



SURFACE VEHICLE RECOMMENDED PRACTICE

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Validation of Compressibility Test Systems for Friction Materials

RATIONALE

Within any acceptable quality assurance program, the systematic validation of the test system and gage repeatability and reproducibility (Gage R&R) are of primary importance. Manufacturing or product data is only as good as the instruments that evaluate processes or measure products. Therefore, it is of primary importance to ensure that measurement devices are adequate for the required measurements within a manufacturing control plan.

This SAE Recommended Practice (RP) uses three main steps:

- Assessment of test system using a predefined checklist to verify main features and control capabilities with deflection profile evaluations.
- Measurement of actual deflection using standard proving rings (also known as the standard judge and soft judge).
- Gage R&R using actual pads following a pre-selection process.

Using test systems which satisfy the statistical limits and acceptance criteria established in this RP, in addition to any agreed-upon requirements between the testing system supplier and the test system user, provides a robust method to ensure valid and relevant test results.

This RP accompanies and supports the SAE Surface Vehicle Standards SAE J2468 and SAE J3079-2.

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1. SCOPE

This SAE Recommended Practice (RP) applies to the validation process for test systems used to measure deflection (compressibility, creep, or swell and growth) of friction materials and friction material assemblies. The materials or assemblies can fit passenger cars, light trucks, and commercial vehicles equipped with hydraulic or air brake systems, using disc or drum brakes.

2. REFERENCES

2.1 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

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 J160 Swell, Growth, and Dimensional Stability of Friction Materials and Noise Insulators when Exposed to Elevated Temperatures

SAE J2468 High-Preload Deflection and Compressibility Test Procedures for Friction Materials

SAE J3079-2 Low-Preload Deflection Measurement for Brake Pads, Noise Shims, and Brake Pad Assemblies

2.1.2 ISO Publications

Copies of these documents are available online at <http://webstore.ansi.org/>.

ISO 3 Preferred Numbers - Series of Preferred Numbers

ISO 6310 Road Vehicles - Brake Linings - Compressive Strain Test Methods

3. DEFINITIONS

Table 1 - Symbols and definitions

Symbol	Definition	Units
A_o	Brake pad contact area with the rotor	mm ²
A_p	Piston(s) hydraulic area	mm ²
A_s	Sample or coupon contact area with the heating platen	mm ²
C_i	The inner chamfer of piston adaptor	mm
C_o	The outer chamfer of piston adaptor	mm
d_c	Corrected deflection	µm
$d_{c,400}$	Corrected deflection at elevated temperature (400 °C)	µm
d_e	Machine deflection	µm
$d_{e,400}$	Machine deflection at elevated temperature (400 °C)	µm
d_m	Measured deflection	µm
$d_{m,400}$	The measured deflection at elevated temperature (400 °C)	µm
d_o	Deflection offset	µm
$d_{o,400}$	Deflection offset at elevated temperature (400 °C)	µm
d_z	Zeroed deflection	µm
$d_{z,400}$	Zeroed deflection at elevated temperature (400 °C)	µm
h_{cycle}	Hysteresis for the entire cycle	%
h_{load}	Hysteresis at a specific step (equivalent hydraulic pressure or force) within the cycle	% or µm
h_o	External height of the piston simulator without the interface feature with the upper platen	mm
h_i	The internal depth of the piston simulator	mm
F	Total force applied to the sample during testing	N
SV/Proc	Total study variation as a percent of six times s_i ; also referred to as “%Process”	µm
s_i	Desired maximum process standard deviation (sigma)	µm
s_b	Between-batch standard deviation	µm
SV	Study variation	µm
s_w	Within-batch standard deviation	µm
r_i	Inner radii of piston adaptor	mm
r_o	Outer radii of piston adaptor	mm
t_a	Total assembly thickness	mm
t_b	Backing plate thickness	mm
t_f	Friction material thickness	mm

3.1 COMPRESSIBILITY

Transient deflection or reduction in thickness of the brake friction material or brake pad assembly due to compressive load. Measure deflection in the direction of the applied load, perpendicular to the friction surface (µm).

3.2 CORRECTED DEFLECTION (d_c)

Measured deflection minus the machine deflection using Equation 1:

$$d_c = d_m - d_e \quad (\text{Eq. 1})$$

3.3 CREEP (C_{load})

Tendency of the test sample to deform gradually under a clamp load. Calculate creep using deflection data that is zeroed (d_z) before the third loading cycle. Calculate creep at discrete pressure levels by subtracting the zeroed deflection at the discrete pressure during the third loading cycle from the zeroed deflection 0.5 second before the end of the creep load condition. Use Equation 2.

$$C_{load} = d_z @ \text{load 0.5 second before the end of the creep loading condition} - d_z @ \text{load during third cycle apply} \quad (\text{Eq. 2})$$

