SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Wear Test Procedure on Inertia Dynamometer for Brake Friction Materials

RATIONALE

This revision of the wear test procedure includes several changes to: (a) harmonize with other SAE Recommeded Practices (RPs), (b) modernize and expand the test sequences, and (c) address typographical and editorial corrections from previous versions. Some specific updates include the following:

- Harmonization with SAE J2789 for inertia calculation and with SAE J2986 for wear measurements.
- Expansion of the wear versus temperature (Method A) includes temperatures below 100 °C for friction materials with ferrous metals and decelerations below 0.3 g. These updates reflect normal customer usage and field measurements using the worldwide harmonized light vehicle test procedure (WLTP) adapted for a brake duty cycle.
- Extension of the block wear test (Method B) with separate temperatures for front and rear brakes and lower energy levels.
- Common burnish schedule for all test methods to ensure consistent conditioning in preparation for the actual wear test. The new burnish method harmonizes with the FMVSS 135 burnish, common in other inertia dynamometer tests.

FOREWORD

The harmonization efforts by different industry groups and associations from the European community, the United States, and Japan cover several aspects to characterize brake friction materials used in automotive applications. Brake lining wear life, its dynamics, and behavior under different temperatures and speeds are critical to the successful development and production of commercially available disc brake pads and linings, both for the original equipment and the aftermarket segments. Equally important is evaluating the wear characteristics of the given friction material and its mating part when subjected to a series of brake stops or snubs derived from an actual driving pattern. Different combinations of speed, temperature, and deceleration, closer to what the vehicle experiences during regular driving, yield different levels of wear and transfer layer phenomena. When tested under a control testing environment on an inertia dynamometer, this driving pattern replication could provide information on the wear behavior and level of a given lining and rotor or drum combination.

This RP harmonizes test procedures to evaluate wear characteristics of automotive brake lining and pads. This RP establishes a standardized dynamometer procedure related to the actual condition of vehicles on the market. Therefore, this committee is making two different test sequences available. The first Method, Method A, equivalent to the Japanese standard JASO C427-83 to quantify the wear sensitivity to the temperature experienced by the lining and rotor/drum combination. The second method, Method B (also known as block wear), includes variable speed, deceleration, and temperature levels.

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This RP may be used in conjunction with other applicable standards or test procedures (ISO, SAE, Federal Codes, or other specific testing programs) to fully assess a friction material's adequacy for a particular application or vehicle platform.

TABLE OF CONTENTS

1. SCOPE

1.1 This SAE Recommended Practice (RP) specifies a dynamometer test procedure to characterize wear rates of automotive service brake linings (brake shoes) and disc brake pads.

1.2 Unique motor vehicles, motorcycles, and trailers with nominal gross combination weight rating exceeding 40 tons are not part of this document.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J2789 Inertia Calculation for Single-Ended Inertia-Dynamometer Testing

SAE J2986 Brake Pads, Lining, Disc, and Drum Wear Measurements

3. DEFINITIONS

Apply the following terms and definitions to facilitate the application of this document.

3.1 INITIAL SPEED

The speed at the time brake application is initiated and read using a calibrated rotational speed sensor.

3.2 FINAL SPEED

Unless otherwise stated, the speed at the time of brake release. Unless otherwise noted on the different test, the final speed is 0.5 km/h.

3.3 BRAKING DECELERATION

Reduction in the equivalent vehicle speed due to an active braking torque between two points in time. The braking torque is provided by controlling and modulating the brake pressure. In a practical test, convert the deceleration level into an equivalent brake torque using the equation given in 4.7.

3.4 INITIAL BRAKE TEMPERATURE

The temperature of the drum(s) or disc(s), according to the procedure when the brake application is initiated. When testing more than one brake simultaneously, the initial brake temperature is the highest of all brakes measured on the drum(s) or disc(s).

4. SYMBOLS AND ABBREVIATIONS

Use the symbols and abbreviations from Table 1 to perform the calculations needed during the test.

