GM WORLDWIDE ENGINEERING STANDARDS	**Test Procedure** **Chassis**	**Draft** **GMW15208**

Tire Braking Traction

1 Scope

Note: Nothing in the specification supersedes applicable laws and regulations unless specific exemption has been obtained.

Note: In the event of conflict between the English and domestic language, the English language shall take precedence.

1.1 Purpose. The purpose of this test procedure is to describe a method to determine the braking traction performance of passenger and light truck tires under specified conditions.

This procedure describes the test equipment, test conditions, and test tire preparation requirements.

1.2 Foreword.

1.2.1 This test uses a tow vehicle and a two-wheel test trailer with a specially instrumented axle to measure the fore-aft and vertical forces on a tire during braking. Test wheel speed and vehicle speed are also measured.

1.2.2 The procedure is used primarily for determining the braking traction performance of a tire relative to a specified control tire or to other tires tested under similar test conditions.

1.3 Applicability.

1.3.1 This test procedure provides a method to determine the braking traction performance of passenger and light truck tires under specified conditions.

1.3.2 The measured surface friction values obtained with the equipment and procedures stated herein may not necessarily agree or correlate directly with those obtained by other surface friction measuring devices.

1.3.3 Specifications in this procedure refer to an Industry defined 2K Skid Trailer Measurement System capable of 2000 lbf Vertical Test Load.

2 References

Note: Only the latest approved standards are applicable unless otherwise specified.

2.1 External Standards/Specifications.

ASTM E-1136	ASTM E-274
ASTM E-1337	ASTM F-377
ASTM F-408	ASTM E-556
ASTM F-457	ASTM E-867
ASTM D-2240	

2.2 GM Standards/Specifications.

2.3 Additional References. Tire and Rim Association (T&RA) Year Book, Current Issue, Tire and Rim Association, 3200 W. Market Street, Akron, OH, 44313.

3 Resources

3.1 Facilities.

(Refer to 4.2.1 Environmental Conditions)

3.2 Equipment.

3.2.1 The test vehicle system consists of a specially fabricated test trailer and tow vehicle.

3.2.1.1 Tow Vehicle: The tow vehicle shall have the capability of towing and maintaining the trailer at specified test speeds in the prescribed range. Speeds are to be kept constant to within specified limits through all levels of application of braking forces. The tow vehicle also serves as a test control and data readout center.

3.2.1.2 Towed Trailer: The test trailer is instrumented to measure the vertical and longitudinal forces at the tire/test surface interface with braking torque applied. The rate of brake application shall be sufficient to control the time interval between the brake application and peak braking force to be between specified tolerances.

3.2.1.3 Vertical Load: The trailer design must allow application of specified static vertical loads on the test wheel and a static down load of 10% to 15% of the static vertical load at the hitch point.

3.2.2 Test Control Tolerances

3.2.2.1 Test Load: ± 22 N (± 5 lbf)

3.2.2.2 Test Speed: ± 0.8 kph (± 0.5 mph)

3.2.2.3 Brake application time interval between initial brake application and peak braking force: 0.5 to 1.0 seconds

3.2.2.4 External Water Depth: 1.25 mm ±0.25 mm (0.050 inches ±0.010 inches) above surface texture depth

3.2.2.5 Test Trailer Suspension: Each of the trailer wheels shall have a suspension capable of holding toe and camber changes to within ±0.05° with maximum vertical suspension displacements under both static and dynamic conditions.

3.2.3 Instrumentation

3.2.3.1 The instrumentation system shall conform to the following overall requirements at operating temperatures between 4 °C and 38 °C (40 °F and 100 °F)

3.2.3.2 Overall system accuracy: ± 1.5% of applied load from 890 N (200 lbf) to full scale; for example, at 890 N (200 lbf), applied calibration force of the system output shall be determinable within ± 13 N (± 3 lbf).

