EUROPEAN RAILWAY AGENCY

INTEROPERABILITY UNIT

TECHNICAL DOCUMENT

FRICTION ELEMENTS FOR WHEEL TREAD BRAKES FOR FREIGHT WAGONS

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AMENDMENT RECORD

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1. Introduction

The present document provides the necessary specifications to perform the assessment of conformity of friction elements for wheel tread brakes. It is referred to in point 6.1.2.5 and Appendix D of the technical specification for interoperability relating to the subsystem 'rolling stock – freight wagons' following its amendment related to 'friction elements for wheel tread brakes' (ready for adoption in 2015).

The present document is based on EN 16452:2015 Railway applications - Braking - Brake blocks.

2. Terms and definitions

For the purposes of this document the following terms and definitions apply.

Bg arrangement:	arrangement with one friction element per friction element holder
Bgu arrangement:	arrangement with two friction elements per friction element holder
1Bg:	unilateral configuration with one friction element per friction element holder
2Bg:	bilateral configuration with one friction element per fiction element holder
1Bgu:	unilateral configuration with two friction elements per friction element holder
2Bgu:	bilateral configuration with two friction elements per friction element holder
friction element:	stator part of a tread brake adapted to generate a friction force when engaged with a wheel tread
friction element force:	force with which the friction element is made to come into contact with the wheel tread
friction element back plate:	element onto which the friction element is fixed, acting as the interface between the friction element and friction element holder
friction material:	consumable portion of the friction element that acts on the wheel tread in order to provide the specified brake performance
size of friction element:	product of height and width of the friction element without any correction for grooves
instantaneous friction coefficient:	value of friction coefficient at any one instant
mean friction coefficient:	value of instantaneous friction coefficient integrated over distance
dynamic friction coefficient:	coefficient of friction achieved by the friction material during relative movement between the friction material surface and wheel tread
static friction coefficient:	coefficient of friction achieved by the friction material at the point where relative movement between the friction material surface and wheel tread starts to take place
parking brake:	brake used to prevent a stationary train from moving under specified conditions, until intentionally released (also called 'immobilization braking')

wheel tread temperature: average temperature out of three values measured by three rubbing thermocouples spaced equally across the wheel tread

3.   Abbreviations

m	[t]	Mass to be braked per wheel for design mass (including rotating mass) in conformity with EN 15663
m_1	[t]	Mass m in working order
m_2	[t]	Mass m under normal payload
m_{1W}	[t]	Mass m in working order divided by the number of wheels
F_B	[kN]	Nominal brake application force per wheel
F_{B1}	[kN]	Total friction element application force per wheel for braked mass m_1
F_{B2}	[kN]	Total friction element application force per wheel for braked mass m_2
F_b	[kN]	Instantaneous application force per wheel
F_{PB}	[kN]	Parking brake application force
v	[km/h]	Theoretical initial speed at the brake application initiation
v_m	[km/h]	Maximum service speed
μ_a	[-]	Instantaneous friction coefficient determined at every instance of the braking by the ratio between the total brake force F_{tR} and the total application force F_b
μ_m	[-]	Mean friction coefficient determined from reaching 95 % of the nominal application force F_B of the instantaneous friction coefficient μ_a for the stopping distance s_2
μ_{dyn}	[-]	Dynamic friction coefficient
μ_{stat}	[-]	Static friction coefficient
Θ_0	[°C]	Mean initial temperature of the wheel tread at the beginning of the brake application
s_1	[m]	Stopping distance from beginning of the brake application to rest
s_2	[m]	Stopping distance from the moment on when $F_b = 0.95 F_B$ to rest
D	[mm]	Diameter of wheel
P	[-]	Brake type – P = passenger

4. Dynamic friction coefficient

4.1 Test program

The dynamometer test program for friction elements for wheel tread brakes to determine the dynamic friction coefficient μ_{dyn} is set out in table 1. The corresponding terms, definitions and abbreviations are explained in sections 2 and 3.

Table 1: Dynamometer test program to determine the dynamic friction coefficient

Friction element arrangement			To be defined by the applicant				
Wheel type			In conformity with EN 13979-1				
Wheel diameter			$\emptyset$ X $\pm$ 5 mm last machining size before wheel is fully worn in accordance with EN 13979-1				
Water flow rate			X l/h (without specific requirements 14 l/h should be used)				
No. of brake application			Initial speed	Total F_B per wheel	Initial temp.	Mass to brake per wheel	Weighing after	Remarks
			v	F_B	Θ_0	m		
			[km/h]	[kN]	[°C]	[t]	No.	
1.1 - 1.X			$3/4\,v_m$	$2/3\,F_{B2}$	20-100	m_2	1.X	Brake applications to rest under dry conditions to allow bedding of the friction elements up to at least 85 % of the friction element surface
1 2	3 4	5 6	$3/4\,v_m$ v_m	F_{B2}	50-60	m_2		Brake applications to rest under dry conditions, after a period of cooling
7 to 26			$3/4\,v_m$	$2/3\,F_{B1}$	20-100	m_1		Conditioning stops
27 28 29 30	39 40 41 42		$3/4\,v_m$ $1/4\,v_m$ v_m $1/2\,v_m$	$2/3\,F_{B1}$	50-60	m_1		Brake applications to rest under dry conditions, after a period of cooling
31 32 33 34	43 44 45 46		$3/4\,v_m$ $1/4\,v_m$ v_m $1/2\,v_m$	$1/3\,F_{B1}$	50-60	m_1		Brake applications to rest under dry conditions, after a period of cooling
35 36 37 38	47 48 49 50		$3/4\,v_m$ $1/4\,v_m$ v_m $1/2\,v_m$	F_{B1}	50-60	m_1		Brake applications to rest under dry conditions, after a period of cooling

Table 1 (continued)

No. of brake application			Initial speed v [km/h]	Total F_B per wheel F_B [kN]	Initial temp. Θ_0 [°C]	Mass to brake per wheel m [t]	Weighing after No.	Remarks
51			$3/4\ v_m$	-	-	-		10 kW drag brake application for a period of 15 min in dry condition done immediately after brake nº 50 without interruption. This is to evenly distribute the residual stress within the wheel
52 53 54 55	64 65 66 67	76 77 78 79	$3/4\ v_m$ $1/4\ v_m$ v_m $1/2\ v_m$	$2/3\ F_{B1}$	20-30	m_1		Brake applications to rest under wet conditions, after a period of cooling
56 57 58 59	68 69 70 71	80 81 82 83	$3/4\ v_m$ $1/4\ v_m$ v_m $1/2\ v_m$	$1/3\ F_{B1}$	20-30	m_1		Brake applications to rest under wet conditions, after a period of cooling
60 61 62 63	72 73 74 75	84 85 86 87	$3/4\ v_m$ $1/4\ v_m$ v_m $1/2\ v_m$	F_{B1}	20-30	m_1		Brake applications to rest under wet conditions, after a period of cooling
88 89 90 91		92 93 94 95	$3/4\ v_m$ $1/4\ v_m$ v_m $1/2\ v_m$	F_{B2}	20-30	m_2		Brake applications to rest under wet conditions, after a period of cooling
96			$3/4\ v_m$	-	-	-	96	10 kW drag brake application for a period of 15 min in dry condition done immediately after brake nº 95 without interruption to dry the friction element
97 98 99 100		109 110 111 112	$3/4\ v_m$ $1/4\ v_m$ v_m $1/2\ v_m$	$2/3\ F_{B2}$	50-60	m_2		Brake applications to rest under dry conditions, after a period of cooling
101 102 103 104		113 114 115 116	$3/4\ v_m$ $1/4\ v_m$ v_m $1/2\ v_m$	$1/3\ F_{B2}$	50-60	m_2		Brake applications to rest under dry conditions, after a period of cooling