Table 1 - Symbols and abbreviations

Symbol	Description	Units
a	Required braking deceleration.	g
A	Area of the rubbing surface on linings or pads.	cm^2
E_k	Total mechanical work for a brake event.	kgf·m, N·m, J
GVWR	Gross vehicle weight rating.	kg
I_{front}	Required inertia on the front axle.	$kgf·m·s^2$, $kg·m^2$
I_{rear}	Required inertia on the rear axle.	$kgf·m·s^2$, $kg·m^2$
I'	Effective inertia for a given brake event.	$kgf·m·s^2$, $kg·m^2$
N	Total number of brake applications at a given step of the test sequence.	-
RPM	Revolutions per mile.	revs/mile
RR	Tire dynamic rolling radius.	m
T_{hk}	Sum of average thickness loss of the inner and outer pad, or leading and trailing lining.	mm
T_{front}	Required braking torque on the front axle.	kgf·m, N·m
T_{rear}	Required braking torque on the rear axle.	kgf·m, N·m
T'	Effective braking torque for a given brake event.	kgf·m, N·m
X	Percentage of brake torque provided by the front axle, according to SAE J2789.	%
Y	Percentage of brake torque provided by the rear axle, according to SAE J2789.	%
W	Vehicle weight.	kg
V	Specific wear rate.	10^{-7} cm^3/kgf·m, 10^{-7} cm^3/N·m, 10^{-7} cm^3/J
ω_i	Initial angular velocity of the brake at the start of the brake event.	rad/s
ω_f	Final angular velocity of the brake at the end of the brake event.	rad/s

4.1 REQUIRED BRAKING DECELERATION, a

The nominal rate of change in vehicle speed during braking after the initial transient condition. This rate does not include the brake achieving the target deceleration level indicated for a specific event.

4.2 EFFECTIVE BRAKING DECELERATION, a'

The actual rate of change in vehicle speed during braking is computed (after the initial transient condition) as a function of brake rotational speed and tire dynamic rolling radius for a specific event.

4.3 GROSS VEHICLE WEIGHT RATING, GVWR

The maximum vehicle weight specified by the manufacturer.

4.4 REQUIRED INERTIA, I_{front}, I_{rear}

Calculate test inertias (front or rear) according to SAE J2789 and the closest value achievable by the dynamometer utilizing mechanical and electric (simulated) inertia. Determine the inertia level for vehicle deceleration below 0.65 g, with the vehicle loaded to the gross vehicle weight rating (GVWR), indicated by the test requestor.

4.5 EFFECTIVE INERTIA, I'

Inertia reflected at the foundation brake computed as a function of the torque readings, angular deceleration of the brake, and the tire dynamic rolling radius.

4.6 TIRE DYNAMIC ROLLING RADIUS, RR

Tire radius equivalent to the revolutions per mile (RPM) published by the tire manufacturer for the specific tire size. If unknown, the rolling radius can be calculated from the RPM value using Equation 1. Use the tire dynamic rolling radius to calculate test inertia and the dynamometer rotational speed in revolutions per minute (r/min) for the given linear vehicle speed.

$$RR = \frac{1609.344}{2 \cdot \pi \cdot RPM} \quad \text{(Eq. 1)}$$

4.7 REQUIRED BRAKING TORQUE, T_{front}, T_{rear}

The continuous braking torque from the foundation brake, combining the gross vehicle weight, tire dynamic rolling radius, brake work split, and deceleration according to Equations 2 and 3.

$$T_{front} = \frac{1}{2} \cdot \frac{X \cdot W \cdot RR \cdot a}{9.81} \quad \text{(Eq. 2)}$$

$$T_{rear} = \frac{1}{2} \cdot \frac{X \cdot W \cdot RR \cdot a}{9.81} \quad \text{(Eq. 3)}$$

4.8 EFFECTIVE BRAKING TORQUE, T'

The continuous braking torque obtained from inertia, deceleration, and tire dynamic rolling radius during the actual test, according to Equation 4.

