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# Passenger car tyres — Method for measuring relative wet grip performance — Loaded new tyres

*Pneumatiques pour voitures particulières — Méthode de mesure de l'adhérence relative sur revêtement mouillé — Pneumatiques neufs en charge*

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# Contents

# Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 31, *Tyre, rims and valves*.

This third edition cancels and replaces the second edition (ISO 23671:2015), which has been technically revised.

The main changes compared to the previous edition are as follows:

— the method accuracy and reproducibility has been improved by updating the formulae and coefficients for wet grip index calculation;

— the method of track validation  has been revised to be done only with 16 in SRTT instead of with BPN or 14 in SRTT,

— the wet grip performance measurement using a control tyre in case of vehicle method has been withdrawn.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

# Passenger car tyres — Method for measuring relative wet grip performance — Loaded new tyres

## 1 Scope

This document specifies the method for measuring relative wet grip braking performance index to a reference under loaded conditions for new tyres for use on passenger cars on a wet-paved surface.

The methods developed are meant to reduce variability. The use of a reference tyre is necessary to limit the variability of the testing procedures.

This document applies to all passenger car tyres except for:

— special-use tyres marked with "ET";

— T-type temporary spare tyres;

— tyres fitted with additional devices to improve traction properties (e.g. studded tyres).

## 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4000-1, *Passenger car tyres and rims — Part 1: Tyres (metric series)*

ASTM E965-96, *Standard Test Method for Measuring Pavement Macro texture Depth Using a Volumetric Technique*

ISO 4223-1, *Definitions of some terms used in the tyre industry — Part 1: Pneumatic tyres*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4223-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

**3.1**
**test run**
single pass of a loaded tyre over a given test surface

**3.2**
**braking test**
series of a specified number of *test runs* (3.1) of the same tyre repeated within a short time frame

**3.3**
**braking test cycle**
series of *braking tests* (3.2) that consist of an initial braking test of the *reference tyre set* (3.6), of up to three braking tests of *candidate tyre sets* (3.5), and a final braking test of the same reference tyre set

**3.4**
**test tyre**
tyre that is used for an evaluation programme

**3.5**
**candidate tyre**
**candidate tyre set**
*test tyre* (3.4) (set) that is part of an evaluation programme and that is evaluated with the reference tyre using the same test method

**3.6**
**reference tyre**
**reference tyre set**
special *test tyre* (3.4) (set) that is used as a benchmark in an evaluation programme

Note 1 to entry: The reference tyre (SRTT) is defined in ASTM F2493-20.

Note 2 to entry: These tyres have carefully controlled design features to minimize variation.

**3.7**
**braking force**
longitudinal force between a tyre and the road resulting from braking torque application

Note 1 to entry: It is expressed in newtons.

**3.8**
**peak braking force coefficient**
$\mu_{peak}$
<trailer (or tyre test vehicle) method> maximum value of the *dynamic tyre braking force coefficient* (3.9) that occurs prior to the *lockup* (3.11) of a wheel  as the braking torque is progressively increased

**3.9**
**dynamic tyre braking force coefficient**
$\mu(t)$
<trailer (or tyre test vehicle) method> ratio between the *braking force* (3.7) and the *vertical load* (3.12) acquired in real time

**3.10**
**average braking force coefficient**
*BFC*
<vehicle method> ratio between the average deceleration in a *test run* (3.1) and the acceleration gravity $(9,81 \ m \cdot s^{-2})$

**3.11**
**lockup**
condition of a wheel in which its rotational velocity about the wheel spin axis is zero and which prevents it from rotating in the presence of applied wheel torque

**3.12**
**vertical load**
normal force of a tyre exerted on the road resulting from the mass supported by the tyre

Note 1 to entry: It is expressed in newtons.

**3.13**
**tyre test vehicle**
dedicated vehicle which has instruments to measure the vertical and the longitudinal forces on one tyre during braking

**3.14**
**tyre set**
<trailer (or tyre test vehicle) method> set of one (1) tyre

**3.15**
**tyre set**
<vehicle method> set of four (4) tyres

# 4 Methods for measuring wet grip index

For the evaluation of the wet grip index ($G$) of a candidate tyre, the wet grip braking performance of the candidate tyre is compared to the wet grip braking performance of the reference tyre on a straight, wet, paved surface. It is measured with one of the following methods:

— vehicle method consisting of testing a tyre set mounted on a commercialized vehicle;

— test method using a trailer or a tyre test vehicle equipped with the test tyre set.

In case of verification of the wet grip index ($G$) the same test method used for its declaration shall be used.

NOTE        Differently from the previous edition of this document, as far as case of vehicle method is concerned, when the candidate tyre size is significantly different from that of the reference tyre, a direct comparison on the same vehicle may not be possible and the test method using a trailer or a tyre test vehicle can be used.

# 5 General test conditions

## 5.1 Track characteristics

The surface shall have a uniform gradient of not more than 2 % in both longitudinal and lateral directions and shall not deviate more than 6 mm when tested with a 3 m straight edge.

The test surface shall have a pavement of uniform age, composition, and wear. The test surface shall be free of loose material and foreign deposits.

