Designation: F 403 – 98

Standard Test Method for Tires for Wet Traction in Straight-Ahead Braking, Using Highway Vehicles[1]

This standard is issued under the fixed designation F 403; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the accelerometer-based measurement of braking traction of tires designed for and mounted on cars or trucks without ABS equipped brakes traveling straight ahead on a wet or dry paved surfaces, snow, or ice.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 274 Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire[2]

F 457 Test Method for Speed and Distance Calibration of a Fifth Wheel Equipped with Either Analog or Digital Instrumentation[3]

F 538 Terminology Relating to the Characteristics and Performance of Tires[3]

F 811 Practice for Accelerometer Use In Vehicles for Tire Testing[3]

F 1650 Practice for Evaluating Tire Traction Performance Data Under Varying Test Conditions[3]

3. Terminology

3.1 *Definitions*

3.2 *braking force, [F], n*—of a tire, the negative longitudinal force resulting from braking torque application. **F 538**

3.3 *braking force coefficient, n*—of a tire, the ratio of braking force to normal force. **F 538**

3.4 *braking force coefficient, peak, n*—of a tire, the maximum value of tire braking force coefficient that occurs prior to wheel lockup as the braking torque is progressively increased. **F 538**

3.5 *braking force coefficient, slide, n*—of a tire, the value of braking force coefficient obtained on a locked wheel.

3.6 *braking torque, [ML^2/T^2], n*—of a vehicle, the negative wheel torque. **F 538**

3.7 *longitudinal force, [F], n*—of a tire, the component of a tire force vector in the X' direction. **F 538**

3.8 *normal force, [F], n*—of a tire, the component of a tire force vector in the Z' direction. **F 538**

3.9 *test run, n*—a single pass of a loaded tire over a given test surface. **F 538**

3.10 *tire-axis system, n*—the origin of the tire-axis system is the center of the tire contact. The X' axis is the intersection of the wheel plane and the road plane with a positive direction forward. The Z' axis is perpendicular to the road plane with a positive direction downward. The Y' axis is in the road plane, its direction being chosen to make the axis system orthogonal and right-hand.

3.10.1 *Discussion*—See Fig. 1. **F 538**

3.11 *tire forces, [F], n*—the external forces acting on a tire by the road. **F 538**

3.12 *torque, [FL], n*—of a wheel, the external torque applied to a tire from a vehicle about the wheel spin axis. **F 538**

3.13 *vertical load, n*—the normal reaction of the tire on the road which is equal to the negative of the normal force. **F 538**

4. Summary of Test Method

4.1 The measurements are conducted on either two front tires or as an option, one front and one rear tire positioned diagonally across the vehicle. Brakes are to be applied firmly until both test tires are locked and then held locked for a period of at least 1 s at speeds ranging from 20 mph (32 km/h) to 60 mph (96 km/h). The other wheels are free rolling.

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[1] This test method is under the jurisdiction of ASTM Committee F-9 on Tires and is the direct responsibility of Subcommittee F09.20 on Vehicular Testing.

Current edition approved Nov. 10, 1998. Published January 1999. Originally published as F 403 – 74. Last previous edition F 403 – 80.

[2] *Annual Book of ASTM Standards*, Vol 04.03.

[3] *Annual Book of ASTM Standards*, Vol 09.02.