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

3.2.3.4 Braking Forces: The braking force measuring transducer shall measure longitudinal reaction force within a range between 0 and 8.9 kN (0 and 2000 lbf) generated at the tire-pavement interface as a result of brake application. The tire force-measuring transducer shall be of such design as to measure the tire-pavement interface force with minimum inertial effects. Transducers are recommended to provide an output directly proportional to force with hysteresis less than 1% of the applied load, nonlinearity less than 1% of the applied load up to the maximum expected loading, and sensitivity to any expected cross-axis loading or torque loading less than 1% of the applied load. The force transducer shall be mounted in such a manner as to experience less than 1° angular rotation with respect to its measuring plane at the maximum expected loading.

3.2.3.5 Vertical Load: The vertical load measuring transducer shall measure the vertical load at the test wheel during brake application. The transducer shall have the same specifications as those described in 3.2.3.4

3.2.3.6 Vehicle speed measuring transducers such as "fifth wheel" or a free-rolling wheel coupled tachometer shall provide speed resolution and accuracy of ± 0.4 kph (± 0.25 mph). Output shall be directly viewable by the driver and shall be simultaneously recorded. Fifth wheel systems shall conform to ASTM Method F-457.

3.2.3.6.1 Test wheel speed measuring transducers attached to the wheel spindle shall provide speed resolution and accuracy of ± 0.4 kph (± 0.25 mph) during all transient braking torque applications.

3.2.3.6.2 All speed signal conditioning and recording equipment shall provide linear output and shall allow data reading resolution to meet the requirements of 3.2.3.6 and 3.2.3.6.1.

3.2.3.7 All strain-gage transducers shall be equipped with shunt calibration resistors or equivalent that can be connected before or after test sequences. The resultant shunt calibration signal shall be at least 50% of the normal vertical load and shall be recorded.

3.2.3.8 A digital data acquisition system shall be employed to record the unfiltered braking force, vertical load, test wheel speed, and vehicle speed analog outputs. All data channels should be sampled (as close to simultaneous as possible to minimize phase shifting) at 100 samples per second.

Note: Vehicle speed can be analog filtered to remove noise if necessary for meter read out, etc since this is basically a steady-state signal.

3.3 Test Vehicle/Test Piece.

3.3.1 Control Tire. ASTM Standard Reference Test Tire: A Uniroyal P195/75R14 standard test tire defined by ASTM E-1136 specification.

3.3.2 Test Tires- Test pieces provided by requestor.

3.4 Test Time.

3.5 Test Required Information.

- Tire Size
- Tire Manufacturer
- Test Rim Width
- Test Load
- Test Pressure
- Test Speed
- Test Type (Peak only or Peak/Slide)
- Test Surface
- Test Surface Condition
- Test Environmental Requirements

3.6 Personnel/Skills.

4 Procedure

The braking traction measurements are conducted with a test tire mounted on the test trailer towed by a vehicle. The trailer contains a transducer, instrumentation, and actuation controls for the braking of the test tire.

The test apparatus is brought to specified test speed. The brake is progressively applied until sufficient torque results to exceed the maximum tire braking force (peak traction). The brakes can then be immediately released for peak only (or chirp) tests, or locked up to allow sliding traction measurements. Longitudinal force, vertical load, test wheel speed, and vehicle speed are recorded with the aid of suitable instrumentation and data acquisition equipment.

The Slide and/or Peak braking coefficients of the tire/road surface are determined for each application of brake torque.

4.1 Preparation.

4.1.1 Test Tires Preparation and Use

4.1.1.1 Insofar as it is possible in tests comparing tire design structures and/or materials, all test tires should be approximately of the same age and shall have been stored at essentially the same conditions.

4.1.1.2 Prior to testing, test tires should be stored in a moderate temperature environment and be protected from excessive heating by solar radiation.

4.1.1.3 Mount test and control tires using conventional mounting methods on the appropriate test rim as specified in 4.2.2.3. Care should be taken to use rims with the correct offset to account for possible test trailer transducer offset sensitivity. Care should also be taken to appropriately mount directional tires.