It shall be a dense asphalt surface.

The maximum chipping size shall be from 8 mm to 13 mm.

The macro texture depth *MTD* shall be measured as specified in ASTM E965-96 using the area of the track to be used for the wet grip test and shall be (0,7 ± 0,3) mm.

In order to verify the frictional properties of the surface, the reference tyre shall be used as follows.

a)   In case of vehicle method, the texture depth is measured in both lanes where the tyres are going to brake.

   The temperature-corrected arithmetic mean of the average braking force coefficients ($BFC_{corr}$) of at least six valid measurements of the reference tyre (see Clause 6) shall be not less than 0,57 and not greater than 0,79.

   The arithmetic mean of the average braking force coefficients ($BFC_{ave}$) of the reference tyre is corrected by the wetted surface temperature as follows:

$$BFC_{corr} = BFC_{ave} + a \cdot (\vartheta - \vartheta_0)$$

   where

$\vartheta$    is the wetted surface temperature in degree Celsius;

$a$    is equal to $0{,}002\ °C^{-1}$;

$\vartheta_0$    is equal to $20\ °C$.

Homogeneity of the track friction shall be verified by determining $BFC_{corr}$ values in two braking tests in the same direction with the reference tyre on aligned segments of the track covering the entire potential braking area, including where the texture depth was measured. The $BFC_{corr}$ of the two braking tests shall not differ by more than 10 % of the average of the two values:

$$2\times\left|\frac{BFC_{corr,1}-BFC_{corr,2}}{BFC_{corr,1}+BFC_{corr,2}}\right| \le 10\ \%$$

b) In case of method using a trailer or a tyre test vehicle, the temperature-corrected average of the peak braking force coefficients ($\mu_{peak,corr}$) of at least six valid measurements of the reference tyre (see Clause 7) shall be not less than 0,65 and not greater than 0,90 at 65 km/h.

The average of the measured peak braking force coefficients ($\mu$peak,ave) of the reference tyre is corrected by the wetted surface temperature as follows:

$$\mu_{peak,corr}=\mu_{peak,ave}+a\cdot\left(\vartheta-\vartheta_0\right)$$

where

$\vartheta$    is the wetted surface temperature in degree Celsius;

$a$    is equal to $0{,}002\ °C^{-1}$;

$\vartheta_0$    is equal to $20\ °C$.

The peak braking force coefficient is measured in the same area where the texture depth was evaluated and the average peak braking force coefficient is evaluated from at least six test runs in the same direction.

## 5.2 Wetting conditions

The surface may be wetted from the track-side (''external watering'') or, in case of method using a trailer or a tyre test vehicle, by a wetting system incorporated in the test vehicle or the trailer ("self-watering").

If "external watering" is used, water the test surface at least half an hour prior to testing in order to equalize the surface temperature and water temperature. External watering should be supplied continuously throughout testing.

For both external watering and self-watering systems, for the used braking lanes, the water depth shall be between 0,5 mm and 1,5 mm measured from the peaks of the pavement.

## 5.3 Atmospheric conditions

The wind conditions shall not interfere with wetting of the surface (wind-shields are allowed).

Both the wetted surface and the ambient temperature shall be between:

— 5 °C and 20 °C for tyres bearing 3PMSF marking;

— 5 °C and 35 °C for tyres bearing M + S marking without the 3PMSF marking for the wetted surface and between 5 °C and 40 °C for the ambient temperature;

— 12 °C and 35 °C for the tyres bearing neither M + S marking nor 3PMSF marking for the wetted surface and between 12 °C and 40 °C for the ambient temperature.

Moreover, the wetted surface temperature shall not vary during the test by more than 10 °C.

The ambient temperature shall remain close to the wetted surface temperature; the difference between the ambient and the wetted surface temperature shall be less than 10 °C.

# 6 Measurement of tyre wet grip index on a commercialized vehicle

## 6.1 Principle

The test method covers a procedure for measuring the deceleration performance of passenger car tyres during braking, using an instrumented passenger car having an anti-lock braking system (ABS).

Starting with a defined initial speed, the brakes are applied hard enough on four wheels at the same time to activate the ABS. The average deceleration is calculated between the initial speed of 80 km/h and the final speed of 20 km/h.

## 6.2 Equipment

### 6.2.1 Vehicle

'Instrumented passenger car' means a commercialized-model passenger car equipped with an ABS and the measuring equipment listed in 6.2.2 for the purpose of this testing method.

The age of the car shall be less than five years and its mechanical conditions shall be according to car manufacturer recommendations with no alert from ABS (e.g. warning lights).

Permitted modifications are:

— those allowing the number of tyre sizes that can be mounted on the vehicle to be increased;

— those permitting automatic activation of the braking device to be installed;

— those permitting the vehicle to be guided or accelerated externally.

Any other modification of the vehicle and specifically of the braking system is prohibited.

### 6.2.2 Measuring equipment

The exposed portions of the measuring system shall tolerate 100 % relative humidity (rain or spray) and all other conditions, such as dust, shock and vibrations, which may be encountered in regular operation.

The vehicle shall be fitted with a sensor suitable for measuring speed on a wet surface and distance covered between two speeds.