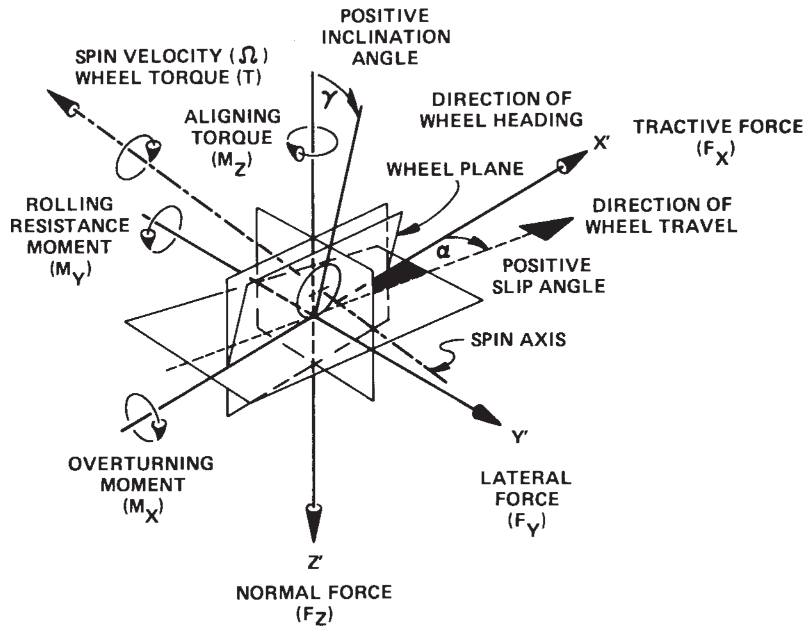

FIG. 1 Tire-Axis System

4.2 Recommended vehicle test speeds are: 20, 40, and 60 mph (32, 64, and 96 km/h). The maximum test speed selected for a given road surface texture and water film thickness should be below hydroplaning speed.

5. Significance and Use

5.1 The measured values are traction properties of tires in operation on a passenger car or light truck representative of the type on which the test tires would be used. These are obtained on a given road surface, under given environmental conditions (ambient and road surface temperature, humidity, wind speed and direction, purity, and film depth of water used to wet the road surface) in accordance with the stated test procedures and reflect the performance of the total vehicle-environmental system. A change in any one of these factors may change the measurements of a subsequent run of the test.

5.2 These test methods are suitable for research and development purposes, where tires are compared during a single series of tests. They may not be suitable for regulatory statutes or specification acceptance because the values obtained may not necessarily agree or correlate either in rank order or absolute traction performance level with those obtained on other road surfaces (or the same surface after additional wear), under other environmental conditions, or other test vehicles (especially if not representative of the normal usage of the test tires) or with results obtained with other test procedures.

6. Apparatus

6.1 *Test Vehicle*—The test vehicle shall be a rear-wheel drive, four-wheel passenger car or a light truck under 10 000 lbf (44.5 kN) GVW (gross vehicle weight), representative of the type on which the test tires are used.

6.2 *Instrumentation*:

6.2.1 *Accelerometer*, to measure longitudinal deceleration of the vehicle. The accelerometer shall have the following specifications:

6.2.1.1 Minimum frequency response: dc to 10 Hz.

6.2.1.2 Minimum full-scale range ±1.0 g,

6.2.1.3 Accuracy of ±0.01 g, and

6.2.1.4 Maximum cross-axis sensitivity of 0.002 g/g.

6.2.2 *Fifth Wheel*, to measure vehicle speed. The fifth wheel shall have the following specifications:

6.2.2.1 Minimum full-scale range of 100 mph (160 Km/h),

6.2.2.2 The magnitude of the bias shall be less than or equal to 1 mph (1.609 Km/h), and

6.2.2.3 A 95 % repeatability interval of $I(r)$ = 2 mph (3.218 Km/h).

6.2.3 *Tach-Generator*, to measure the revolutions per minute of each test wheel, installed on the vehicle. The tach-generator shall have the following specifications:

6.2.3.1 Minimum full-scale range of 0 to 1200 rpm (0 to 125.7 rps), and

6.2.3.2 The magnitude of the bias shall be ≤1 rpm (≤0.105 rps).

6.2.4 *Multichannel Recorder*, having the following specifications:

6.2.4.1 Minimum frequency response of dc flat (±1 %) to 30 Hz full scale,

6.2.4.2 Gain shall be sufficient to permit full-scale display for full-scale input signal level,

6.2.4.3 Input impedance shall be seven to ten times larger than the output impedance of signal source,

6.2.4.4 Must be insensitive to vibrations, acceleration and ambient temperature range. The error in reading shall not exceed 1 % of full scale when subjected to vibrational acceleration of 5 *g*'s in the 0.5 to 40-Hz frequency range and operating temperature range from 32 to 110°F (0 to 43°C).

6.2.4.5 Shall not be affected by storage temperature variations between −20 and +160°F (−29 and +71°C), and

6.2.4.6 Shall have a variable chart speed with at least 25 mm/s.

6.2.5 *Power Supply* for transducers and recorder, meeting requirements specified by transducers and recorder manufacturers.