Table 1 (continued)

No. of brake application		Initial speed v [km/h]	Total F_B per wheel F_B [kN]	Initial temp. Θ_0 [°C]	Mass to brake per wheel m [t]	Weighing after No.	Remarks
105 106 107 108	117 118 119 120	$3/4\ V_m$ $1/4\ V_m$ V_m $1/2\ V_m$	F_{B2}	50-60	m_2		Brake applications to rest under dry conditions, after a period of cooling
121 122 123 124		$3/4\ V_m$ $1/4\ V_m$ V_m $1/2\ V_m$	F_{B2}	110-120[a]	m_2		Brake applications to rest under dry conditions with high initial temperature, after a period of cooling
125 126 127 128		$3/4\ V_m$ $1/4\ V_m$ V_m $1/2\ V_m$	$2/3\ F_{B2}$	50-60	m_2	128	Brake applications to rest under dry conditions, after a period of cooling
129		$3/4\ V_m$	-	20-60	-		Simulation of a downhill brake application with a power of 45 kW for a period of 34 min
130		$3/4\ V_m$	F_{B2}	-	m_2		Brake application to rest under dry conditions immediately after the simulation of a downhill brake application, without any cooling break
131 to 140		V_m	$2/3\ F_{B2}$	50-60	m_2		Conditioning stops
141 142 143 144	145 146 147 148	$3/4\ V_m$ $1/4\ V_m$ V_m $1/2\ V_m$	F_{B2}	50-60	m_2	148	Brake applications to rest under dry conditions, after a period of cooling
149		$3/4\ V_m$	-	-	-		10 kW drag brake application for a period of 10 min in dry condition done immediately after brake nº 148 without interruption. This is to evenly distribute the residual stress within the wheel

[a] If the temperature obtained during stop numbers 120 and 122 is below 110 °C, stop numbers 121 and 123 shall be performed with the temperature achieved at the time.

During the tests described in table 1 the following conditions shall be respected:

- The speed and ventilation conditions shall be as set out in table 2.

Table 2: Speed and ventilation conditions

	Speed simulated on the test bench [km/h]		Speed of the cooling air [km/h]	
	Under dry conditions	Under wet conditions	Under dry conditions	Under wet conditions
During braking at $v \leq 80$km/h $v > 80$km/h	v v	v v	v/2 40	10 10
Between the brake applications	100	50	40	10

- The time to reach 95 % of the demanded F_B shall be 4 s ± 0,2 s.

- During bedding-in the following minimum numbers of brake stops shall be carried out: 40 for organic friction elements and 80 for sintered friction elements.

- If interruptions of the test program occur, before recommencing the program the previous 5 stops shall be repeated. In this case the initial temperature for the first stop shall be in the range from 20 °C to 60 °C.

- In the case of an interruption prior to the first wet stop, one brake application identical to the last brake application under dry conditions shall be carried out outside of the program.

- Concerning the brake applications under wet conditions, the wheel wetting shall not be interrupted during each entire set of stops under wet conditions (including cooling period). For any first stop under wet conditions after a stop under dry conditions, the start of the wheel tread wetting shall take place only when the temperature of the wheel tread is below 80 °C.

- During the test under wet conditions the water shall be equally distributed over the wheel tread.

- During the simulation of a downhill the chosen power and speed shall be kept constant.

4.2 Values to be determined in order to define the area of use

The values for the following parameters shall be determined and recorded within the area of use:

a) Tested configuration consisting of
- friction element arrangement
- wheel type
- nominal and tested wheel diameter

b) Mean dynamic friction coefficient of non-bedded and bedded state. The mean dynamic friction coefficient of the non-bedded and bedded state are defined as the average of the first 5 and the last 5 measured values of brake application n° 1.1 to 1.X.

c) Mean dynamic friction coefficient under dry conditions versus the initial operating speed v for the different brake forces F_B applied and the mass to brake per wheel m using the template diagrams set out in table 3.

Table 3: Template diagrams and allocated brake application n°

$\frac{1}{3} F_{B1}$	$\frac{2}{3} F_{B1}$	F_{B1}
μ_m [-] vs v [km/h]	μ_m [-] vs v [km/h]	μ_m [-] vs v [km/h]
Brake application n° 31 to 34 and 43 to 46	Brake application n° 27 to 30 and 39 to 42	Brake application n° 35 to 38 and 47 to 50
$\frac{1}{3} F_{B2}$	$\frac{2}{3} F_{B2}$	F_{B2}
μ_m [-] vs v [km/h]	μ_m [-] vs v [km/h]	μ_m [-] vs v [km/h]
Brake application n° 101 to 104 and 113 to 116	Brake application n° 97 to 100 and 109 to 112	Brake application n° 105 to 108 and 117 to 120

d) Mean dynamic friction coefficient variation under wet conditions. The variation shall be expressed as the averages of the measured mean dynamic friction coefficients under wet conditions (brake application n° 52 to 95) in proportion to the corresponding averages of mean dynamic friction coefficients under dry conditions (brake application n° 27 to 50, 105 to 108 and 117 to 120). Example: the average value of brake applications n° 57, 69 and 81 divided by the average value of brake applications n° 32 and 44.

e) Mean dynamic friction coefficient variation at high initial temperature. The variation shall be expressed as the mean dynamic friction coefficients at a wheel tread temperature above 110 °C (brake application n° 121 to 124) in proportion to the corresponding mean dynamic friction coefficients at a wheel tread temperature below 60 °C (brake application n° 125 to 128). Example: The value of brake application n° 122 divided by the value of brake applications n° 126.

f) Chart of the instantaneous dynamic friction coefficient and wheel tread temperature versus time of brake application n° 129.

g) Mean dynamic friction coefficient variation after simulation of a downhill brake application. The variation shall be expressed as the averages of the measured mean dynamic friction coefficients after downhill braking (brake application n° 141 to 148) in proportion to the corresponding averages of mean dynamic friction coefficients before downhill braking (brake application n° 105 to 108 and 117 to 120). Example: the average value of brake applications n° 142 and 146 divided by the average value of brake applications n° 106 and 118.

In relation to the characteristics described in this chapter, in case the manufacturer chooses to apply some of the harmonised acceptance criteria for dynamic friction performance as specified in EN 16452:2015, the compliance to these harmonised acceptance criteria have to be stated in the technical documentation as part of the area of use of the fiction element for wheel tread brakes.

5. Static friction coefficient

5.1 Test program

The dynamometer test program to determine the static friction coefficient μ_{stat} of friction elements for wheel tread brakes is set out in table 4. The corresponding terms, definitions and abbreviations are explained in sections 2 and 3.