To measure vehicle speed, a fifth wheel or a non-contact precision (e.g. radar, GPS) speed-measuring system shall be used.

The following tolerances shall be respected:

— for speed measurement: ±1 % or ±0,5 km/h, whichever is greater;

— for distance: ± 1 × 10$^{-1}$ m.

The measured speed or the difference between the measured speed and the reference speed for the test should be displayed inside the vehicle, so that the driver can adjust the speed of the vehicle.

A data acquisition system may be used for storing the measurements.

## 6.3 Conditioning of the test track

Condition the pavement by conducting at least ten test runs with tyres not involved in the test programme at 90 km/h (which is higher than the initial test speed to guarantee that a sufficient length of track is conditioned).

## 6.4 Test speed measurement requirements

The speed at the start of braking shall be (85 ± 2) km/h.

The average deceleration shall be calculated between 80 km/h and 20 km/h.

## 6.5 Tyres, rims and fitment on vehicle

### 6.5.1 Tyre preparation and break-in

Trim the test tyres to remove all protuberances on the tread surface caused by mould air vents or flashes at mould junctions.

Fit the test tyres on rims in accordance with ISO 4000-1 (or as specified by the appropriate tyre and rim standards organizations) using conventional mounting methods. Rim width code shall not differ more than 0,5 from the measuring rim width code. Ensure proper bead seating by the use of a suitable lubricant. Excessive use of lubricant should be avoided to prevent slipping of the tyre on the wheel rim.

Place the fitted test tyres in a location such that they all have the same ambient temperature prior to testing, and shield them from the sun to avoid excessive heating by solar radiation.

The tyres should be stabilized in performance prior to testing, which means that no evolution of the BFC value in test runs should be detectable; in any case there will be an ex-post verification according to 6.6.4. In all cases, tyre designed tread depth and designed tread block or rib integrity shall not change significantly with break-in, which means the pace and "severity" of the break-in need to be carefully controlled to avoid such changes.

Maximum spacers (adapter) width allowed to mount tyres on the vehicle is 60 mm.

### 6.5.2 Tyre load

The static load on each axle tyre shall lie between 60 % and 90 % of the tested tyre load capacity. Tyre loads on the same axle should not differ by more than 10 %.

It is prohibited to exceed the maximum axle load of the vehicle.

### 6.5.3 Tyre inflation pressure

On the front axle, the test inflation pressure $p$ shall be calculated as follows:

$$p = p_{ref} \times \left( 1,3 \times \frac{Q}{Q_{ref}} \right)^{1/\alpha}$$

where

$p_{ref}$ is the reference inflation pressure (250 kPa for standard-load and 290 kPa for extra-load versions, regardless of the reference pressure in the applicable standard);

$Q$ is the average tyre load on the front axle;

$Q_{ref}$ is the reference load capacity according to load index (LI);

α equals 0,8 and is the pressure exponent defined in the applicable standard.

On the rear axle, the inflation pressures shall be 220 kPa (for both standard-load and extra-load versions).

Check the tyre pressure just prior to testing at ambient temperature and adjust if required.

## 6.6 Procedure

### 6.6.1 Test run

The following applies for each test run.

Accelerate the vehicle in the starting zone up to (85 ± 2) km/h.

The brakes shall always be activated at the same area on the track, and same direction, with a longitudinal tolerance of 5 m and a lateral tolerance of 0,5 m.

Braking tests shall occur on the same lanes and in the same direction that were used to examine the surface (with a lateral tolerance of 0,5 m).

The brakes can be activated either automatically or manually.

The manual activation of the brakes depends on the type of transmission given below.

a) Manual transmission: As soon as the driver is in the measuring zone and having reached (85 ± 2) km/h, disengage the clutch and depress the brake pedal sharply, holding it down as long as necessary to perform the measurement.

b) Automatic transmission: As soon as the driver is in the measuring zone and having reached (85 ± 2) km/h, select neutral gear and then depress the brake pedal sharply, holding it down as long as necessary to perform the measurement.

Automatic activation of the brakes is performed by means of a detection system made of two parts, one indexed to the track and one on board the vehicle.

If any of the above-mentioned conditions is not met when a measurement is made (e.g. speed tolerance, longitudinal and lateral tolerance for the braking starting point), the measurement is discarded and a new test run is made.

For each braking test and for tyres not tested before, the first two runs are discarded.

### 6.6.2 Processing of measurement results

For each test run in conformity with the above conditions, the braking force coefficient *BFC* is calculated between 80 km/h and 20 km/h as follows:

$$BFC = \frac{v_i^2 - v_f^2}{2 \times d \times g} = \frac{d_0}{d}$$

$$d_0 = \frac{v_i^2 - v_f^2}{2 \times g} = 23{,}596 \text{ m}$$

where

$v_f$    is the final speed (m·s⁻¹) = 5,556 m·s⁻¹;

$v_i$    is the initial speed (m·s⁻¹) = 22,222 m·s⁻¹;

$d$    is the distance covered (m) between $v_i$ and $v_f$;

$g$    is the acceleration due to gravity (rounded to 9,81 m·s⁻²).