7. Selection and Preparation of Test Tires

7.1 All test tires should be approximately of the same age and shall be stored essentially at the same conditions.

7.2 Test tires shall be trimmed to remove all protuberances in the tread area caused by mold air vents or flashes at mold junctions.

7.3 Test tires shall be mounted on Tire and Rim Association (T & RA)[4] recommended rims by using conventional mounting methods. Proper bead seating shall be assured by use of suitable lubricant and the subsequent warm-up procedures. Excessive use of lubricant should be avoided to prevent slipping of the tire on the wheel rim.

7.4 Test tires shall be balanced statically.

7.5 Test tires shall have a minimum of 50 miles (80 km) break-in at T & RA[4] load and inflation at speeds of 60 to 70 mph (96 to 113 km/h) without excessive cornering, braking, or acceleration to avoid uneven wear. The break-in is necessary to remove mold lubricant and mold sheen from tread surface. Break-in mileage should be accumulated on the front and rear axles equally for a given tire. New tire average wear prior to testing shall not exceed 10 % of the new tire tread depth.

7.6 Mounted test tires shall be placed near the test site in such a location that they all have the same ambient temperature prior to testing. Test tires should be shielded from the sun to avoid excessive heating by solar radiation.

7.7 Test tires shall be checked for specified pressure just prior to testing.

7.8 It is recommended that the sample size of test tires be a minimum of three sets (of two each).

8. Preparation of Apparatus

8.1 *Test Vehicle*:

8.1.1 Check the front wheels of the test vehicle loaded to the test weight prior to testing. Set alignment in accordance with the manufacturer's specifications.

8.1.2 Weigh the test vehicle prior to testing with a half-full tank of gasoline, instrumentation, and test personnel seated in the same locations as that to be used during testing. Adjust vehicle static weight by ballasting to match static wheel load specified for test tires. In no case shall the static wheel load exceed the maximum wheel load capacity of the vehicle. The load recommended by the T & RA[4] Yearbook for 26-psi (180-kPa) inflation pressure for a "*P*"-type tire or 24-psi (165-kPa) inflation pressure for an alphanumeric-type tire, shall be regarded as standard.

NOTE 1—In some cases it may not be possible to use static loads recommended by the T & RA[4] Yearbook, particularly on high-friction surfaces.

8.1.3 Install the test tires on the front wheels or on one front and one rear wheel diagonally. Use a pair of similar tires, not necessarily identical to test tires, on the wheels not undergoing test. Apply brakes only to test tires. The other tires remain free rolling.

8.1.4 For front-braked vehicles, rear brakes shall be inoperative; for diagonally braked vehicles, the wheels not undergoing tests shall have inoperative brakes.

8.2 *Instrumentation*:

8.2.1 Install the accelerometer in accordance with the manufacturer's specification and rigidly fix to the vehicle's sprung mass at or near its center of gravity such that it measures acceleration of the sprung mass in the direction parallel to the vehicle longitudinal axis and parallel to the ground plane at zero roll and pitch of the vehicle. It may be desirable to provide a hinge pivot in the mounting to permit a system calibration check.

8.2.2 Install the fifth wheel in accordance with the manufacturer's specifications and locate it as near as possible to the mid-track position on the vehicle. Record the output of the fifth wheel. Situate the output so that the test driver will be able to monitor the vehicle speed.

8.2.3 Install the tach-generators on the test wheels in accordance with the manufacturer's specifications (see 6.2.3).

9. Calibration

9.1 Conduct calibration of the accelerometer statically by tilting the accelerometer on the rotary table or another test fixture to incrementally increased or decreased angles with respect to a true horizontal plane and record the accelerometer output values for each angle value by observing the chart trace deflections on the recorder used in testing.

9.1.1 Set the rotary table at zero inclination.

9.1.2 Mount the accelerometer on the rotary table according to the manufacturer's specifications and adjust the amplifier or recorder setting, or both, until the chart trace reads zero.

9.1.3 Rotate the rotary table about horizontal axis to 10° (0.173 *g*) in a clockwise direction and record the chart table displacement.

9.1.4 Continue 9.1.3 at 30° (0.5 *g*), 45° (0.707 *g*), 60° (0.866 *g*), and 90° 00′ (1.0 *g*).

9.1.5 Rotate the rotary table from the 90° 00′ (1.0 *g*) position in a counterclockwise direction to 60° (0.866 *g*) angle and record the chart trace displacement in inches.