Table 4: Dynamometer test program to determine the static friction coefficient

Friction element configuration	To be defined by the applicant				
Wheel type	In conformity with EN 13979-1				
Wheel diameter	∅ X ± 5 mm last machining size before wheel is fully worn in accordance with EN 13979-1				
No. of brake application	**Initial speed**	**Parking brake application force**	**Initial temp.**	**Mass to brake per wheel**	**Remarks**
	v	F_{PB}	Θ_0	m	
	[km/h]	[kN]	[°C]	[t]	
R.1 - R.X	v_m	2/3 F_{PBmax}	20-100	m_2	Brake applications to rest under dry conditions to allow bedding of the friction elements up to a contact pattern of 100 % is reached
1 to 5 6 to 10 11 to 15 16 to 20	-	1/4 F_{PBmax} 1/2 F_{PBmax} 3/4 F_{PBmax} F_{PBmax}	< 30	-	-

During the test described in table 4 the following conditions shall be respected:

- The wheel tread hollow wear at the start of the test shall not exceed 1 mm. The state of the surface of the wheel tread shall be documented in the test report.

- The torque shall be continuously increased. The start of the rotation shall occur between 0,3 s and 2,0 s after the beginning of the build-up of the rotating torque.

- The relative movement between wheel and friction element shall be measured with an accuracy of at least 30 milliradian. It shall be ensured that displacements due to clearances are excluded.

For each brake application (n° 1 to 20) the static friction coefficient shall be determined which is the value of the instantaneous friction coefficient at the time corresponding to the commencement of sliding (mean value calculated from the measurement records for the intersection between the linearised characteristic line of the rotation angle and the time axis) as described in figure 1.
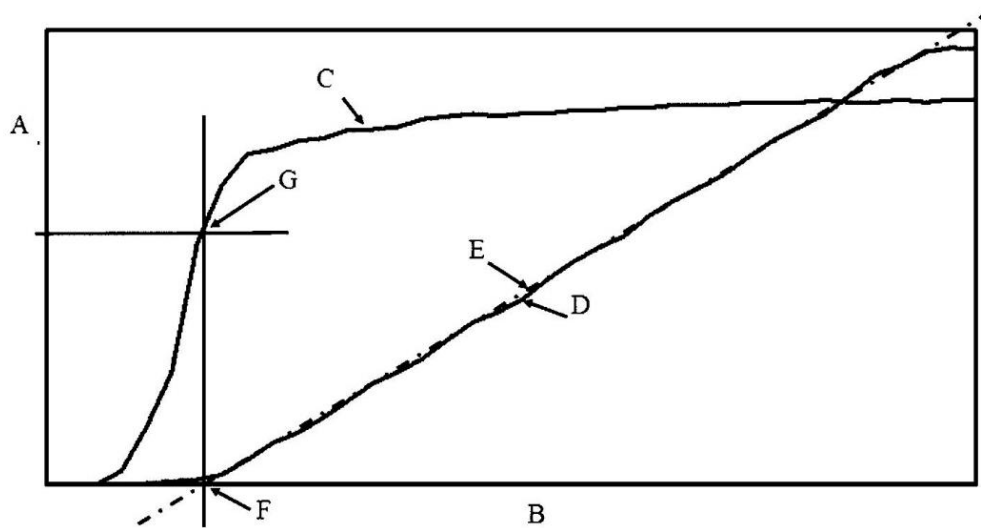
Key

A   friction coefficient (µ) / rotation angle of wheel
B   time axis
C   example of friction coefficient curve
D   rotation angle of wheel
E   straight regression line
F   intersection between straight regression line and time axis
G   value of static coefficient

Figure 1: Principles for the determination of the static friction coefficient

## 5.2   Values to be determined in order to define the area of use

For each force the average value of the 5 measurements shall be determined. The lowest average value is the characterising static friction coefficient.

6. Mechanical characteristics

The mechanical characteristics of the assembly between back plate and friction element for wheel tread brakes shall be tested in accordance with the test procedures set out in sections 6.1 and 6.2.

6.1 Shear strength

The test shall be performed with the mounting as set out in figure 2. In the case of a friction element consisting of two parts or a mono-bloc friction element with a central groove, a wedge (g) shall be placed in the central groove as shown.
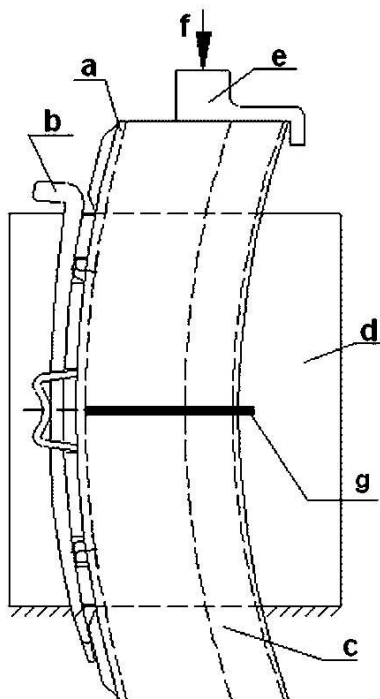
Key

a   brake shoe insert back plate
b   brake shoe insert fixing key
c   friction element
d   side panel
e   force application fixing
f   test force F_{test}
g   brake shoe insert groove filling device

Figure 2:   Shear strength test mounting arrangement

The test force F_{test} shall be applied in a continuous and progressive way up to 1.5 times the maximum permissible braking force applied at one friction element within 4 s and shall be kept for a period of at least 2 min.

At the end of the test there shall not be any indication of detachment of the back plate from the friction element or any other visible mechanical damage.

6.2   Flexural strength

Two tests shall be performed, one with the mounting 1 and one with the mounting 2 as set out in figure 3. The end of the supports shall have a radius of 5 mm. For both tests new friction elements shall be used and the test force F_{test} shall be applied five times. F_{test} is the maximum permissible application force applied at one friction element.

The following distances shall be respected:

- Ls 1 = friction element length - 50 mm.
- Ls 2 = half friction element length - 50 mm.
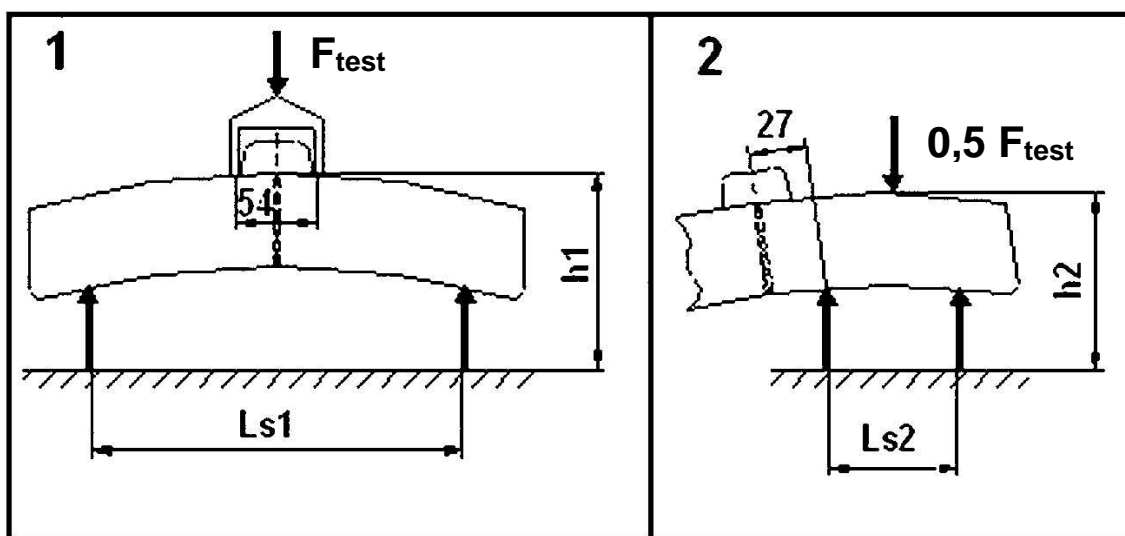
Key

1 mounting for performing test n°1
2 mounting for performing test n°2

Figure 3:   Flexural strength test mounting arrangement

Within 4 s the test force shall be applied progressively until either the maximum test force F_{test} is achieved or the maximum displacement $\Delta h1$ respectively $\Delta h2$ for the intended application occurs taking into account the nominal geometry of a new friction element and a new wheel.