### 6.6.3 Braking test cycle and braking tests

Within the same braking test cycle, each test run of each braking test shall be made in the same direction and in accordance with 6.6.1 and 6.6.2. Several braking test cycles may be performed consecutively, where the final braking test of the reference tyre set of a braking test cycle may serve as the initial braking test of the reference test tyre set for next braking test cycle.

Up to three different candidate tyre sets may be measured within the same braking test cycle according to the following procedure:

a) Initial braking test of the reference tyre ($R_i$): First, the reference tyre set is mounted on the instrumented passenger car and at least four runs shall be made.

b) Braking test of a candidate tyre ($T_n$): The reference tyre set is replaced by a candidate tyre set ($T_n$) and at least six (6) test runs with the candidate tyre set shall be performed.

c) Up to two more candidate tyre sets may be measured.

d) Final braking test of the reference tyre ($R_f$): The braking test cycle shall be closed by at least four test runs of the same reference tyre set as that at the beginning of the test cycle.

EXAMPLES

The run order for a braking test cycle with three candidate tyre sets ($T_1$ to $T_3$) plus a reference tyre R would be the following:

$R_i - T_1 - T_2 - T_3 - R_f$

The run order for a series of braking test cycles with a total of five candidate tyre sets ($T_1$ to $T_5$) would be the following:

$R_i - T_1 - T_2 - T_3 - R_f/R_i - T_4 - T_5 - R_f$

where the final braking test of the reference tyre set of the first braking test cycle serves as initial braking test of the second braking test cycle

### 6.6.4 Validation of results

For each braking test, the coefficient of variation $CV(BFC)$ is calculated as follows:

$$CV(BFC) = \frac{\sigma_{BFC}}{BFC_{ave}} \times 100\,\%$$

where

$$\sigma_{BFC} = \sqrt{\frac{1}{N-1} \times \sum_{i=1}^{N} \left(BFC_i - BFC_{ave}\right)^2}$$

denotes the corrected sample standard deviation and $BFC_{ave}$ denotes the arithmetic mean of the braking force coefficients $BFC_i$ of $N$ test runs.

For the reference tyre:

a) The coefficient of variation $CV(BFC)$ of the initial and the final braking test of the reference tyre within one braking test cycle shall be less than or equal to 4 %.

b) The arithmetic means of the braking force coefficients of the initial and the final braking test shall not differ by more than 5 % of the average of the two values. The validation coefficient ($C_{val}$) shall be less or equal than 5% and is given by the following formula:

$$C_{val}(BFC) = 2 \times \left| \frac{BFC_{ave}(R_i) - BFC_{ave}(R_f)}{BFC_{ave}(R_i) + BFC_{ave}(R_f)} \right| \leq 5\,\%$$

where $BFC_{ave}(R_i)/BFC_{ave}(R_f)$ is the arithmetic mean of the braking force coefficients in the initial/final braking test of the reference tyre within a braking test cycle.

c) The temperature-corrected average braking force coefficients [$BFC_{corr}$, see 5.1, a)] as calculated from the initial and from the final braking test of the reference tyre within a braking test cycle shall be not less than 0,57 and not greater than 0,79.

If one or both of the above conditions are not met, all test cycles shall be performed again (candidates and references).

For the candidate tyre, the coefficients of variation $CV(BFC)$ are calculated for each candidate tyre. If one coefficient of variation is higher than 4 %, discard the data for this candidate tyre and repeat the test.

### 6.6.5 Calculation of the adjusted braking force coefficients of the reference tyre

For the calculation of the wet grip index $G(T_n)$, the braking force coefficient BFC of the reference tyre set is adjusted according to the positioning of each candidate tyre set ($T_n$) within a given braking test cycle.

This adjusted braking force coefficient $BFC_{adj}(R)$ of the reference tyre is calculated in accordance with Table 1, where $BFC_{ave}(R_i)$ and $BFC_{ave}(R_f)$ are the same as defined in 6.6.4.

$G(T_n)$ is the wet grip index of the candidate tyre $T_n$ ($n$ = 1, 2, 3).

**Table 1 — Calculation of the adjusted braking force coefficients of the reference tyre**

| Number of candidate tyre sets within one braking test cycle | For the calculation of | Use the corresponding adjusted BFC of the reference tyre as follows |
|---|---|---|
| 1: $R_i - T_1 - R_f$ | $G(T_1)$ | $BFC_{adj}(R) = \frac{1}{2} \times [BFC_{ave}(R_i) + BFC_{ave}(R_f)]$ |
| 2: $R_i - T_1 - T_2 - R_f$ | $G(T_1)$ | $BFC_{adj}(R) = \frac{2}{3} \times BFC_{ave}(R_i) + \frac{1}{3} \times BFC_{ave}(R_f)$ |
| | $G(T_2)$ | $BFC_{adj}(R) = \frac{1}{3} \times BFC_{ave}(R_i) + \frac{2}{3} \times BFC_{ave}(R_f)$ |
| 3: $R_i - T_1 - T_2 - T_3 - R_f$ | $G(T_1)$ | $BFC_{adj}(R) = \frac{3}{4} \times BFC_{ave}(R_i) + \frac{1}{4} \times BFC_{ave}(R_f)$ |
| | $G(T_2)$ | $BFC_{adj}(R) = \frac{1}{2} \times [BFC_{ave}(R_i) + BFC_{ave}(R_f)]$ |
| | $G(T_3)$ | $BFC_{adj}(R) = \frac{1}{4} \times BFC_{ave}(R_i) + \frac{3}{4} \times BFC_{ave}(R_f)$ |

**6.6.6 Calculation of the relative wet grip performance index of the tyre**

The wet grip index of the candidate tyre $G(T_n)$ represents the relative wet grip performance index of the candidate tyre $T_n$ ($n=1, 2,$ etc.) compared to the reference tyre.