$$T' = \frac{I' \cdot a'}{RR} \quad \text{(Eq. 4)}$$

4.9 MECHANICAL WORK, E_k

Total mechanical work (change in kinetic energy) for a given test section, according to Equation 5.

$$E_k = \frac{I \cdot (\omega_i^2 - \omega_f^2) \cdot N}{2} \quad \text{(Eq. 5)}$$

4.10 THICKNESS LOSS, T_{hk}

Average thickness loss to determine the specific wear rate. First, to obtain the thickness loss value, calculate the average thickness loss for each brake pad or (drum) brake lining per the test sequence. Then, add the thickness losses from both friction materials to obtain the total loss to use on Equation 6.

4.11 SPECIFIC WEAR RATE, V

Wear rate, expressed as volumetric loss of friction material per unit of kinetic energy dissipated according to Equation 6.

$$V = \frac{T_{hk} \cdot A}{10 \cdot E_k} \quad \text{(Eq. 6)}$$

5. TEST CONDITIONS

5.1 Pressure Ramp Rate

5000 kPa/s ± 1000 kPa/s, then adjust the pressure ramp rate to achieve the target deceleration rate in approximately 0.5 second.

5.2 Sampling Rate

Use a minimum of 50 Hz for pressure and torque and 10 Hz for temperature.

5.3 Temperature Measurement

5.3.1 Brake Disc or Brake Drum

Position the thermocouple in the inner face for the brake disc at the effective radius, 1.0 mm ± 0.15 mm deep, or on the brake drum at the centerline of lining width. Reset the thermocouple(s) depth at every wear measurement inspection.

5.3.2 (Optional) For Brake Pads or Brake Shoes

Position one thermocouple in each pad, with a depth of 2.0 mm ± 0.15 mm near the friction surface center. For disc brake pads with grooves, install the thermocouple at least 4.0 mm from the groove edge on the leading side of each pad. For inner pads on single-piston calipers, install the thermocouple as close as feasible to the caliper body on the pad's leading side. For brake shoes, install a thermocouple at a depth of 1.0 mm ± 0.15 mm near the center of each shoe's friction surface. Reset the thermocouple(s) depth at every wear measurement inspection.

5.3.3 (Optional) Additional Inspections and Data Monitoring for Wear and Thermocouple Behavior

To inspect the friction material's excessive wear and avoid the thermocouple(s) to reach the surface during a test cycle, monitor the in-stop traces for both pads. Assess unusual trends (temperature spikes, sudden changes on the trace, or significantly different temperature rise during the event), and inspect the thermocouples accordingly. During block wear tests per Method B, stop the test from performing a thermocouple inspection and resetting the thermocouple(s) depth before the highway block #2 and the hill descent block.

5.4 Warm-Up Brake Applications

Include warm-up applications as part of the total number of stops at each temperature step. Do not exceed 50 warm-up stops per temperature step. Set the cooling air to 0 m/s, or a minimum value to exhaust odors from the test area.

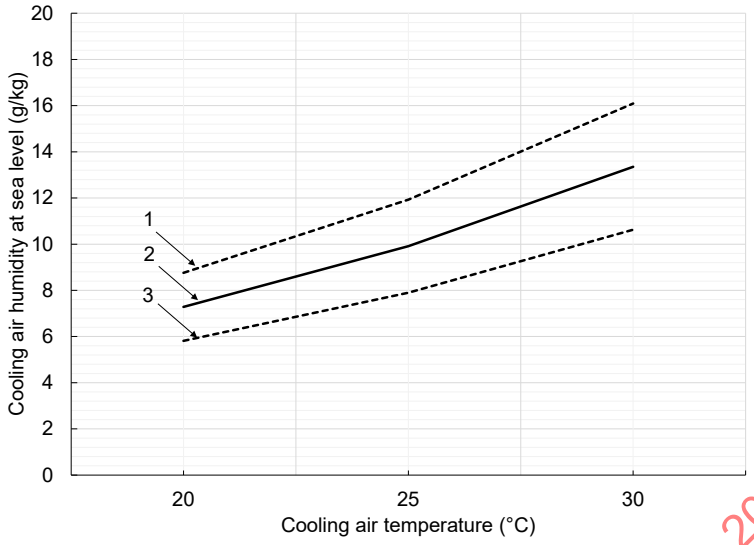
5.5 Burnish for Brake Lining (Drum Brakes)

Unless otherwise indicated by the test requestor, repeat the brake burnish section to attain a 90% surface contact.