The force respectively the displacement shall be kept for a period of at least 2 minutes.

At the end of the test, the friction element shall not show any crack initiation or fracture of the back plate. In the case of a friction element that has a groove or slot as shown in figure 3 cracking is permitted in the area where the friction element is at its thinnest where the groove meets the back plate.

7. Suitability for train detection by systems based on track circuits

The following rig test to demonstrate the suitability for train detection by systems based on track circuits is only applicable if the friction element is intended to be used in subsystems which fall under the following scope:

- Nominal wheel diameters of 680 mm to 920 mm
- Friction element configurations 1Bg, 1Bgu, 2Bg and 2Bgu
- Mass per wheel ≥ 1.8 t

Cast iron brake blocks are deemed to be suitable for train detection by systems based on track circuits.

7.1 Test program

A number of 10 friction element samples of a given size as set out in clause 7.1.3 shall be subject to the test program provided in figure 4 and further described in clauses 7.1.1 to 7.1.6.
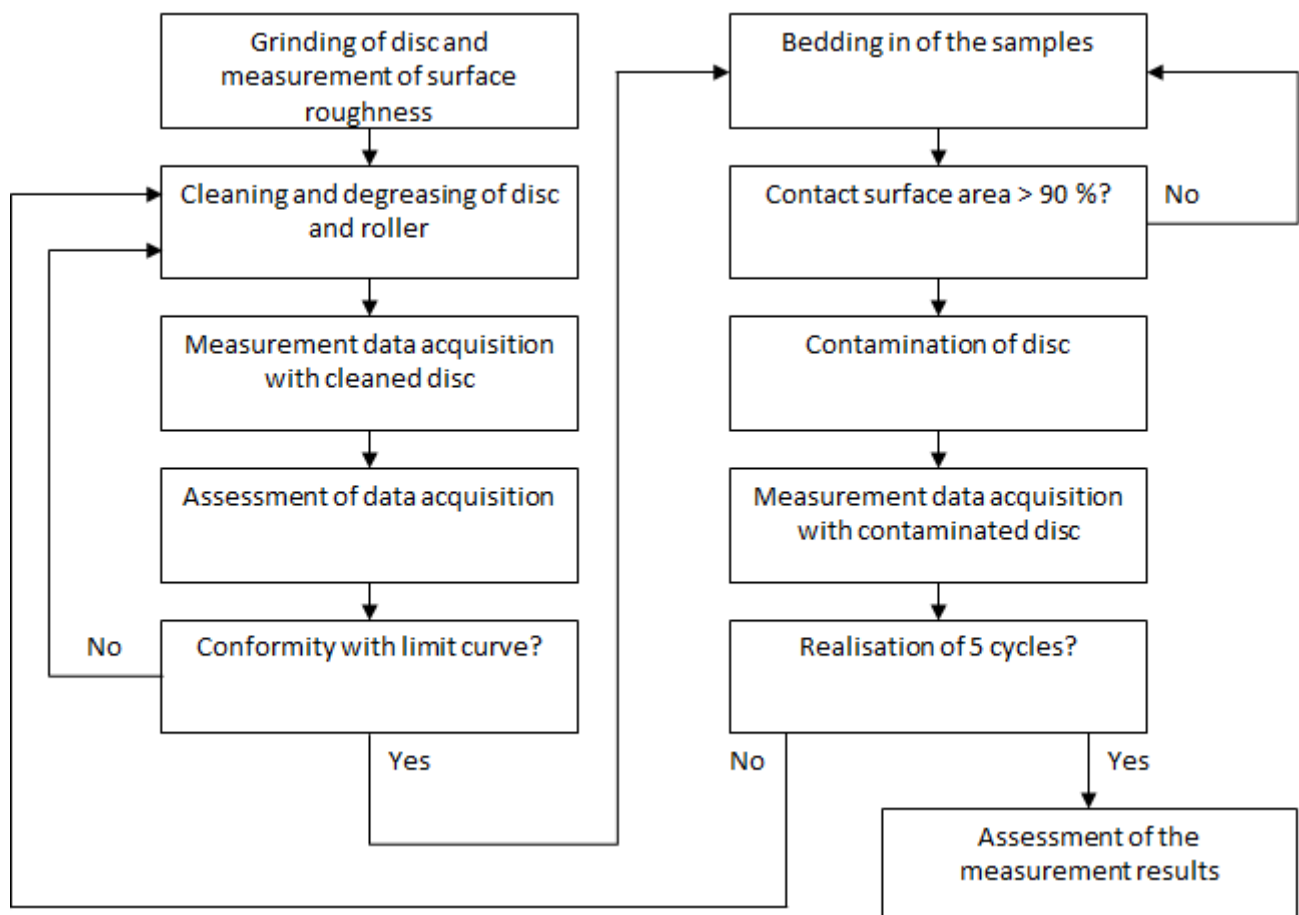

Figure 4: Flow chart of the test program

7.1.1 Grinding of disc and measurement of surface roughness

Before the first test of each pair of friction element samples the disc shall be grinded and the surface roughness R_z (maximum height of profile) shall be lower than or equal to 12 µm.

7.1.2 Cleaning and degreasing of disc and roller

The disc shall be cleaned and degreased with emery paper of grade 180, cloths in micro-fibres and of water/spray acetone in order to remove the residual material and satins from previous tests.

The roller and the surface of the carbon brush shall be cleaned and degreased in order to remove dust particles adhering to the surface.

7.1.3 Cutting of the samples

The cutting of samples shall be carried out without lubrication. The samples shall be cut along the friction surface of the friction element. The friction surface of the samples shall be the one which was originally the closest to the friction surface of the friction element in order to maintain the original application orientation of the material. The sample dimensions are provided in figure 5.
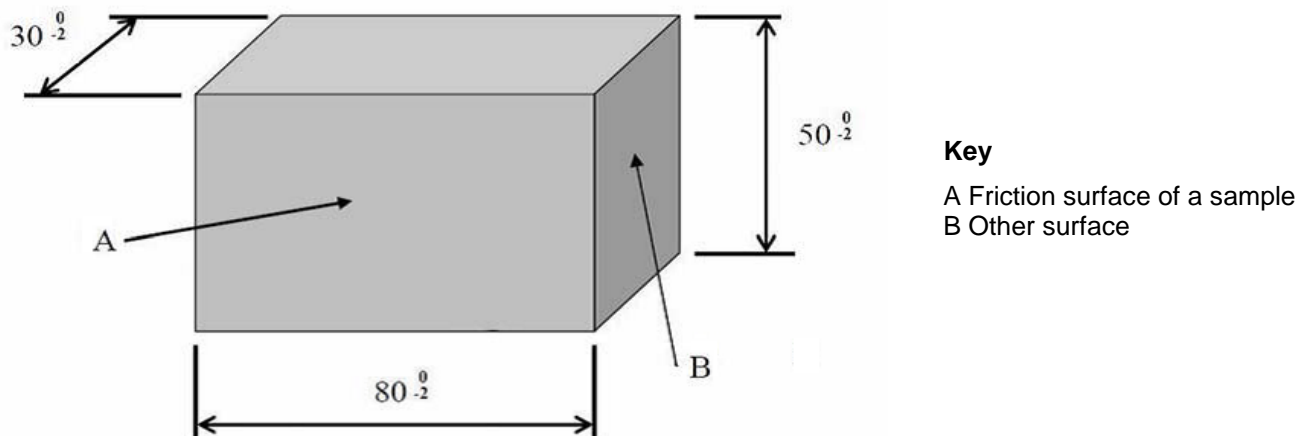