It is calculated by the formula:

$$G(T_n) = K_{vehicle} \times \left\{ BFC(T_n) - \left[ a \times \Delta BFC(R) + b \times \Delta\vartheta + c \times (\Delta\vartheta)^2 + d \times \Delta MTD \right] \right\}$$

where $K_{vehicle} = 1{,}87$ is a factor to grant consistency between the previous edition of this document and this revised edition, and to ensure convergence between the vehicle and trailer method;

$$\Delta BFC(R) = BFC_{adj}(R) - BFC(R_0)$$

where

$BFC_{adj}(R)$ is the adjusted braking force coefficient for the candidate tyre $T_n$ in accordance with Table 1;

$BFC(R_0)$ equals 0,68 and is fixed as the braking force coefficient for the reference tyre in the reference conditions;

coefficient $a$, $b$, $c$ and $d$ are given in Table 2;

$$\Delta\vartheta = \vartheta - \vartheta_0$$

where

$\vartheta$ is the measured wet surface temperature in degree Celsius when the candidate tyre $T_n$ is tested;

$\vartheta_0$ is the wetted surface reference temperature condition for the candidate tyre $T_n$ according to its sidewall marking as listed in Table 2.

$$\Delta MTD = MTD - MTD_0$$

where

$MTD$   is the measured macro texture depth of the track (see 5.1);

$MTD_0$ equals 0,8 and is the macro texture depth of the reference track.

**Table 2 — Coefficients for the calculation of the relative wet grip performance index of the tyre (vehicle method)**

| Tyre sidewall marking | $\vartheta_0$ °C | $a$ | $b$ °C$^{-1}$ | $c$ °C$^{-2}$ | $d$ mm$^{-1}$ |
|---|---|---|---|---|---|
| Neither M + S marking nor 3PMSF marking | 20 | +0,99382 | +0,00269 | −0,00028 | −0,02472 |
| M + S marking without 3PMSF marking | 15 | +0,92654 | −0,00121 | −0,00007 | −0,04279 |
| 3PMSF marking | 10 | +0,72029 | −0,00539 | +0,00022 | −0,03037 |

An example for the test report is given in Annex A.

# 7 Measurement of tyre wet grip index on a trailer or a tyre test vehicle

## 7.1 Principle

The measurements are conducted on tyres mounted on a trailer towed by a vehicle or a tyre test vehicle. The brake in the test position is applied firmly until sufficient braking torque is generated to produce the maximum braking force that will occur prior to wheel lockup at a test speed of 65 km/h.

## 7.2 Test apparatus

### 7.2.1 General

**7.2.1.1**   The test apparatus consists of tow vehicle and trailer or a tyre test vehicle.

**7.2.1.2**   The test apparatus shall have the capability of maintaining the specified speed, (65 ± 2) km/h, even under the maximum braking forces.

**7.2.1.3**   The test apparatus shall be equipped with one test position and the following accessories:

— equipment to actuate brakes in the test position;

— in the case of "self-watering system" a water tank to store sufficient water to supply the watering system;

— a recording equipment to record signals from transducers installed at the test position and to monitor water application rate if the self-watering option is used.

In the case of the one axle trailer, in order to reduce "pitch disturbance", the longitudinal distance from the centre line of the articulation point of the coupling to the transverse centre line of the axle of the trailer shall be at least ten times the "hitch height" or the "coupling (hitch) height".

In order to reduce "lateral disturbance", trailer should be technically designed to minimize lateral displacement during the application of maximum braking force. Visual lateral displacement should be avoided during braking manoeuvre.

**7.2.1.4**   The limiting change of toe and camber for the test position shall be within ±0,5° with maximum static vertical load. Suspension arms and bushings shall have sufficient rigidity necessary to minimize free play and ensure compliance under application of maximum braking forces. The suspension system shall provide adequate load-carrying capacity and be of such a design as to isolate suspension resonance.

**7.2.1.5**   The test position shall be equipped with a typical or special automotive hydraulic brake system which can apply sufficient braking torque to produce the maximum value of braking test wheel longitudinal force at the conditions specified.

**7.2.1.6**   The brake application system shall be able to control the time interval between initial brake application and peak longitudinal force as specified in 7.4.4 below.