9.1.6 Continue to rotate the rotary table in the counterclockwise direction incrementally through the reverse sequence of angles specified in 9.1.3 and 9.1.4 until the initial zero value is reached.

9.1.7 Plot the values of longitudinal acceleration in *g*'s versus chart trace displacement.

9.1.8 Determine the value of static calibration constant *C*, the slope of the curve longitudinal acceleration versus chart trace displacement. Record calibration values, date of calibration, and model and serial number of accelerometer.

9.2 Calibrate fifth wheel in accordance with Method F 457.

9.3 *Tach-Generator Calibration*:

9.3.1 Calibrate the tach-generator in accordance with the manufacturer's specifications.

[4] Current Issue; available from the Tire and Rim Assn., 175 Montrose West Ave., Suite 150, Copley, OH 44321.

9.3.2 For front-braked vehicles equipped with radial tires on the rear, a tach-generator mounted in the transmission and calibrated to a fifth wheel may be used for speed measurements.

10. General Test Conditions

10.1 Conduct tests on a smooth and level surface. The surface shall have a uniform grade of not more than 2 % and shall not deviate more than 0.25 in. (6.35 mm) when tested with a 10-ft (3-m) straightedge.

10.2 The test surface shall be a pavement of uniform age, composition, and wear (Note 3). The test surface shall be free of loose material or foreign deposits.

NOTE 2—Uniformity of test surface, age, and composition shall be estimated by visual inspection.

10.3 Water the test surface at least ½ h prior to testing in order to equalize the surface temperature and water temperature.

10.4 Measure the skid number of the test surface in accordance with Test Method E 274 at 40 mph (64 km/h).

10.5 Apply the minimum amount of water necessary to keep the test surface uniformly wet through testing. The amount of water shall be sufficient to keep the tops of protruding asperities wet and shall be the same depth for every test.

10.6 Do not conduct the test when wind conditions interfere with wetting of the test surface as specified in 10.5.

11. Procedure

11.1 Mark with pylons or other identification marks a point on the course at which the transmission should be set in neutral prior to brake application.

11.2 Water the test surface at least ½ h prior to testing. Apply the minimum amount of water necessary to keep the test surface uniformly wet.

11.3 Condition the test surface by making a minimum of 20 test runs at the test speed to stabilize the surface.

11.4 Record ambient temperature, surface temperature, wind velocity, and wind direction with respect to the path of vehicle travel.

11.5 Approach the test site in a straight line at a speed of 4 to 8 mph (6 to 13 km/h) above the nominal test speed.

11.6 Shift the transmission into neutral and turn on the recorder.

11.7 Apply the brakes after the nominal speed is reached. The rate of brake application should be such as is necessary to produce an increase of initial deceleration at the rate of 1 to 3 *g*'s/s. A brake applier, needle valve in the brake line, or any other device can be used where necessary to improve consistency of brake application and meet the requirements in Section 11.

11.8 Continue to apply brakes until both test wheels (both front wheels in case of front-wheel braking or one front and one rear wheel in case of diagonal braking) are locked (Note 3) and then hold locked for a period of at least 1 s at speeds ranging from 20 to 60 mph (32 to 96 km/h).

NOTE 3—Locking of the test wheels is indicated on the tach-generator or other lockup indicators used in testing.

11.9 Release brakes.

11.10 Turn off recorder.

11.11 Repeat 11.5 to 11.10 ten times (five in each direction) at each test speed and each test surface.

11.12 Test consecutive sets of tires by repeating 11.6 to 11.11 provided that the water is not turned off and the tests are completed within 1 day.

11.13 One set of test tires shall be designated as a control set. Test the control tires adjacent to each set of test tires for example in the sequence CTTCTTC.... etc., where C = control and T = test tire.