Key

A Friction surface of a sample
B Other surface

Figure 5: Sample

7.1.4 Bedding in of samples

For each cycle two new samples shall be bedded in. The bedding in shall be performed by stop brakings on the cleaned and degreased disc under the following conditions:

- Speed of 100 km/h in the centre of the samples' friction surface
- Braked mass of 0,41 t
- Surface pressure of 40 N/cm^2

The bedding in shall achieve a contact surface area of more than 90 %.

7.1.5 Contamination of disc

The disc shall be contaminated by continuous braking under the following conditions:

- Speed of 70 km/h in the centre of the samples' friction surface
- Brake torque of 51 Nm
- The contamination phase ends as soon as the disc temperature has reached 400 °C or after 2 400 s of continuous braking

Before carrying out the measurement as described in clause 7.1.6 the disc shall be cooled down below 40 °C.

7.1.6 Measurements

The measurement of the impedance shall be carried out with a measurement set up as schematically described in figure 6.
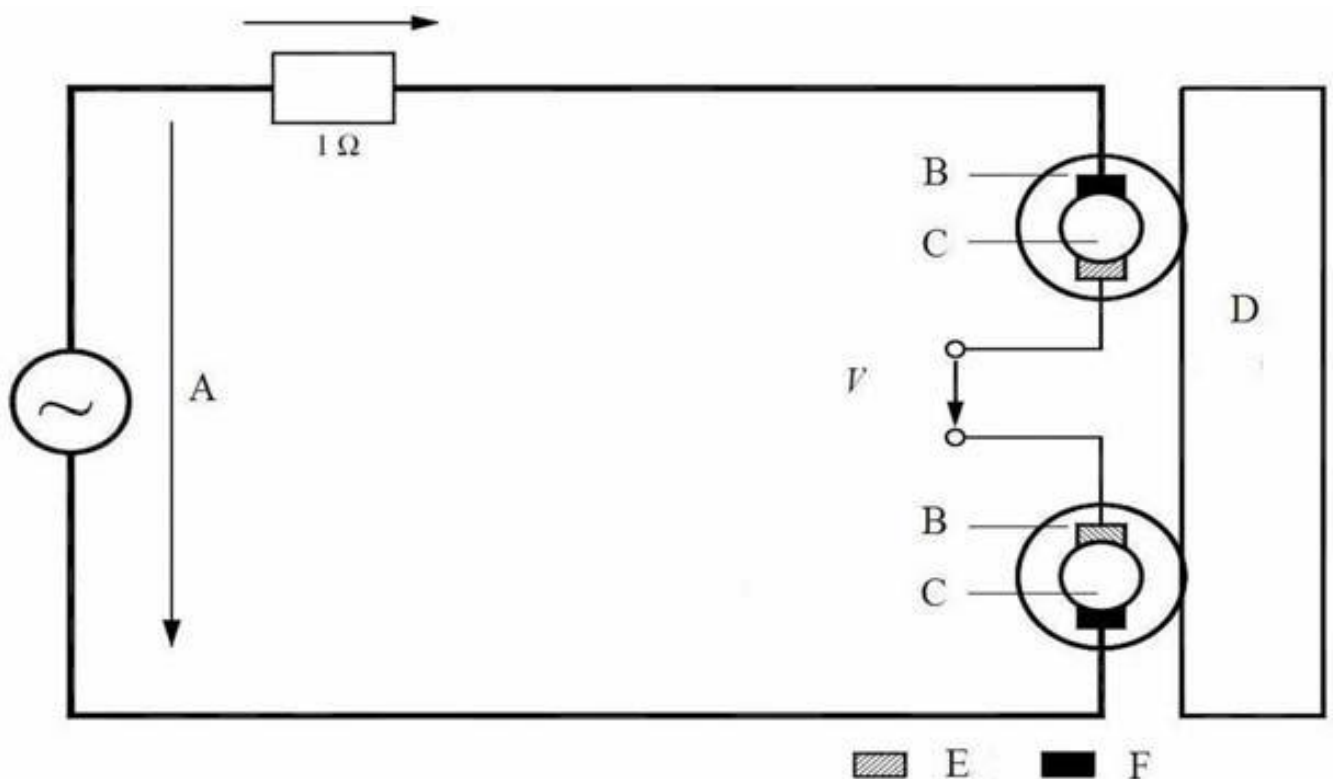
Key

A Applied voltage (electrical cycle)
C Shaft made of copper
E Carbon brush – measured voltage
V Measured voltage

B Roller made of rail steel
D Disc made of wheel steel (clean/contaminated)
F Carbon brush – applied voltage

**Figure 6:** Schematic diagram of the measurement set up

The electrical contact to the disc is achieved by means of two rollers with a contact force of 14 N each (view of rollers, shaft and brushes in figure 6 are rotated by 90°).

The impedance measurement

- of the cleaned disc and
- of the contaminated disc

relates to four different measuring traces equally distributed over the radius in the contaminated area. In accordance with figure 4 five measurement cycles shall be conducted, so that the impedance of 20 traces is measured at a total.

The impedance on each trace is measured both statically and dynamically by applying the electrical cycle as defined in figure 7. During the dynamical measurement the disc shall rotate at a speed of 60 rpm.