Caution: Assure proper bead seating by the use of a suitable lubricant. However, excessive use of lubricant should be avoided to prevent slipping of the tire on the wheel rim.

4.1.1.4 Remove mold vent and flash protuberances from tread surfaces of test and control tires. Test and control tires should not have any force or run out grind. Tread labels should be removed.

4.1.1.5 Check the test tires for the specified inflation pressure at ambient temperature, cold, just prior to testing. The test tire inflation pressure shall be as specified in 4.2.2.2.

4.1.1.6 All test tires shall be preconditioned prior to initial testing. Pretest conditioning is to be done only once per tire and prior to any actual test measurements. This process is recommended to minimize test variability caused by transient, non-preconditioned, tire braking performance.

4.1.1.6.1 Pretest tire conditioning shall be conducted on a dry and level surface. Each tire shall be chirped ten (10) times at 32 kph (20 mph) under test load. It is recommended that these chirps be applied and recorded under normal test control mode (not manual mode) for consistency of brake apply and to provide reference for actual test setup.

4.1.1.7 Measure and record durometer of each tire prior to break in, including control tires**.** (reference ASTM D-2240 procedure)

4.2 Conditions.

4.2.1 Environmental Conditions.

4.2.1.1 Standard Test Surfaces
Braking traction tests for TPC qualification are conducted on the following surfaces:

4.2.1.1.1 Dry test surface: A clean, level or slightly graded, well maintained coarse aggregate asphaltic concrete such as Michigan Highway Department 31-A or Texas Highway Department Type D road surface designation. The peak and slide coefficients of this surface are recommended to be as follows when measured with the ASTM E-1136 tire at 64 kph:

64 kph peak coefficient: 0.90 +/-0.05

64 kph Slide coefficient: 0.65 +/-0.05

4.2.1.1.2 Wetted Test Surface: A clean, level or slightly graded, concrete or asphaltic concrete which has been constructed or modified to exhibit the following recommended peak and slide coefficients when measured with the ASTM E-1136 tire:

32 kph peak coefficient: 0.52 +/-0.05

32 kph slide coefficient: 0.31 +/-0.05

97 kph peak coefficient: 0.39 +/-0.05

97 kph slide coefficient: 0.22 +/-0.05

4.2.1.1.2.1 Adequate wind fence protection must be provided to minimize the influence of wind on water distribution.

4.2.1.1.2.2 The wetted surface watering distribution system must provide adequate water depth control. Water depth must be maintained at 1.25 mm ± 0.25 mm (0.050 ± 0.010 inches) above surface texture depth.

4.2.1.1.2.3 Water Depth: The water depth measurement must be accurate to within ± 0.125 mm (± 0.005 inches).

4.2.2 Test Conditions.

Note: Hard Metric Tires are tested as P-Metric unless specified otherwise.

Note: Deviations from the requirements of the procedure shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

4.2.2.1 Load:

- **Passenger Car:** 85% of the 180 kPa (26 psi) load in T&RA manual.
- **Light Truck Metric**: 5560 N (1250 lbs).
- **Compact Spare**: 70% of the 420 kPa (60 psi) load in the T&RA Manual.
- **Light Truck Passenger**: 85% of the 180 kPa (26 psi) load in T&RA manual or 5560 N (1250 lbs), whichever is less.
- **ASTM E-1136 Control Tire**: 4586N (1031 lbs)

4.2.2.2 Inflation Pressure:

- **Passenger Car:** 241 kPa (35 psi).
- **Light Truck Metric**: 345 kPa (50 psi).
- **Compact Spare**: 414 kPa (60 psi).
- **Light Truck Passenger**: 241 kPa (35 psi).
- **ASTM E-1136 Control Tire**: 241 kPa (35 psi) cold

4.2.2.3 Test Rim Width:

- As specified by test engineer ± 0.5 inches.
- **ASTM E-1136 Control Tire**: 5.5 ± 0.5 inches.