**7.2.1.7**   The test apparatus shall be designed to accommodate the range of passenger car tyre sizes to be tested.

**7.2.1.8**   The test apparatus shall have provisions for adjustment of vertical load as specified in 7.5.

### 7.2.2   Apparatus with a self-watering system

The apparatus may be optionally equipped with a self-watering system (pavement-wetting system), less the storage tank, which, in the case of the trailer, is mounted on the tow vehicle. The water being applied to the pavement ahead of the test tyres shall be supplied by a nozzle suitably designed to ensure that the water layer encountered by the test tyre has a uniform cross section at the test speed with a minimum splash and over-spray. The nozzle configuration and position shall ensure that the water jets are directed towards the test tyre and pointed towards the pavement at an angle of 20° to 30°. The water shall strike the pavement 0,25 m to 0,45 m ahead of the centre of tyre contact. The nozzle shall be located 25 mm above the pavement or at the minimum height required to clear obstacles which the tester is expected to encounter, but in no case more than 100 mm above the pavement. The water layer shall be at least 25 mm wider than the test tyre tread and applied so the tyre is centrally located between the edges. The volume of water per unit of wetted width shall be directly proportional to the test speed. The quantity of water applied at 65 km/h shall be 18 l·s$^{-1}$ per metre of width of wetted surface in case of a water depth of 1,0 mm. The nominal values of rate of water application shall be maintained within ±10 %.

### 7.2.3   Instrumentation

#### 7.2.3.1   General

The test wheel position on the trailer or the tyre test vehicle shall be equipped with a wheel rotational velocity measuring system and with transducers to measure the braking force and vertical load at the test wheel.

#### 7.2.3.2   General requirements for measurement system

The instrumentation system shall conform to the following overall requirements at ambient temperatures between 0 °C and 45 °C:

— overall system accuracy, force: ±1,5 % of the full scale of the vertical load or braking force;

— overall system accuracy, speed: ±1,5 % of speed or ±1,0 km/h, whichever is greater;

— ruggedness: the exposed portions of the system shall tolerate 100 % relative humidity (rain or spray) and all other adverse conditions, such as dust, shock and vibrations, which may be encountered in regular operation.

#### 7.2.3.3   Vehicle speed

To measure vehicle speed, a fifth wheel or a non-contact precision (e.g. radar, GPS) speed-measuring system should be used.

#### 7.2.3.4 Braking forces

The braking force-measuring transducers shall measure longitudinal force generated at the tyre–road interface as a result of brake application within a range from 0 % to at least 125 % of the applied vertical load. The transducer design and location shall minimise inertial effects and vibration-induced mechanical resonance.

#### 7.2.3.5 Vertical load

The vertical load-measuring transducer shall measure the vertical load at the test position during brake application. The transducer shall have the same specifications as described previously.

#### 7.2.3.6 Signal conditioning and recording system

All signal conditioning and recording equipment shall provide linear output with necessary gain and data reading resolution to meet the specified previous requirements. In addition, the following requirements apply:

— The minimum frequency response shall be flat from 0 Hz to 100 Hz within ±1 % full scale.

— The signal-to-noise ratio shall be at least 20/1.

— The gain shall be sufficient to permit full-scale display for full-scale input signal level.

— The input impedance shall be at least ten times larger than the output impedance of the signal source.

— The equipment shall be insensitive to vibrations, acceleration, and changes in ambient temperature.

### 7.3 Selection and preparation of test tyres

**7.3.1** Trim the test tyres to remove all protuberances on the tread surface caused by mould air vents or flashes at mould junctions.

**7.3.2** Fit the test tyres on rims in accordance with ISO 4000-1 (or as specified by the appropriate tyre and rim standards organizations) using conventional fitting methods. Rim width code shall not differ more than 0,5 from the measuring rim width code. Ensure proper bead seating by the use of a suitable lubricant. Excessive use of lubricant should be avoided to prevent slipping of the tyre on the wheel rim.

**7.3.3** The tyres should be stabilized in performance prior to testing, which means that no evolution of the $\mu_{peak}$ value in test runs should be detectable; in any case there will be an ex-post verification according to 7.6.4. In all cases, tyre designed tread depth and designed tread block or rib integrity shall not change significantly with break-in, which means the pace and "severity" of the break-in needs to be carefully controlled to avoid such changes.

**7.3.4** Place the fitted test tyres near the test site in such a location that they all have the same ambient temperature prior to testing and shield them from the sun to avoid excessive heating by solar radiation.

**7.3.5** Check the test tyres for the specified inflation pressure at ambient temperature (cold), just prior to testing.

### 7.4 Preparation of test track and apparatus

#### 7.4.1 Conditioning of the track

Condition the track by conducting at least ten test runs at 65 km/h with a tyre not involved in the test programme.

### 7.4.2 Towed trailer

Install the test tyre on the measuring device.

Load each of the wheels to the specified test load.

Adjust the hitch height and transverse position as necessary for a given test.

Check the wiring connections between tow vehicle and the trailer for opens and shorts.

### 7.4.3 Tyre test vehicle

Install the test tyre on the measuring device.

Load the test tyre to the specified test load.

### 7.4.4 Instrumentation and equipment

Install the fifth wheel, when used, in accordance with the manufacturer's specifications and locate it as near as possible to the mid-track position of the tow trailer or the tyre test vehicle.

The rate of braking application shall be such that the time interval between initial application of force and peak longitudinal force is in the range 0,2 s to 0,5 s.