Key
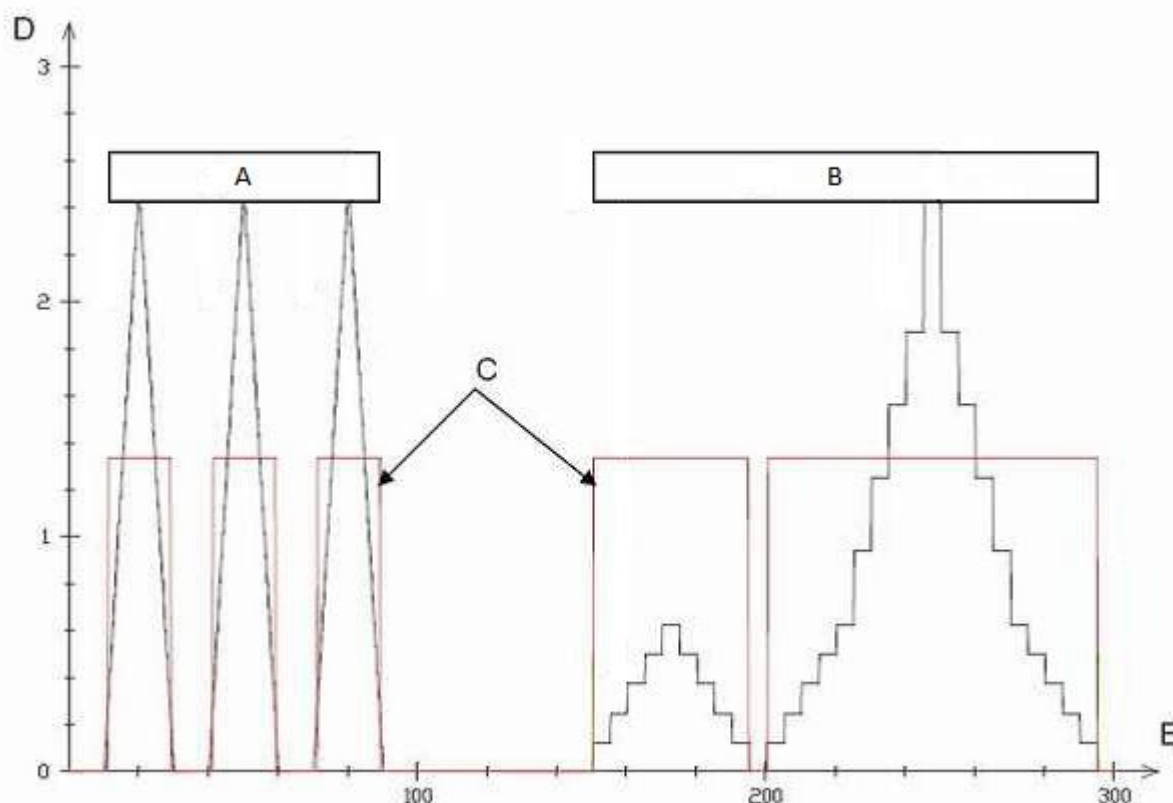
A Static tests   B Dynamic tests   C Area for measurements
D Applied voltage [V]   E Time [s]

Figure 7:   Electrical cycle

The resulting current and voltage are measured by a four-wire impedance measurement method and digitalized. The frequency of applied voltage and current is set to 42 Hz. A summation and a verified sliding mean value averaging provide a new impedance value every 10 ms.

7.2   Assessment of the measurement results
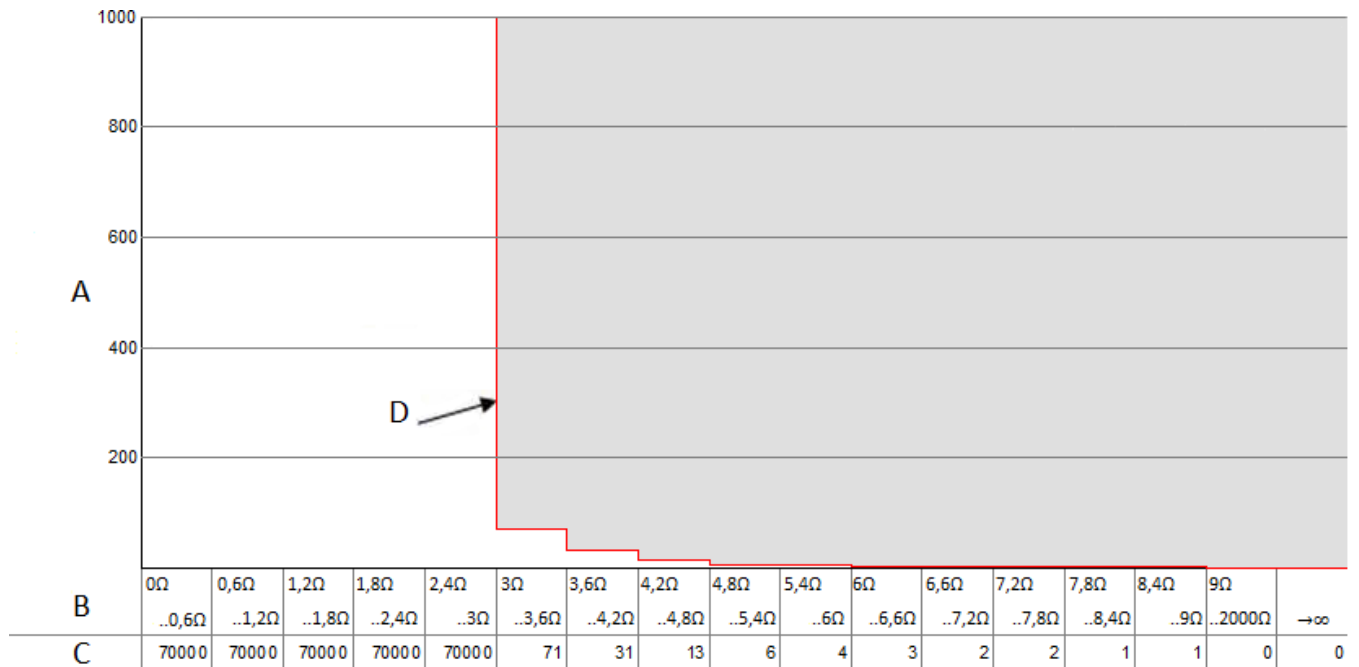
An automatic evaluation of the results shall be carried out.

The (several hundred thousand) impedance values obtained during the course of the measurements shall be allocated to the impedance classes indicated as 'B' in figures 8 and 9. The total number of impedance values of each impedance class shall be compared with the limit values indicated as 'C' in figures 8 and 9.

The number of impedance values measured with the cleaned disc shall be lower in each impedance class than the corresponding limit values as set out in figure 8. If the limit values are not respected, the cleaning of the disc shall be carried out once again as described in figure 4.

B	0Ω ..0,6Ω	0,6Ω ..1,2Ω	1,2Ω ..1,8Ω	1,8Ω ..2,4Ω	2,4Ω ..3Ω	3Ω ..3,6Ω	3,6Ω ..4,2Ω	4,2Ω ..4,8Ω	4,8Ω ..5,4Ω	5,4Ω ..6Ω	6Ω ..6,6Ω	6,6Ω ..7,2Ω	7,2Ω ..7,8Ω	7,8Ω ..8,4Ω	8,4Ω ..9Ω	9Ω ..2000Ω	→∞
C	70000	70000	70000	70000	70000	71	31	13	6	4	3	2	2	1	1	0	0

Key

A Frequency distribution of impedance per class
B Impedance classes
C Limit values of frequency distribution of impedance per class
D Limit curve

Figure 8: Limit values per impedance class for cleaned disc

The number of impedance values measured with the contaminated disc shall be lower in each impedance class than the corresponding limit values as set out in figure 9.