4.2.2.4 Normal Tests. All candidate tires of one construction should normally be evaluated for 32 kph and 97 kph wet traction performance prior to testing the same tires for dry traction performance. This test sequence procedure should be used for all wet and dry testing to minimize test variability caused by new tire burnish effects. An analysis of the wet traction data for test variability compliance should be done before the tires are used for dry testing (Appendix A). This will permit the tires to be retested for wet traction before the dry testing is conducted. The same physical tire should be tested for both wet and dry traction.

4.2.2.5 Special Tests. A special tire braking traction test may include variations in test load, tire inflation pressure test speed, test surface or surface conditions.

4.3 Instructions.

4.3.1 Warm up electronic test equipment as required for stabilization.

4.3.2 If external watering is used, apply water to the test surface at least one-half hour prior to testing in order to stabilize the water flow and surface temperature. Caution: Do not test when wind conditions interfere with wetting of the surface as specified in 4.2.1.1.2.

4.3.3 Install a test tire in the test position on the test trailer. A tire with a similar loaded radius and high cornering properties should be used on the opposite side to level the axle and to minimize trailer yaw during brake torque application (Recommended off side tire should have OD within ± 13 mm [1/2 inch] of test tire OD).

4.3.4 Check and, if necessary, adjust the test trailer static weight on the test tire to the value specified in 4.2.2.1.

4.3.5 Check and adjust tire inflation pressure as required immediately before testing to the specified value in 4.2.2.2.

4.3.6 When testing on an externally wetted test surface, offset the trailer test wheel sufficiently to prevent tracking of the towing vehicle. An offset distance of 305 to 406 mm (12 to 16 inches) is suggested. The test wheel offset should be outboard of the tow vehicle.

4.3.7 Record tire identification and other pertinent data as detailed in 5.3. On externally wetted surfaces, measure the water depth with a variable height probe type device to meet requirements of 4.2.1.1.2.2.

4.3.8 Adjust trailer and/or truck ride height to null any components of the vertical load, which are introduced into the fore aft channel.

4.3.9 Record electrical calibration signals prior to and after testing each surface, or as needed to ensure valid data.

4.3.10 Perform pretest tire conditioning as described in 4.1.1.6 if using a new tire.

4.3.11 Normalize test wheel speed to vehicle speed prior to conducting any tire test. This is to allow accurate calculation of % slip by accounting for changes in RPK with test tire size.

4.3.12 Conduct the test at the required test vehicle speed. Take at least eight measurements (10 recommended) of the coefficients of interest for each test condition (eg. Slide and/or peak).

4.3.13 Control Tire: Run a control tire at the beginning and end of each test sequence and every third test in between. For example, C_1, T_1, T_2, C_2, T_3, T_4, C_3, where *C* represents a control tire and *T* represents a test tire.

4.3.14 Notes:

For Peak/Slide testing: A single control tire may be tested wet repeatedly up to seven times as long as the tread surface maintains a new appearance. This number will vary with test surfaces. Control and test tires should only be tested once on dry surfaces.

For Peak Only (Chirp) Testing: Control and test tires can be tested multiple times on wet or dry surfaces. The number will vary with test surface and surface condition, but should usually be limited to 30 brake applies or until significant visible tread pattern scuffing or other damage.

Misc: Additional candidate tires (> 2) may be tested between control tires for dry tests assuming test conditions remain stable and time between control tire tests is minimized.

4.3.15 Three tires of each candidate construction should be tested, preferably on different days, under each of the specified test conditions.

5 Data

5.1 Calculations.

Note: The peak and slide braking coefficient shall be determined for each run (brake application).

Note: Coefficient vs % Slip values are calculated for each individual run (brake application) up to 90% slip or maximum % slip obtained. The individual Coefficient vs % Slip data is then used to calculate Composite Coefficient vs % Slip summaries.