3.4 DEFLECTION OFFSET (d_o)

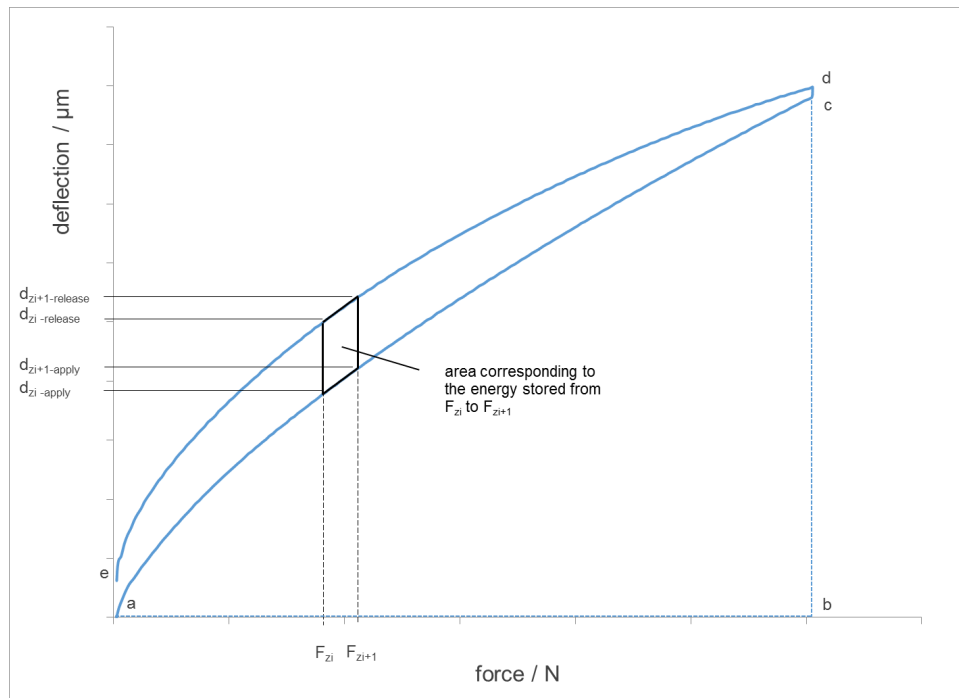
Corrected deflection value 0.5 second before the loading cycle.

3.5 EQUIVALENT HYDRAULIC PRESSURE (p_{eq})

Total applied force by the total piston hydraulic area.

3.6 HYSTERESIS PER CYCLE (h_{cycle}) (CYCLE HYSTERESIS)

Lag in deflection that occurs with brake pads and shims during the unloading condition compared to the loading condition. Hysteresis creates a loop in the deflection versus load curve and depends, among other parameters, on the load application rate, the dwell times, and the material under testing. Calculate hysteresis as the ratio (or percent) of the stored energy over the total input energy during the apply cycle. See Figure 1; use Equations 3 to 5.



Area a-b-c: total input energy during the apply cycle

Area a-c-d-e: total energy stored within the hysteresis loop

Figure 1 - Deflections and forces to calculate cycle hysteresis

$$h_{load} = \frac{E_{release} - E_{apply}}{E_{apply}} \quad (\text{Eq. 3})$$

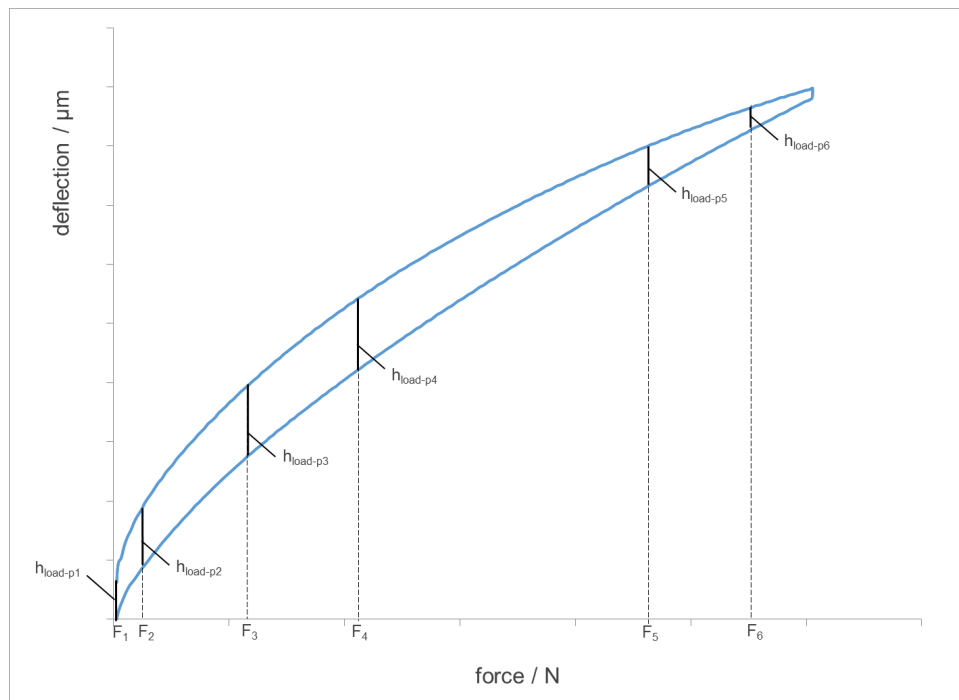
$$E_{apply} = \sum_{z=1}^n (F_{zi+1} - F_{zi})(d_{zi+1 \text{ apply}} + d_{zi \text{ apply}})/2 \quad (\text{Eq. 4})$$