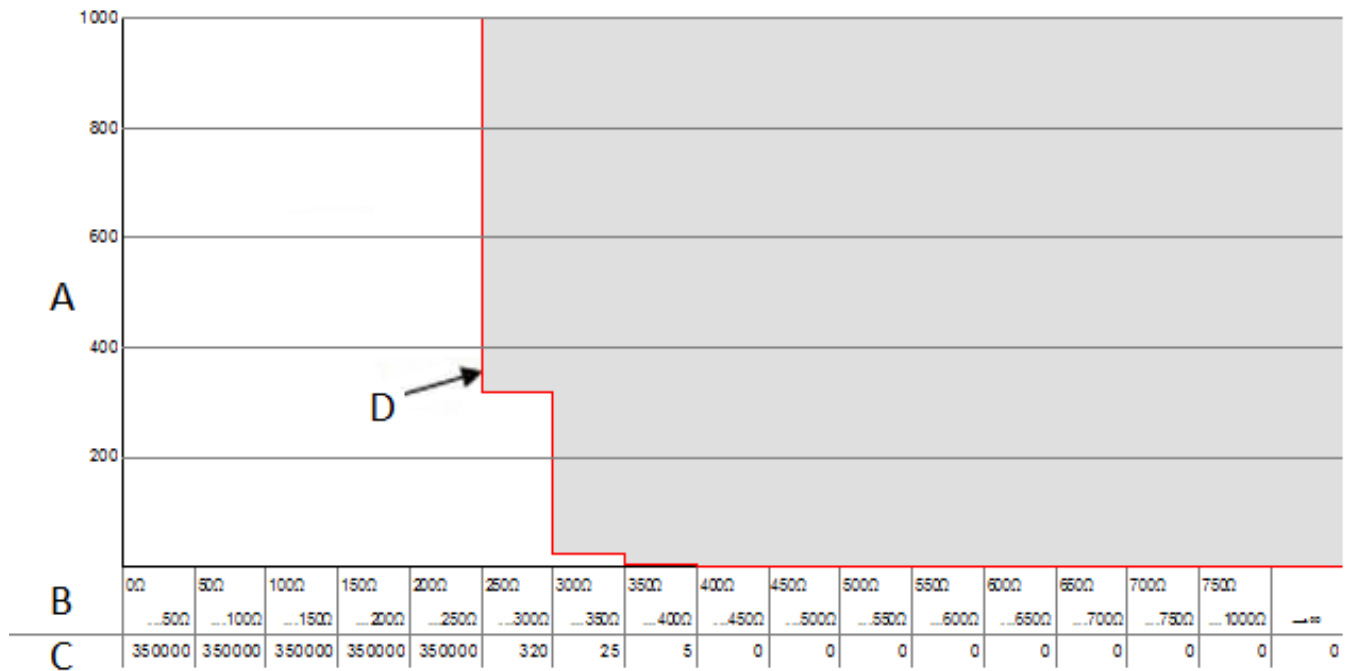**Key**

A Frequency distribution of impedance per class
B Impedance classes
C Limit values of frequency distribution of impedance per class
D Limit curve

Figure 9: Limit values per impedance class for contaminated disc

8. Suitability for severe environmental conditions

The suitability of the friction element acting on wheel tread brakes for severe environmental conditions shall be tested in accordance with the test procedures set out in sections 8.1 or 8.2. The corresponding terms, definitions and abbreviations are explained in sections 2 and 3.

Cast iron brake blocks are deemed to be suitable for severe environmental conditions.

8.1 Test run

8.1.1 Test program to demonstrate the braking properties under severe environmental conditions

The goal of this test run is to compare the results of tests without snow fly-off ('reference tests') with those with snow fly-off ('winter tests') and to determine the braking properties of friction elements acting on wheel tread brakes for severe environmental conditions under real conditions of use.

'Reference tests' and 'winter tests' shall be performed consecutively within one single period of up to 4 weeks. A running period of at least 10 min is to be observed between brake applications, with a maximum of 4 brake applications performed per hour.

The brake initiation speeds shall be

- 60 km/h (for information purposes, to monitor the plausibility and comparability of the efficiency between 'reference tests' and 'winter tests'),
- if the maximum speed is 100 km/h or more: 85 % of the intended maximum speed but not more than 100 km/h, and
- 100 % of the intended maximum speed

respectively.

The tests shall be performed…

- …with a train consisting of one locomotive and 5 wagons fulfilling the following:
    - The locomotive shall have disconnected dynamic and indirect braking.
    - The maximum dynamic mass of the locomotive shall be lower than 100 t.
    - The test wagons shall be of the same design with the same equipment and have an 'open' bogie design e.g. Y25.
    - The wheelset load when empty (without payload) shall be max. 7 t.
    - The arrangement of the friction elements shall be the one with the lowest intended specific pressure at emergency brake.
    - The emergency brake shall be applied.
    - The bedding in shall achieve a contact surface area of more than 85 %.
- …on lines with mean gradient over the stopping distance lower than 3 ‰; maximum gradient lower than or equal to 5 ‰ and curve radii higher than or equal to 1000 m

- …under the following environmental conditions:
    - 'Reference test': No snow fly-off (snow level 0, see figure 10) at external temperatures of up to + 5 °C.
    - 'Winter tests': During the winter semester with snow on the lines and with snow fly-off (snow level 3 to 5, see figures 11 and 12) at external temperatures between zero and -10 °C.

Figure 10:   Reference test (snow level 0)

Figure 11:   Winter test (snow level 2 to 3)

Figure 12:   Winter test (snow level 4 to 5)

The number of 'reference tests' shall be at least 8 and maximum 20 for each brake initiation speed (60 km/h excluded) whereby the quotient of the standard deviation and the average braking distance shall not exceed 10 %.

The number of 'winter tests' shall be at least 8 (60 km/h excluded) whereby the quotient of the standard deviation and the average braking distance shall not exceed 20 % to ensure that the braking distance is representative for the assessment.

The following values shall be measured:

- Speed
- Braking distance
- Time
- Brake pipe pressure
- External temperature

8.1.2   Values to be determined in order to define the area of use

The average braking distances of the 'winter tests' at each speed and the average braking distances of the 'reference tests' shall be determined.

8.2 Dynamometer test

8.2.1 Test program to demonstrate the braking properties under severe environmental conditions

The dynamometer test program to demonstrate the extreme winter braking properties is set out in table 6 and table 7 and is only applicable if the friction element…

- …is intended to be used in subsystems which fall under the following scope:

  - Nominal wheel diameters of 680 mm to 920 mm
  - Friction element configuration
    - 1Bg (if the test was performed in configuration 1Bg or 2Bgu)
    - 1Bgu (if the test was performed in configuration 1Bgu or 2Bgu)
    - 2Bg (if the test was performed in configuration 2Bg or 2Bgu)
    - 2Bgu (if the test was performed in configuration 2Bgu)
  - Mass per wheel ≥ 1.8 t

- …complies with one of the following cases of the mean dynamic friction coefficient as determined in accordance with section 4.2 point b):

Table 5: Cases of the mean dynamic friction coefficient

Case	Mean dynamic friction coefficient	Total F_B per wheel F_B [kN]	Initial speed v [km/h]
1	$0,28 < \mu_m < 0,32$	9	100
2	$0,27 < \mu_m < 0,31$	9	120
3	$0,17 < \mu_m < 0,19$	16	100
4	$0,16 < \mu_m < 0,18$	16	120

To demonstrate the extreme winter braking properties of friction elements complying with cases 1 and 2 of table 5 the test program of table 6 shall be applied, for friction elements complying with cases 3 and 4 of table 5 the test program of table 7 shall be applied.