5.6 Cooling Air Conditions

5.6.1 Environmental Conditions

Control brake cooling air temperature 25 °C ± 5 °C, and humidity to 50% ± 10% RH. Use a psychrometric chart to find acceptable air temperature and relative humidity conditions to meet absolute humidity requirements. See Figure 1 for the absolute humidity at sea level corresponding to the tolerances allowed for temperature and relative humidity.



Key:
1: 60% relative humidity
2: 50% relative humidity
3: 40% relative humidity

Figure 1 - Cooling air humidity as a function of cooling air temperature

5.6.2 Cooling Air Velocity

Set the air velocity to 11 m/s and adjust so that the air blows uniformly and continuously against the brake's projected area. If the initial brake temperature does not reach the target value, adjust the air velocity as necessary, and include in the final test report.

To minimize variability on the cooling rate(s), ensure harmonizing the test setup and cooling conditions when conducting a test program with multiple friction couples on the same brake configuration.

Setup the cooling air duct outlet as close as possible to 300 mm away from the test hardware and document it in the final test report.

5.6.3 Brake Setup

Mount the brake assembly as close as possible to the vehicle position. In general, this helps correlate with issues like brake drag, off-brake wear, off-brake disc thickness variation, system stiffness, and NVH assessment.

5.6.4 Airflow Direction with Regards to Brake Setup

Document and report the airflow inlet regarding direction (vertical or horizontal) and orientation relative to the caliper and the brake assembly.

5.7 Preparation for Test

5.7.1 Make sure there are no abnormalities on the brake assembly before installing it on the test equipment. Verify there is no grease or any other foreign matter adhered to the linings or pads.

5.7.2 Install thermocouples to the drum(s) or disc(s) and lining to the specified location. Clean the friction surface using acetone or other appropriate solution.

Unless otherwise indicated by the test requestor, set Lateral Runout to 50 µm or less when measured 10 mm from the outer diameter on the outboard side of the rotor. Verify drum ovality to 75 µm or less.

NOTE: Discs or drums not meeting the limits from this clause may influence the test results.

6. TEST PROCEDURE

The methods indicated in Tables 3 to 7 show the test sequence required on the same drum or disc and the same brake linings or pad assemblies. Table 2 provides an overview of each method.

Table 2 - Overview and applicability of different wear test methods

Method	Method A - Wear versus Temperature			Method B - Block Wear Evaluation	
	General Wear Test (A1) Section 6.1.3; Table 3	**General Wear Tests at Low Deceleration (A2) Section 6.1.2; Table 4**	**High-Speed Wear Test (A3) Section 6.1.3; Table 5**	**High Energy Block Wear Test (B1) Section 6.2.1; Table 6**	**Moderate Energy Block Wear Test (B2) Section 6.2.2; Table 7**
Description	Legacy test method harmonized with the JASO C427 for average vehicle driving speeds. Also includes two sections at lower temperatures (60 °C and 80 °C).	Variation of the A1 Method, with lower deceleration levels to better represent regular vehicle activity. Also includes two sections at more moderate temperatures: 60 C and 80 °C.	Legacy test method harmonized with JASO C427 to assess laboratory wear behavior at higher driving speeds.	Legacy test method aligned with European laboratory test methods to replicate different levels of vehicle activity.	Variation of the B1 test method with lower deceleration and temperatures to better replicate normal levels of vehicle activity.
Main applications	General evaluation, benchmarking, fingerprinting of passenger cars and light trucks. The lower temperature sections are more critical for friction materials, including ferrous metals. This method applies to friction materials with high wear rates at low temperatures. Suitable for evaluation of wheel dust.	General evaluation, benchmarking, fingerprinting of vehicles, including vehicles above 3500 kg of GVWR. The low-temperature sections are more critical for friction materials, including ferrous metals. This method applies to friction materials with high wear rates at low temperatures. Suitable for evaluation of wheel dust.	Additional wear test typically added to the A1 and A2 test methods.	General evaluation, benchmarking and fingerprinting of friction couples for passenger cars and light trucks.	General evaluation, benchmarking, fingerprinting of vehicles, including vehicles above 3500 kg of GVWR.