$$E_{release} = \sum_{z=1}^n (F_{zi+1} - F_{zi})(d_{zi+1 \text{ release}} + d_{zi \text{ release}})/2 \quad (\text{Eq. 5})$$

3.7 HYSTERESIS AT LOAD (h_{load})

Lag in deflection that occurs with brake pads and shims during the unloading condition compared to the loading condition for a given equivalent hydraulic pressure (or force). Calculate hysteresis by subtracting the deflection apply step from the deflection during the release step for a given load. Use only the zeroed deflection d_z for this calculation. Alternatively, express h_{load} as a percent of the deflection during the apply step. Use Equation 6; see Figure 2.

$$h_{\text{load-i}} = d_{\text{zi release}} - d_{\text{zi apply}} \quad (\text{Eq. 6})$$



$F_1, F_2, \dots, F_6$: specific load steps or loads equivalent to specific hydraulic pressure levels

$h_{\text{load-p1}}, h_{\text{load-p2}}, \dots, h_{\text{load-p6}}$: hysteresis for load steps 1 to 6

Figure 2 - Deflections and forces to calculate hysteresis

3.8 LOAD CYCLE

Loading of the brake pad that occurs after the preload. For this test procedure, the load cycle uses a constant rate to apply load during the apply and release conditions, with a constant load dwell time at the maximum and the minimum loads.

3.9 MEASURED DEFLECTION (d_m)

Deflection measured during the test.

3.10 MACHINE DEFLECTION (d_e)

Deflection measured during the third cycle of the machine deflection test.

3.11 PISTON HYDRAULIC AREA (A_p)

Area of the caliper bore used to convert the test system's actuator load to equivalent hydraulic pressure. This area is generally larger than the area calculated using the outside diameter of the piston simulator.

3.12 PISTON SIMULATOR

Device to apply the load replicating the interface with the caliper pistons from the vehicle application.

3.13 PRELOAD

Steady-state load applied to the test sample before the load cycle.

3.14 ZEROED DEFLECTION (d_z)

Corrected deflection adjusted to 0.0 μm during the preload condition, 0.5 second before the loading cycle. Use Equation 7.

$$d_z = d_c - d_o \quad (\text{Eq. 7})$$

4. EQUIPMENT

Table 2 illustrates the requirements for test systems intended to perform compressibility testing per SAE J3079-2.

Table 2 - Minimum test system capabilities and specifications

Parameter	Minimum Requirement or Capability
The test facilities and equipment shall be in good working order and shall have a valid calibration label	Calibration records
Load capacity for hydraulic brake applications - approximately to allow a twin 60 mm piston simulator at 10000 kPa of equivalent system pressure	60 kN
Analog-to-digital converter for force measurement	16 bit minimum
Rate to apply the equivalent system pressure	1000 to 10000 kPa/s
Control of equivalent pressure at preload	± 5 kPa
Control of equivalent pressure at target load	± 10 kPa
Rated accuracy for instrumentation controlling equivalent system pressure	± 5 kPa
Signal noise for instrumentation controlling equivalent system pressure	≤ 5 kPa
Resolution of the deflection measuring device	± 0.1 μm
Force exerted on piston simulator by the deflection measuring device	≤ 1 N
Flatness and parallelism of steel plate	≤ 2 μm
Temperature control accuracy of heating platen	± 2 $^{\circ}\text{C}$
Sampling rate for force and deflection measurement	1 to 1000 Hz
Sampling rate for temperature measurement	1 to 50 Hz

4.1 Facilities

Test facility capable of maintaining test equipment and test hardware at $23^{\circ}\text{C} \pm 5^{\circ}\text{C}$ and $50\% \pm 10\%$ RH.

4.2 Test Stand

Test system with a uniaxial load frame, loading device, control system, and data acquisition that provides loading of the brake pad like it in a brake caliper assembly.

4.3 Alignment System

The test stand must have the self-alignment capability to allow the piston simulator to align its contact surface to the brake pad under test. The alignment system cannot cause additional compliance in the deflection measurements.

4.4 Deflection Measurement Device

Use a device for measuring piston simulator deflection with a resolution of ± 0.1 μm . The deflection measurement device shall exert less than 1.0 N of force during measurement.

NOTE: Accuracy in a range of one-tenth of a micron requires attention to cleanliness and validation that plates, adaptors, and test pieces do not contain burs and other contaminants.