12. Calculations and Interpretations of Test Results

12.1 Read from the oscillograph record the following values of vehicle responses shown in Fig. 2; peak deceleration, slide

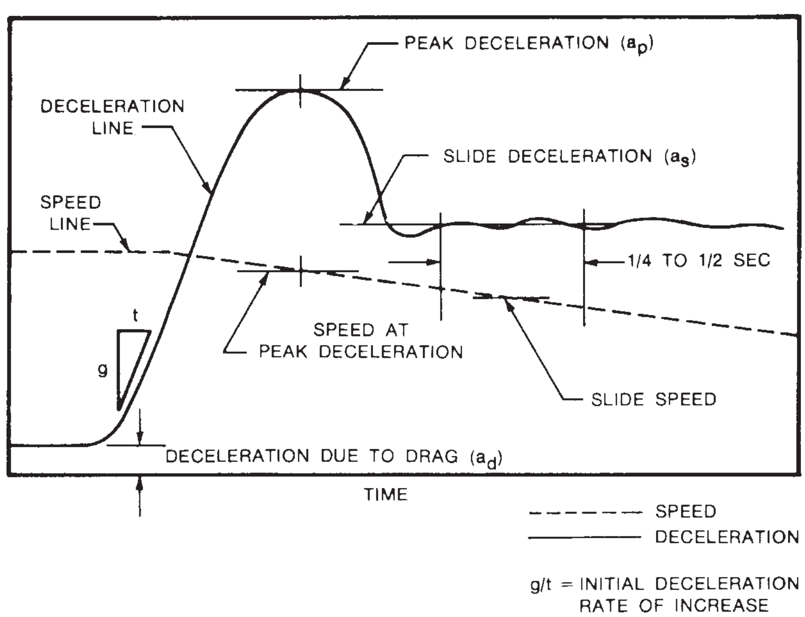

FIG. 2 Tire Traction-Braking

deceleration, deceleration due to drag, speed corresponding to peak, and slide values of vehicle deceleration. The slide value of vehicle deceleration is determined as an average value read from oscillographic trace during the time interval of ¼ to ½ s after peak traction has been attained. When a digital peak and slide deceleration indicator is used, read the peak and slide deceleration values directly from the indicator.

12.2 When front-wheel braking is used, compute the peak or slide values of braking coefficient as follows:

$$\mu = \frac{a - a_d}{W_f/W + (a - a_d)(h/l)} \quad (1)$$

where:
μ = braking coefficient peak or slide, respectively,
μ_p = peak value,
μ_s = slide value,
a = either vehicle deceleration at peak or during slide, g,
a_d = drag deceleration, g,
W = total vehicle weight, lb,
W_f = static front vehicle weight, lb,
h = vehicle's center of gravity height, in., and
l = vehicle's wheel base, in.

When diagonal-wheel braking is used, determine the peak and slide values of braking coefficient directly from the measured peak and slide values of vehicle deceleration as follows:

$$\mu = 2(a - a_d) \quad (2)$$

where:
a = vehicle deceleration peak or slide, respectively, g, and
a_d = drag deceleration.

12.2.1 The peak values of braking coefficient computed from vehicle deceleration frequently may deviate from their true value, that is, the value actually existing at the tire. Deviations may result because the values of circumferential deformation of each test tire, at which the peak values are reached, may not necessarily occur at the same time. This will tend to lower the peak values of vehicle deceleration. In the case of diagonal braking, additional discrepancies in peak values may be caused by the difference between front and rear brakes (disk versus drum).

12.2.2 Furthermore, peak and slide values of braking coefficient computed from vehicle deceleration values obtained from diagonal braking may be influenced by poorly controlled water depths on the rear tire and the effects of anti-dive and anti-lift suspension properties. These suspension properties may produce a deviation of dynamic wheel loads from static loads used in computation of traction coefficients. Thus, front-wheel braking is preferred to diagonal braking and the latter shall be considered an optional procedure.

12.3 Calculate the average peak values $\bar{\mu}_{pt}$ and $\bar{\mu}_{pc}$ of peak braking coefficient for ten repeated runs for each set of test and control tires for each test condition.

12.4 The values of peak braking coefficient tend to show a decline in time when testing proceeds over a period of several hours or days. The most common reason for this is test pavement polishing. To offset this trend in test tire performance, it is recommended that the values of peak braking coefficient of test tires shall be adjusted by comparing them to the corresponding values of control tires. Procedure for adjustment of values of peak braking coefficient due to time trends is shown in 12.5 through 12.10 as follows.

12.5 Plot the average values μ_{pt} and μ_{pc} of peak braking coefficient calculated in 12.3 for each set of test and control tires versus their consecutive order of testing for each day separately as shown in Fig. 3.