6.1 Method A - Wear versus Temperature Evaluation

6.1.1 General Wear Test (A1)

For wear characteristics versus brake temperature, use Table 3. The initial temperatures between parentheses apply to optional sections. When conducting the temperature steps at 100 °C or below, select which temperatures to include in the actual project.

Table 3 - General wear tests (A1)

Section	Initial Speed (km/h)[1]	Initial Drum Brake Temperature (°C)	Initial Disc Brake Temperature (°C)	Braking Deceleration (g)	Number of Stops (N)
Burnish	80	100	100	0.30	200
Wear test 60 °C	50	60	60	0.30	500
Wear test 80 °C	50	80	(80)	0.30	500
Wear test 100 °C	50	100	100	0.30	1000
Wear test 150 °C	50	150	150	0.30	1000
Wear test 200 °C	50	200	200	0.30	1000
Wear test 250 °C	50	(250)	250	0.30	1000
Wear test 300 °C	50	300	300	0.30	500
Wear test 350 °C	50	(350)	350	0.30	500
Wear test 400 °C	50	-	400	0.30	200
Wear test 450 °C	50	-	(450)	0.30	200
Wear test 500 °C	50	-	(500)	0.30	200
Second wear test 100 °C	50	100	100	0.30	500
Second wear test 200 °C	50	200	200	0.30	500
Second wear test 250 °C	50	(250)	250	0.30	500
Second wear test 300 °C	50	300	300	0.30	250
Second wear test 400 °C	50	-	(400)	0.30	100

[1] Final speed per 3.2.

6.1.2 General Wear Tests at Low Deceleration (A2)

For wear characteristics versus brake temperature at lower decelerations, use Table 4. Initial temperatures between parentheses apply to optional sections. When conducting the optional temperatures at 100 °C or below, select which temperatures to include on the actual project. Temperatures below 100 °C are more relevant for friction materials with ferrous metals.

Table 4 - General wear test at low deceleration (A2)

Section	Initial Speed (km/h)[1]	Initial Drum Brake Temperature (°C)	Initial Disc Brake Temperature (°C)	Braking Deceleration (g)	Number of Stops (N)
Burnish	80	100	100	0.30	200
Wear test 60 °C	50	60	60	0.15	500
Wear test 80 °C	50	80	80	0.15	500
Wear test 100 °C	50	100	100	0.15	1000
Wear test 150 °C	50	150	150	0.15	1000
Wear test 200 °C	50	200	200	0.15	1000
Wear test 250 °C	50	(250)	250	0.15	1000
Wear test 300 °C	50	(300)	300	0.15	500
Wear test 350 °C	50	(350)	(350)	0.15	500
Wear test 400 °C	50	-	(400)	0.15	200
Wear test 450 °C	50	-	(450)	0.15	200
Wear test 500 °C	50	-	(500)	0.15	200
Second wear test 100 °C	50	(100)	(100)	0.15	500
Second wear test 200 °C	50	(200)	(200)	0.15	500
Second wear test 250 °C	50	(250)	(250)	0.15	500
Second wear test 300 °C	50	(300)	(300)	0.15	250
Second wear test 400 °C	50	-	(400)	0.15	100

[1] Final speed per 3.2.