5.1.1 Filtering

5.1.1.1 Digitally filter the digitized input analog signals of braking force, vertical load, test wheel speed, and vehicle speed using a five (5) point moving average technique.

5.1.1.2 Digital Filtering Methodology. Calculate an average value for the first five digital data points. Drop the first data point and add the sixth data point, calculate another five (5) point average value. Repeat this procedure for all remaining data points. This sequence is done individually on all the above digitized input analog signals. The following example computations illustrate the method using one channel.

(pt1 + pt2 + pt3 + pt4 + pt5)/5 = PT1

(pt2 + pt3 + pt4 + pt5 + pt6)/5 = PT2

(pt3 + pt4 + pt5 + pt6 + pt7)/5 = PT3

5.1.1.3 A new set of data points (indicated by capital letters) are then defined to represent the filtered data for each channel i.e., (Avg $pt_x = PT_y$).

PT1, PT2, PT3, etc. - tractive force

PT1, PT2, PT3, etc. - vertical force

5.1.2 Determining and Calculating Peak Braking Coefficient

5.1.2.1 Using the digitally filtered data, *PT1, PT2, PT3,* etc., scan the longitudinal channel and determine the highest absolute filtered value, PT_y, prior to wheel lock up. Calculate an average peak braking force value using the highest filtered value, PT_y, and one filtered point directly before, PT_{y-1}, and directly after it, PT_{y+1}. This three point average is the peak braking force value developed for this individual lock up.

5.1.2.2 Determine the vertical load value from its respective digitally filtered data that corresponds to the highest absolute value for braking force, from 5.1.2.1. Calculate an average vertical load value using this corresponding value and one point directly before and directly after it. This three point average is the vertical load value that corresponds to the average peak braking force for this individual lock up.

5.1.2.3 Calculate the peak braking coefficient by dividing the three point average peak braking force, determined from 5.1.2.1 by the three point average vertical load, as determined in 5.1.2.2 The peak braking coefficient should be reported to three (3) decimal places.

5.1.2.4 For each test, the mean and standard deviation for peak braking coefficient are calculated from the individual peak determinations.

5.1.2.5 Individual peak coefficients are deleted if they fall outside the mean ± 1.5 standard deviations.

5.1.2.6 The average peak coefficient and standard deviation are recomputed after any deletions, as outlined in 5.1.2.5.

5.1.3 Determining and Calculating Slide Braking Coefficient

5.1.3.1 The digitized input values for the braking force and vertical load are summed for one second, beginning 0.2 s after test wheel lockup. Calculate an average braking and vertical value using the cumulative sums.

5.1.3.2 Calculate the slide braking coefficient by dividing the one second average slide braking force by the one second average vertical load.

5.1.3.3 For each test, the mean and standard deviation for slide braking coefficient are calculated from the individual slide determinations.

5.1.3.4 Individual slide coefficients are deleted if they fall outside the mean ±1.5 standard deviations.

5.1.3.5 The average slide coefficient and standard deviation are recomputed after any deletions, as outlined in 5.1.3.4.

5.1.4 Control Tire Technique.

5.1.4.1 In conducting tire traction tests, every effort is made to hold non-interest variables constant in order to minimize errors caused by changes in these variables. However, the present state of the art still requires usage of a "control tire." A control tire (as defined in section 7) is repeatedly tested during a day's running to monitor changes in these variables. Test tire coefficients are then adjusted using "control tire" information to account for possible test condition changes induced by uncontrolled variables.

5.1.4.2 The technique presently used for applying "control tire" information is to correct all test tires tested between any two control tire tests by the ratio of the weighted overall control tire mean to the weighted mean of the two adjacent control tires.