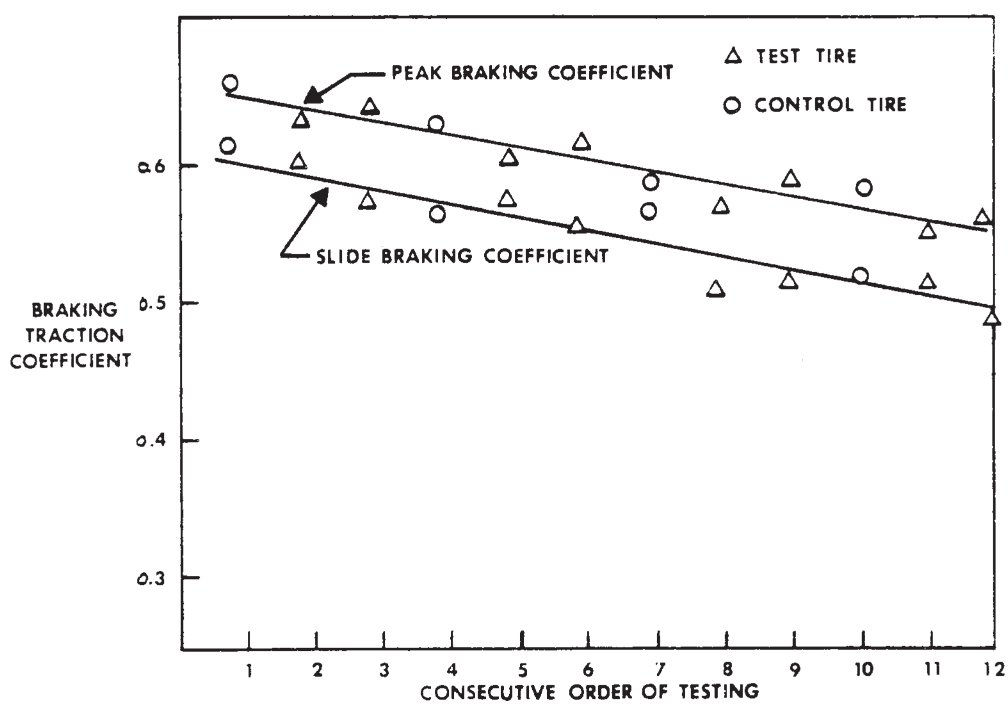

FIG. 3 Effect of Environmental Factors on Braking Traction

12.6 Perform linear regression analysis of each day's data points for control tires only and plot regression line through these points.

12.6.1 Calculate the values of coefficients a_p and b_p for regression equation:

$$M_{pc} = a_p + b_p m \quad (3)$$

where:

M_{pc} = predicted value of peak braking coefficient for control tire,
a_p = intercept,
b_p = slope, and
m = consecutive run numbers of data points for test or control tires (m = 1, 4, 7, 10, 13...for control tire and m = 2, 3, 5, 6, 8, 9, 11, 12...for test tire).

12.6.1.1 The values of *a* and *b* are computed as follows:

$$a_p = \frac{1}{n}\left(\sum_{m=1,4...}^{m_{max}} \mu_{pcm} - b_p \sum_{m=1,4...}^{m_{max}}\right) \quad (4)$$

$$b_p = \frac{n \sum_{m=1,4...}^{m_{max}} m\bar{\mu}_{pcm} - \sum_{m=1,4...}^{m_{max}} m \sum_{m=1,4...}^{m_{max}} \bar{\mu}_{pcm}}{n \sum_{m=1,4...}^{m_{max}} m^2 - \left(\sum_{m=1,4...}^{m_{max}} m\right)^2} \quad (5)$$

where n = total number of data points for control tire only.

12.6.2 Calculate the grand mean peak value $\bar{\mu}_{pc}$ of the average value $\bar{\mu}_{pc}$ of peak braking coefficient, determined in 12.3 for control tire, by averaging the values of $\bar{\mu}_{pc}$ over the whole test (several days).

