitted with reference tyre;

z) % of distance covered over the maximal lateral acceleration for the vehicle fitted with reference tyre;

aa) measured tyre load for each reference tyre.

bb) Reference tyres visual inspection report

15.3 For each candidate tyre, the following information shall be reported:

cc) model of vehicle used for candidate tyre;

dd) tyre data, including manufacturer, brand name, trade name, size, LI and load capacity, speed symbol, reference pressure, and serial number of the tyre;

ee) vehicle tuning at the beginning of the test (Front axle TOE and camber, rear axle TOE and camber) for the vehicle fitted with candidate tyre, unloaded condition;

ff) vehicle tuning at the beginning of the test (Front axle TOE and camber, rear axle TOE and camber) for the vehicle fitted with candidate tyre, loaded condition;

gg) vehicle tuning at the end of the test (Front axle TOE and camber, rear axle TOE and camber) for the vehicle fitted with candidate tyre, loaded condition;

hh) rim width;

ii) cold inflation pressure at the fitment;

jj) cold inflation pressure at [50]% of the test;

kk) cold inflation pressure at the end to the test;

ll) balancing mass at the beginning of the test

mm) balancing mass at the end of the test;

nn) initial tyre mass $MCTS_i$ for each candidate tyre;

oo) final tyre mass $MCTF_i$ for each candidate tyre;

pp) measured tyre load for each candidate tyre

qq) ran distance for each candidate tyre;

rr) standard deviation of longitudinal acceleration for the vehicle fitted with candidate tyre

ss) standard deviation of lateral acceleration for the vehicle fitted with candidate tyre;

tt) % of distance covered over the maximal longitudinal acceleration for the vehicle fitted with candidate tyre;

uu) % of distance covered over the maximal lateral acceleration for the vehicle fitted with candidate tyre;

vv) measured tyre load for each candidate tyre

15.4 Final test results

ww) the measured result of abrasion rate $ARRT$ for the reference tyre during the test at average test temperature as described in paragraph 13

xx) the measured result of abrasion rate $ARTT$ for the candidate tyre during the test at average test temperature as described in paragraph 13

yy) the final result tyre abrasion rate index $AITT$ as described in paragraph 13

Annex A

Accelerations Calculation

A.1 Input for calculation

A.1.1 Required parameters

Following parameters are required for calculation:
- vehicle velocity (v), [m/s]
- longitudinal acceleration ($a_{longitudinal}$), [m/s²]
- lateral acceleration ($a_{lateral}$), [m/s²]

The accelerations are derived by evaluation of GNSS (GLOBAL NAVIGATION SATELLITE SYSTEM)signals. The recommend sampling rate is 10 Hz or more. Otherwise, the below described filtering process is not working.

Filter for measured Values

A.1.2 Speed jumps detection and correction

Before starting the filtering process, all measured values are checked concerning speed jumps. Speed jumps means measurements, which are not plausible. For these detection the velocity is filteredby using a Butterworth filter with a cut-off frequency of 1 Hz. A threshold for the maximum longitudinal acceleration is defined: 9 m/s². That means, that a speed change of maxium 9 m/s² · $t_{sampling}$ is still plausible.

A speed jump will be detected, if there is a speed difference of 2 · $\Delta speed_{possible}$. In case of a detected speed jump, the relevant raw speed values will be replaced by a linear interpolated value.

A.1.3 Butterworth Filter:

For filtering the measurement, a Butterworth filter second order with a cut-off frequency of 1 Hz is used. After this filter the values are smoothed with a “moving average” over 1 second for longitudinal acceleration, all other values over 2 seconds.

All accelerations measured for a velocity less than 7 km/h are excluded.

Matlab code:

```
fg = 1; % cut off frequency

order = 2; % filter order

fsample = 1/dt; % sample rate of measurement

[b,a] = butter(order,fcutoff/(0.5*fsample),'low');

out = filtfilt(b,a,double(datn)); % datn = relevant data
```

A.1.4 Filter for data range:

Matlab code:

```
% define index based on data range

indx = find(speed > limits.vmin/3.6 & speed < limits.vmax/3.6 & abs(ax) < limits.ax & abs(ay) < limits.ay); % impossible accelerations are also eliminated

speed = speed(indx);

ax = ax(indx);

ay = ay(indx);
```

A.1.5 Moving Average:

Matlab code:

```
winAx = filter.ax*fsample;
winOthers = filter.others*fsample;
ax = smooth(ax,winAx,'moving');
ay = smooth(ay,winOthers,'moving');
speed = smooth(speed,winOthers,'moving');
```

A.1.6 Distance-based Standard Deviation

Measured accelerations (sampled with a constant frequency) are transferred in distance-based values: one value per meter. For this a simple interpolation is used. With these accelerations, the standard deviation can be calculate with following well-known formulas:

$$S_{longitudinal} = \sqrt{\frac{1}{N-1} \cdot \sum_{i=1}^{N} \left(a_{longitudinal,i} - \mu_{longitudinal}\right)^2}$$

with $$\mu_{longitudinal} = \frac{1}{N} \sum_{i=1}^{N} a_{longitudinal,i}$$

$$S_{lateral} = \sqrt{\frac{1}{N-1} \cdot \sum_{i=1}^{N} \left(a_{lateral,i} - \mu_{lateral}\right)^2}$$

with $$\mu_{lateral} = \frac{1}{N} \sum_{i=1}^{N} a_{lateral,i}$$

Matlab code:

```
distance = cumsum(speed/fsample);
axDB = interp1(distance,ax,distance(1):1:distance(end)); % one value per 1m
ayDB = interp1(distance,ay,distance(1):1:distance(end));
stdax = round(std(axDB)*1000)/1000;
stday = round(std(ayDB)*1000)/1000;
```

Annex B

Calibration requirement for measurement instruments

This annex summarizes the minimum calibration requirements for the equipment used for tire abrasion rate measurements. Table B1 summarizes the calibration criteria and the intervals for the main equipment used in this document.

Table B1 Calibration requirements for measurement equipment

Instrument	Interval	Criterion
Scale for tyres	Yearly and at major maintenance	[±2 g]
Instrument for toe and camber	Yearly	+/- 0.033°
Acceleration/Speed sensor	Yearly	?
Scale for vehicle	Yearly and at major maintenance	+/- 0.1%
Temperature sensor	Yearly	[±1°C]
Tyre pressure sensor	Yearly	±3 kPa
Scale for tyre and wheel assembly	Yearly and at major maintenance	[±2 g]
…		

B.1.1 Scale for tyres

The calibration of the scale used for the tyres weighing according to paragraph 5.1 shall be traceable to national or international standards.

The scale shall be tested with at least four equally spaced reference weights. The difference of the reading from the reference weight shall be within ±2 g. The resolution shall be at least 1 g. The testing facility shall use certified calibration weights to verify the stability and the proper function of the scale, regularly. The testing facility shall perform the calibration of the scale upon the initial installation, yearly, and at every major maintenance.

To decide which other instruments are critical for detailed calibration procedures, or if only table A1 is enough

Annex C Calculation of reference tyre abrasion rate at 20ºC

This annex illustrates the calculation requested in clause 8.6.2

Calculation of sensitivity of reference tyre to temperature variation:
For each of the 6 sets of reference tyres tested on the circuit, 3 repetitions at 3 temperatures on 2 models of vehicle, an $ARRT_i$ abrasion rate in mg/km/t at a temperature T_i is available (see calculation in 13.12.)
M, the slope of the regression line of the reference tyre abrasion rate to the average measurement temperature during the test is by the following calculation

$$S_s = \frac{\sum_{i=1}^{6}(ARRT_i - \overline{ARRT_i}) \times (T_i - \overline{T_i})}{\sum_{i=1}^{6}(T_i - \overline{T_i})^2}$$ (mg/km/t/ºC) for summer reference tyres

$$S_w = \frac{\sum_{i=1}^{6}(ARRT_i - \overline{ARRT_i}) \times (T_i - \overline{T_i})}{\sum_{i=1}^{6}(T_i - \overline{T_i})^2}$$ (mg/km/t/ºC) for winter reference tyres

Calculation of reference tyres at 20℃(non 3PMSF tyres)

For a reference measured at T_m = 30 with abrasion rate = $ARTT_{30,\ the}$ abrasion rate at 20C will be:

$ARRT_{20} = ARRT_{Tm} + S_s \times (T_m - 20)$

Calculation of reference tyres at 10℃(3PMSF tyres)

For a reference measured at T_m with abrasion rate = ARTT the abrasion rate at 10C will be:

$ARRT_{10} = ARRT_{Tm} + S_w \times (T_m - 10)$