5.1.4.3 The weighted control tire peak and slide data is based on the variability and number of test runs for each individual control tire data entry. In other words, the more variable control tire data will receive less weight in the weighted averages. For example, assuming a test sequence of:

a. Control Tire (C_1)
b. Test Tire (T_1)
c. Test Tire (T_2)
d. Control Tire (C_2)
e. Test Tire (T_3)
f. Test Tire (T_4)
g. Control Tire (C_3)

5.1.4.3.1 Weighted Control Tire Average (C avg.) =

$$\frac{C_1\frac{\sqrt{N_1}}{\sigma_1}+C_2\frac{\sqrt{N_2}}{\sigma_2}+C_3\frac{\sqrt{N_3}}{\sigma_3}}{\frac{\sqrt{N_1}}{\sigma_1}+\frac{\sqrt{N_2}}{\sigma_2}+\frac{\sqrt{N_3}}{\sigma_3}}$$

5.1.4.3.2 Weighted Control Tire Average (C_{12}) **=**

$$\frac{C_1\frac{\sqrt{N_1}}{\sigma_1}+C_2\frac{\sqrt{N_2}}{\sigma_2}}{\frac{\sqrt{N_1}}{\sigma_1}+\frac{\sqrt{N_2}}{\sigma_2}}$$

5.1.4.3.3 Weighted Control Tire Average (C_{23}) =

$$\frac{C_2\frac{\sqrt{N_2}}{\sigma_2}+C_3\frac{\sqrt{N_3}}{\sigma_3}}{\frac{\sqrt{N_2}}{\sigma_2}+\frac{\sqrt{N_3}}{\sigma_3}}$$

5.1.4.3.4 Test tires T_1 and T_2 would be corrected by

$$T_1*\frac{C_{avg}}{C_{12}} \text{ or } T_2*\frac{C_{avg}}{C_{12}}$$

5.1.4.3.5 Test tires T_3 and T_4 would be corrected by

$$T_3*\frac{C_{avg}}{C_{23}} \text{ or } T_4*\frac{C_{avg}}{C_{23}}$$

Where C or T = Control tire or test tire sample mean value
σ = sample standard deviation
N = sample size

5.1.4.3.6 The test tire ratings are then determined by dividing the adjusted test tire coefficients by the overall mean control tire coefficient. The overall control tire mean is computed using the sum of all control tires multiplied by their respective sample size divided by the total control tire sample size.

$$\text{Example: } \frac{C_1*6 + C_2*8 + C_3*7}{6+8+7}$$

5.1.4.3.7 Good judgement in application of this technique is assumed. If variations in control tire values were observed that cannot be accounted for, or if test tire data is "corrected" more than approximately 5%, the entire test should be repeated.

5.1.5 Coefficient vs % Slip Calculations

Values for coefficient of friction vs percent slip are calculated using the filtered data (see 5.1.1). Coefficients (Y) at Integer % Slip values (X) are interpolated from the filtered real time coefficients corresponding to filtered % Slip points which bracket the desired X % Slip. The individual coefficients at X % Slip for multiple runs (brake applies) can then be averaged for composite values.

5.2 Interpretation of Results.

5.2.1 Tire Design Acceptance

Note: See Appendix A for detailed Specification Compliance Process.

5.2.1.1 A three (3) tire test sample is required for development tire submission data being entered into the Global Tire Database. A two (2) tire sample may be accepted for supplemental or comparative tire data.

5.2.1.2 It is the responsibility of each tire supplier to statistically compare test sample variability against their respective historical test variability prior to submitting test data to GM. A chi-squared Analysis of Variance should be used at 95% confidence level. If the analysis indicates that the sample variability is greater than historical, additional testing should be conducted. This analysis should be done for each individual performance test condition, i.e. 32 kph wet peak, 32 kph wet slide, etc.

5.3 Test Documentation. For TIP approved data being uploaded to the GM Global Tire Database, data for TPC files is supplied in the electronic file format shown in Appendix B. In addition, detailed composite coefficient vs % slip data is provided in the electronic file format defined in Appendix C. Otherwise, test results should be reported as shown in the sample test reports in Appendix D and E for wet surface tests and dry surface tests respectively.

The following minimum information should be recorded for each test.