Table 6: Dynamometer test program – friction elements cases 1 and 2

Friction element configuration					1Bg, 1Bgu, 2Bg or 2Bgu				
Wheel type					In conformity with EN 13979-1				
Wheel diameter					$\emptyset$ X ± 5 mm last machining size before wheel is fully worn to EN 13979-1				
No. of brake application					Initial speed	Total F_B per wheel	Initial temp.	Mass to brake per wheel	Remarks
					v	F_B	Θ_0	m_{1W}	
					[km/h]	[kN]	[°C]	[t]	
R.1 - R.X					100	12	20 to100	7,5	Brake applications to rest under dry conditions to allow bedding of the friction elements up to a contact pattern of 100 % is reached
R.X + 1 to R.X + 20					100	12	20 to 100	2,5	20 brake applications to a stop (dry)
1 to 5					100	9	-5 to 60	2,5	Conditioning
6	8	10	12	14	100	9	50 to 60	2,5	Dry brake applications, warm
7	9	11	13	15	120			2,5	
16	18	20	22	24	100	9	-5 to -3	2,5	Dry brake applications, cold (reference brake applications)
17	19	21	23	25	120			2,5	
									Test snow machine and snow quality
26 to 28					120	9	-5 to 90	2,5	Conditioning
a29	a33	a37	a42	a46	20				Cooling, dry to -3 °C
b29	b33	b37	b42	b46	100				Rotating, dry, over 240 s
c29	c33	c37	c42	c46	100				Rotating, with artificial snow over 340 s
29	33	37	42	46	100	9		2,5	Braking with artificial snow
30	34	38	43	47	120	9	-5 to 90	2,5	Conditioning, dry

Table 6 (continued)

No. of brake application					Initial speed	Total F_B per wheel	Initial temp.	Mass to brake per wheel	Remarks
					v	F_B	Θ_0	m_W	
					[km/h]	[kN]	[°C]	[t]	
a31	a35	a39	a44	a48	20				Cooling, dry to -3 °C
b31	b35	b39	b44	b48	120				Rotating, dry, over 240 s
c31	c35	c39	c44	c48	120				Rotating with artificial snow over 900 s
31	35	39	44	48	120	9		2,5	Braking with artificial snow
32	36	40	45	49	120	9	-5 to 90	2,5	Conditioning, dry
		41			120	9	-5 to 90	2,5	Conditioning, dry

Table 7:   Dynamometer test program – friction elements cases 3 and 4

Friction element configuration	1Bg, 1Bgu, 2Bg or 2Bgu				
Wheel type	In conformity with EN 13979-1				
Wheel diameter	∅ X ± 5 mm last machining size before wheel is fully worn to EN 13979-1				
No. of brake application	Initial speed	Total F_B per wheel	Initial temp.	Mass to brake per wheel	Remarks
	v	F_B	Θ_0	m_{1W}	
	[km/h]	[kN]	[°C]	[t]	
R.1 - R.X	100	30	20 to100	7,5	Brake applications to rest under dry conditions to allow bedding of the friction elements up to a contact pattern of 100 % is reached
R.X + 1 to R.X + 20	100	30	20 to 100	2,63	20 brake applications to a stop (dry)
1 to 5	100	16	-5 to 60	2,63	Conditioning

Table 7 (continued)

No. of brake application					Initial speed	Total F_B per wheel	Initial temp.	Mass to brake per wheel	Remarks
					v	F_B	Θ_0	m_W	
					[km/h]	[kN]	[°C]	[t]	
6	8	10	12	14	100	16	50 to 60	2,63	Dry brake applications, warm
7	9	11	13	15	120			2,63	
16	18	20	22	24	100	16	-5 to -3	2,63	Dry brake applications, cold (reference brake applications)
17	19	21	23	25	120			2,63	
									Test snow machine and snow quality
		26 to 28			120	16	-5 to 90	2,63	Conditioning
a29	a33	a37	a42	a46	20				Cooling, dry to -3 °C
b29	b33	b37	b42	b46	100				Rotating, dry, over 240 s
c29	c33	c37	c42	c46	100				Rotating with artificial snow over 340 s
29	33	37	42	46	100	16		2,63	Braking with artificial snow
30	34	38	43	47	120	16	-5 to 90	2,63	Conditioning, dry
a31	a35	a39	a44	a48	20				Cooling, dry to -3 °C
b31	b35	b39	b44	b48	120				Rotating, dry, over 240 s
c31	c35	c39	c44	c48	120				Rotating with artificial snow over 900 s
31	35	39	44	48	120	16		2,63	Braking with artificial snow
32	36	40	45	49	120	16	-5 to 90	2,63	Conditioning, dry
		41			120	16	-5 to 90	2,63	Conditioning, dry

During the tests described in tables 6 and 7 the following conditions shall be respected:

- The cooling air speed shall be as set out in table 8.

Table 8: Cooling air speed

	Speed simulated on the test bench [km/h]		Speed of the cooling air [km/h]	
	Under dry conditions	**With snow**	**Under dry conditions**	**With snow**
During braking	v	v	25	25
Between the brake applications	v	v	25	25

- The brake build-up time shall be 8 s ± 0,2 s.

- During bedding-in the following minimum numbers of brake stops shall be carried out: 40 for organic friction elements and 80 for sintered friction elements.

- All test equipment shall initially have a homogeneous temperature of -7 °C ± 2 °C. The test chamber temperature shall be -7 °C ± 2 °C. The required temperature should therefore be reached in the test chamber at least 12 h before the start of the programme (brake application n° 1).

- The snow shall be dry. Its calculated weight shall be 45 - 52 g per 250 ml measuring cup. It shall fall apart after being pressed in a palm. During the cooling periods with artificial snow and the subsequent brake applications with artificial snow, the flow of artificial snow shall not be interrupted.

- Five valid brake applications under snow (at 100 km/h and 120 km/h) are required.

- Any irregularities during testing on the friction element and the wheel contact surfaces are to be recorded and documented.

- If interruptions occur between brake applications n° 29 to 49 (e. g. due to equipment problems as a result of iced-over snow nozzles), the programme is to be continued by repeating the last conditioning brake application and the subsequent cooling operations. These interruptions are to be recorded in the test report.

8.2.2 Values to be determined in order to define the area of use

The test program shall be carried out three times and the establishment of the suitability shall be done for a maximum test speed of 100 km/h and 120 km/h as follows:

- For a maximum speed of 100 km/h the deviation of the average value of the measured stopping distances s_1 under snow (brake application n° 29, 33, 37, 42 and 46) from the

average value of the measured stopping distances s_1 under dry conditions (brake application n° 16, 18, 20, 22 and 24) shall be determined.

- For a maximum speed of 120 km/h the deviation of the average value of the measured stopping distances s_1 under snow (brake application n° 31, 35, 39, 44 and 48) from the average value of the measured stopping distances s_1 under dry conditions (brake application n° 17, 19, 21, 23 and 25) shall be determined.

9. Thermo mechanical characteristics

The thermo mechanical analysis to be performed at subsystem level (freight wagon) is specified in the point 4.2.4.3.3 of the WAG TSI for the brake system and in the point 4.2.3.6.3 of the WAG TSI for the wheel, taking into account the area of use of the freight wagon.

At the interoperability constituent level (friction element for wheel tread brakes) it is allowed to take into account for the brake application No 129 of Table 1 a more demanding slope than those suggested in the column Remarks; the slope taken into account has then to be recorded in the technical documentation as part of the area of use of the friction element for wheel tread brakes.

At the interoperability constituent level (friction element for wheel tread brakes), in case the manufacturer chooses to perform the test to simulate 'locked brake' as specified in EN 16452:2015, the result of this test has to be recorded in the technical documentation as part of the area of use of the friction element for wheel tread brakes.