## 7.5 General test conditions

The test load shall be (75 ± 5) % of the tyre load capacity (load index).

For the purpose of this document, cold inflation pressure used shall be 180 kPa for standard-load tyres. For extra-load tyres, the cold inflation pressure shall be 220 kPa.

## 7.6 Procedure

### 7.6.1 Test run

The following applies for each test run.

Approach the test site in a straight line at the specified test speed, (65 ± 2) km/h.

Start the recording system.

For self-watering system, deliver water to the pavement ahead of the test tyre approximately 0,5 s prior to brake application.

When the test tyres reach the test site, apply the brakes on the test wheel of the trailer or tyre test vehicle. The test should be run at the same spots on the test pad and same direction in conformity with 5.1. For the trailer method, brakings on each spot of the evaluation program shall occur within 6 m in the length of where the surface was examined (with a tolerance of 0,5 m width).

Stop the recording system.

### 7.6.2 Processing of measurement results

For each test run in conformity with the above conditions, the peak braking force coefficient, $\mu_{peak}$ is calculated as the highest value of the following $\mu(t)$ equation and it occurs before lockup of the wheel.

Analog signals should be filtered to remove noise. Digitally recorded signals must be filtered using a moving average technique.

$$\mu(t) = \frac{f_h(t)}{f_v(t)}$$

where

$\mu(t)$    is the dynamic tyre braking force coefficient in real time;

$f_h(t)$    is the dynamic braking force in real time, in N;

$f_v(t)$    is the dynamic vertical load in real time, in N.

### 7.6.3 Braking test cycle and braking tests

Within the same braking test cycle, each test run of each braking test shall be made in the same direction and in accordance with 7.6.1 and 7.6.2. Several braking test cycles may be performed consecutively, where the final braking test of the reference tyre set of a braking test cycle may serve as the initial braking test of the reference test tyre set for next braking test cycle.

Up to three different candidate tyre sets may be measured with the same braking test cycle according to the following procedure, provided that the tests are completed within one day.

a) Initial braking test of the reference tyre ($R_i$): First, the reference tyre set is mounted and at least six runs shall be made.

b) Braking test of a candidate tyre ($T_n$): The reference tyre set is replaced by a candidate tyre set ($T_n$) and at least six (6) test runs with the candidate tyre set shall be performed.

c) Up to two more candidate tyre sets may be measured.

d) Final braking test of the reference tyre ($R_f$): The braking test cycle shall be closed by at least six (6) test runs of the same reference tyre set as that at the beginning of the test cycle.

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The run order for a series of braking test cycles with a total of five candidate tyre sets ($T_1$ to $T_5$) would be the following:

$R_i$ – $T_1$ – $T_2$ – $T_3$ – $R_f/R_i$ – $T_4$ – $T_5$ – $R_f$

where the final braking test of the reference tyre set of the first braking test cycle serves as initial braking test of the second braking test cycle.

The run order for a braking test cycle with three candidate tyre sets ($T_1$ to $T_3$) would be the following:

$R_i$ – $T_1$ – $T_2$ – $T_3$ – $R_f$

### 7.6.4 Validation of results

For each braking test, the coefficient of variation $CV(\mu_{\text{peak}})$ is calculated as follows:

$$CV\left(\mu_{\text{peak}}\right)=100\%\times\frac{\sigma_\mu}{\mu_{\text{peak,ave}}}$$

where

$$\sigma_\mu = \sqrt{\frac{1}{N-1}\times\sum_{i=1}^{N}\left(\mu_{\text{peak},i}-\mu_{\text{peak,ave}}\right)^2}$$

denotes the corrected sample standard deviation and

$\mu_{\text{peak,ave}}$ denotes the arithmetic mean of the peak braking force coefficients $\mu_{\text{peak},i}$ of $N$ test runs.

Standard deviation and arithmetic mean refer to the measured $\mu_{\text{peak}}$ values of all runs of that braking test.

For the reference tyre:

a) The coefficient of variation $CV(\mu_{\text{peak}})$ of the initial and the final braking test of the reference tyre within one braking test cycle shall be less than or equal to 4 %.

b) The arithmetic means of the peak braking force coefficients of the initial and the final braking test shall not differ by more than 5 % of the average of the two values:

$$C_{\text{val}}\left(\mu_{\text{peak}}\right)=2\times\left|\frac{\mu_{\text{peak,ave}}\left(R_i\right)-\mu_{\text{peak,ave}}\left(R_f\right)}{\mu_{\text{peak,ave}}\left(R_i\right)+\mu_{\text{peak,ave}}\left(R_f\right)}\right|\leq 5\%$$

where

$\mu_{\text{peak,ave}}(R_i)$ is the arithmetic mean of the peak braking force coefficients in the initial braking test of the reference tyre within a braking test cycle;

$\mu_{\text{peak,ave}}(R_f)$ is the arithmetic mean of the peak braking force coefficients in the final braking test of the reference tyre within a braking test cycle.

c) The temperature-corrected average peak braking force coefficients [$\mu_{\text{peak,corr}}$, 5.1.b)] as calculated from the initial and from the final braking test of the reference tyre within a braking test cycle shall be not less than 0,65 and not greater than 0,90.