5.3.1 Tire Identification:

a. Manufacturer
b. Brand or Trade Name
c. Tire Size Designation
d. Tire Load Rating
e. Serial Number (identification number)
f. Construction Number
g. Tire ID
h. Durometer
i. Other Pertinent Information

5.3.2 Test Conditions.

a. Test Site
b. Tester
c. Date and Time
d. Water Depth
e. Surface
f. Surface Condition
g. Rim Diameter, Width and Contour
h. Test Load
i. Test Inflation
j. Ambient Temperature
k. Surface Temperature
l. Test Speed
m. Other Pertinent Information

5.3.3 Test Data.

a. Peak Coefficient
b. Slide Coefficient
c. Percent Slip at Peak

6 Safety

6.1 This procedure may involve hazardous materials, operations, and equipment. This method does not propose to address all the safety problems associated with its use. It is the responsibility of the user of the method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

6.2 The tire and test wheel must be free of obvious defects, as judged by visual inspection. In particular, the bolt holes, the valve, and the base of the rim flange must not be worn excessively.

6.3 The test vehicle, as well as all attachments to it, shall comply with all applicable state and federal laws. All necessary precautions shall be taken beyond those imposed by laws and regulations to ensure maximum safety of operating personnel and other traffic.

7 Notes

Braking Coefficient: The ratio of braking test wheel longitudinal force at the tire/test surface interface to the vertical load on the test tire.

Braking Traction: A performance measure quantified by comparison of a candidate tire's braking coefficient to a control tire's braking coefficient under specified conditions.

Chirp Test: The progressive application of brake torque required to produce the maximum value of longitudinal braking force that will occur prior to wheel lockup, with subsequent brake release to prevent any wheel lockup (no tire slide).

Control Tire: A tire used for monitoring test conditions and used as a reference for comparing test tires' performance. See 5.1.4 for discussion.

Peak Braking Coefficient: The ratio of the maximum value of braking test wheel longitudinal force to the simultaneous vertical force occurring prior to wheel lockup as braking torque is progressively increased.

Skid Number: Braking coefficient multiplied by 100.

Sliding Braking Coefficient: The ratio of the locked wheel longitudinal force and the vertical force integrated for one second, beginning 0.2 s after test wheel lockup.

Test Load: The total vertical load exerted by the test tire on the test surface. See 4.2.2.1.

Test Run: A single pass over the test surface using the specified test procedure to produce test wheel lockup. For each test run, one peak and one sliding braking coefficient may be determined.

Test Sequence: A group of tire tests conducted under the same test conditions on the same day.

Tire Test: A series of test runs, usually eight to ten.

Note: For other definitions pertaining to this test procedure, see Definitions in ASTM E 867 and F 408.

Tire and Rim Association (T&RA) Year Book, Current Issue, Tire and Rim Association, 3200 W. Market Street, Akron, OH, 44313.

ASTM E-1136 Standard Specification for A Radial Standard Reference Test Tire.

ASTM F-377 Method for Calibration of Braking Force for Testing of Pneumatic Tires.

ASTM F-408 Method of Testing Tires for Wet Traction in Straight-Ahead Braking, using a Towed Trailer.

ASTM F-457 Method for Speed and Distance Calibration of a Fifth Wheel Equipped with Either Analog or Digital Instrumentation.

ASTM E-867 Standard Definitions of Terms Relating to Traveled Surface Characteristics.

ASTM E-274 Standard Test Method for Skid Resistance of Paved Surfaces Using A Full-Scale Tire.

ASTM E-556 Standard Method of Calibrating a Wheel Force or Torque Transducer Using a Calibration Platform.

ASTM E-1337 Standard Test Method for Determining Peak Braking Coefficient of Paved Surfaces Using a Standard Reference Test Tire.