12.7 Calculate from regression equation shown in 12.6.1 the predicted value μ_{pc} of each day's peak braking coefficient for control tires for the data points of test tires.

$$m = 2, 3, 5, 6, 8, 9, 11, 12. \quad (6)$$

12.8 Correct the average values $\bar{\mu}_{pt}$ of peak braking coefficient for the test tire determined in 12.3 for environmental changes by multiplying these values by the ratio $\bar{\mu}_{pc}/\mu_{pc}$ by using the values $\bar{\mu}_{pc}$ and μ_{pc} calculated in 12.6.2 and 12.7, respectively.

12.9 Calculate the average values $\bar{\mu}_{pc}$ and $\bar{\mu}_{sc}$ of slide braking coefficient for 10 repeated runs, for each set of test and control tires for each test condition.

12.10 The values of slide braking coefficient tend to show a decline in time when testing proceeds over a period of several hours or days. This time trend is similar to that shown in 12.4 for peak braking coefficient. Procedure for adjustment of values of slide braking coefficient due to time trends is shown in 12.11 through 12.14.

12.11 Plot the average values $\bar{\mu}_{pc}$ and $\bar{\mu}_{sc}$ of slide braking coefficient calculated in 12.9 for each set of test and control tires for each day separately in a manner similar to that shown in Fig. 3 for peak braking coefficient.

12.12 Perform linear regression analysis of each day's data points for control tires only and plot regression line through these points.

12.12.1 Calculate the values of coefficients a_s and b_s for regression equation:

$$M_{sc} = a_s + b_s m \quad (7)$$

where:

M_{sc} = predicted value of slide braking coefficient for control tire,
a_s = intercept,
b_s = slope, and
m = consecutive run numbers of data points for test or control tires (m = 1, 4, 7, 10, 13...for control tires and m = 2, 3, 5, 6, 8, 9, 11, 12...for test tires).

The values of a_s and b_s are computed as follows:

$$a_s = \frac{1}{n}\left(\sum_{m=1,4...}^{m_{max}} \mu_{scm} - b_s \sum_{m=1,4...}^{m_{max}} m\right) \quad (8)$$

$$b_s = \frac{n \sum_{m=1,4...}^{m_{max}} m\bar{\mu}_{scm} - \sum_{m=1,4...}^{m_{max}} m \sum_{m=1,4...}^{m_{max}} \bar{\mu}_{scm}}{n \sum_{m=1,4...}^{m_{max}} m^2 - \left(\sum_{m=1,4...}^{m_{max}} m\right)^2} \quad (9)$$

where n = number of data points for control tire only.

12.12.2 Calculate the grand mean value $\bar{\mu}_{sc}$ of the average value $\bar{\mu}_{sc}$ of slide braking coefficient determined in 12.9 for control tire by averaging the values of over the whole test (several days).

12.13 Calculate from regression equation shown in 12.12.1 the predicted value of each day's slide braking coefficient for control tires for the data points of test tires.

$$m = 2, 3, 5, 6, 8, 9, 11, 12. \quad (10)$$

12.14 Correct the average values μ_{st} of braking coefficient for the test tires determined in 12.9 for environmental changes by multiplying their values by the following ratio:

$$\bar{\mu}_{sc}/\mu_{sc} \quad (11)$$

13. Report

13.1 State that the test was performed in accordance with Test Method F 403.

13.2 Tabulate the corrected average peak and slide values of braking coefficient following the format shown in Fig. 4.

14. Precision and Bias

14.1 *Precision*—Data are not yet available for making a statement on the repeatability or reproducibility of this test method.

14.2 *Bias*—There are no standards or reference values with which the results of this test method can be compared. The function of the test method as indicated in 14.1 is to be able to make comparisons among types of tires tested within the same test program. It is believed that the results of the test method are adequate for making such comparisons without external reference to assessing bias.

TRACTION TEST IN STRAIGHT AHEAD BRAKING (ASTM F- 403)

Vehicle Data Front Wheel ☐ Diagonal Wheel ☐

Make, Year, Model, Type ______

Engine ______

Static Wheel Load LF ______ RF ______ LR ______ RR ______

Road Surface Description

Surface Type ______ Skid Number (E-274) ______

Environmental Data

Ambient Temperature ______ Road Surface Temperature ______

Wind Velocity and Direction ______

Tire Data (Individual test run data)

Type	Make	Size	Braking Traction Coefficient		Relative Braking Traction in %		Rank	Test Speed
			Peak	Slide	Peak	Slide		
Average								

FIG. 4 Data Recording Format