If one or both of the above conditions are not met, the complete test cycle shall be performed again (candidates and references).

For the candidate tyres, the coefficients of variation of the $\mu_{\text{peak}}$ are calculated for all the candidate tyres. If one coefficient of variation is higher than 4 %, discard the data for this candidate tyre and repeat the test.

### 7.6.5 Calculation of the adjusted peak braking force coefficients of the reference tyre

For the calculation of the wet grip index $G(T_n)$, the peak braking force coefficient of the reference tyre set is adjusted according to the positioning of each candidate tyre set ($T_n$) within a given braking test cycle.

This adjusted peak braking force coefficient $\mu_{\text{peak,adj}}(R)$ of the reference tyre is calculated in accordance with Table 3, where $\mu_{\text{peak,ave}}(R_i)$ and $\mu_{\text{peak,ave}}(R_f)$ are the same as defined in 7.6.4.

**Table 3 — Calculation of the adjusted peak braking force coefficient of the reference tyre**

| Number of candidate tyre sets within one braking test cycle | For the calculation of | Use the corresponding adjusted peak braking force coefficients of the reference tyre as follows |
|---|---|---|
| 1: $R_i - T_1 - R_f$ | $G(T_1)$ | $\mu_{peak,adj}(R) = \frac{1}{2} \times \left[ \mu_{peak,ave}(R_i) + \mu_{peak,ave}(R_f) \right]$ |
| 2: $R_i - T_1 - T_2 - R_f$ | $G(T_1)$ | $\mu_{peak,adj}(R) = \frac{2}{3} \times \mu_{peak,ave}(R_i) + \frac{1}{3} \times \mu_{peak,ave}(R_f)$ |
| | $G(T_2)$ | $\mu_{peak,adj}(R) = \frac{1}{3} \times \mu_{peak,ave}(R_i) + \frac{2}{3} \times \mu_{peak,ave}(R_f)$ |
| 3: $R_i - T_1 - T_2 - T_3 - R_f$ | $G(T_1)$ | $\mu_{peak,adj}(R) = \frac{3}{4} \times \mu_{peak,ave}(R_i) + \frac{1}{4} \times \mu_{peak,ave}(R_f)$ |
| | $G(T_2)$ | $\mu_{peak,adj}(R) = \frac{1}{2} \times \left[ \mu_{peak,ave}(R_i) + \mu_{peak,ave}(R_f) \right]$ |
| | $G(T_3)$ | $\mu_{peak,adj}(R) = \frac{1}{4} \times \mu_{peak,ave}(R_i) + \frac{3}{4} \times \mu_{peak,ave}(R_f)$ |

### 7.6.6 Calculation of the relative wet grip performance index of the tyre

The wet grip index $G(T_n)$ of the candidate tyre $T_n$ ($n$ = 1, 2, 3) relative to the reference tyre is calculated by the following formula:

$$G(T_n) = K_{trailer} \times \left\{ \mu_{peak,ave}(T_n) - \left[ a \times \Delta\mu_{peak}(R) + b \times \Delta\vartheta + c \times (\Delta\vartheta)^2 + d \times \Delta MTD \right] \right\}$$

where $K_{trailer}$ = 1,50 is a factor to grant consistency between previous edition of this document and this revised edition, and to ensure convergence between vehicle and trailer method;

coefficient $a$, $b$, $c$ and $d$ are given in Table 4;

$$\Delta\vartheta = \vartheta - \vartheta_0$$

where

$\vartheta$     is the measured wetted surface temperature in degree Celsius when the candidate tyre $T_n$ is tested;

$\vartheta_0$     is the wetted surface reference temperature condition for the tyre $T_n$ according to its sidewall marking as listed in Table 4

$$\Delta\mu_{peak}(R) = \mu_{peak,adj}(R) - \mu_{peak}(R_0)$$

where

$\mu_{peak,adj}(R)$     is the adjusted peak braking force coefficient for the candidate tyre Tn in accordance with Table 3;

$\mu_{peak}(R_0)$     equals to 0,85 and is fixed as the peak braking force coefficient for the Reference tyre in the reference conditions;

$$\Delta MTD = MTD - MTD_0$$

where

$MTD$     is the measured macro texture depth of the track (see 5.1);

$MTD_0$     equals to 0,8 mm and is the macro texture depth of the reference track.

**Table 4 — Coefficients for the calculation of the relative wet grip performance index of the tyre (trailer or test vehicle method)**

| Tyre sidewall marking | $\vartheta_0$ °C | $a$ | $b$ °C$^{-1}$ | $c$ °C$^{-2}$ | $d$ mm$^{-1}$ |
|---|---|---|---|---|---|
| Neither M + S marking nor 3PMSF marking | 20 | +0,99757 | +0,00251 | −0,00028 | +0,07759 |
| M + S marking without 3PMSF marking | 15 | +0,87084 | −0,00025 | +0,00004 | −0,01635 |
| 3PMSF marking | 10 | +0,67929 | +0,00115 | −0,00005 | +0,03963 |

An example for the test report is given in Annex A.