7.2 Acronyms, Abbreviations, and Symbols.

CTS	Component Technical Specifications
T&RA	Tire and Rim Association
VTS	Vehicle Technical Specifications
TPC	Tire Performance Criteria

8 Coding System

This material specification shall be referenced in other documents, drawings, VTS, CTS, etc. as follows:

Test to GMW15208

9 Release and Revisions

9.1 Release. This standard originated in July 2006 and it is replacing T92BKT1, T92BKT3, T92BKT5, T92BKT6.

It was first approved by the Tire Global Subsystem Leadership Team in October 2006. It was first published in October 2006.

9.2 Revisions.

Rev	Approval Date	Description (Organization)
1	TBD	Initial Release

Appendix A

A1. SPECIFICATION COMPLIANCE PROCESS

A1.1. Specification Compliance Process: The specification compliance process, shown below, incorporates two basic statistical techniques

A1.2. The first procedure is to determine specification conformance using a Student "t" statistical analysis. This test is used to determine the probability that the measured traction performance is equal to or greater than the minimum specification level based on the mean traction level and the standard deviation of the test data. If the "t" analysis shows compliance and the test variability is satisfactory, the tire is accepted. If the tire does not meet the minimum performance requirement, a Chi Square analysis of variance can then be used to decide if re-measurements are appropriate. The procedure for determining conformance to traction specifications was developed to account for the test variability associated with various sources of test data.

A1.3. The first step in the process is to determine the traction performance ratings (5.1.4.3.6)) of three (3) candidate tires having the same construction. All six performance test conditions are evaluated separately i.e. wet peak at 32 kph or dry slide at 64 kph.

A1.4. Student "t" Analysis: The second step is to use the "t" test to accept/reject tires. 90% confidence level is used in this procedure. The average performance for each performance condition is used in the calculations.

A1.4.1. The formula for calculating the "t" statistic is:

$$\textit{Calculated "t" value} = \frac{\textit{average performance - minimum specification}}{\dfrac{\textit{sample std.dev.}}{\sqrt{\textit{number of samples}}}}$$

A1.4.2. Comparing the calculated value to the "t" Table value for $t_{90\%,n-1}$ will indicate if specification compliance is met. The calculated "t" value must be equal or greater than the "t" reference value, shown in the Table A1 below, to indicate acceptable performance.

A1.4.3. A sample calculation of test data might be:

Wet Peak @ 32 kph

98% (tire 1)

86% (tire 2)

105% (tire 3)

Average = 96%

Std. Dev. = 9.6%

Samples = 3

Minimum traction specification for Wet Peak @ 32 kph = 95%

$$\text{Calculated "}t\text{" value} = \frac{96 - 95}{\frac{9.6}{\sqrt{3}}} = 0.180$$

"t" Table A1 value for $t_{90\%,\ n-1} = 1.886$

Table A1

Reference "t" Values for 90% Confidence

SAMPLE SIZE (n)	"t" VALUE (for n-1)
5	1.533
4	1.638
3	1.886

Specification Compliance 0.180 < 1.886

Conclusion: Performance Rejected

If the test tire's performance does not meet or exceed the minimum specification requirements with 90% confidence, then proceed to the Chi Square Analysis of Variance portion of the procedure.

A1.4.4. If test tire's performance is accepted, a second step is required to verify that the sample test variability also meets the requirements. The test sample variability must statistically compare against historical test variability prior to final acceptance. A Chi Squared Analysis of Variance should be used at a 95% confidence level (complete procedure described below). If the analysis indicates that the sample variability is greater than historical, additional testing should be conducted. This is done for each individual performance test condition, 32 kph wet peak, 32 kph wet slide, etc.

A1.5. Chi Square Analysis of Variance: This procedure is used to statistically compare the sample test variability (SD_{sample}) to established historical test variability ($SD_{Historical}$). Again this is done for each individual performance test condition. A 95% confidence level is used in this procedure.

A1.6. The formula for calculating the Chi Square statistic is:

$$\text{Chi Square Distribution} = \frac{(\text{Sample size} - 1) \times (\text{Sample std. dev.})^2}{(\text{Historical std. dev.})^2}$$

The calculated Chi Square value is compared to the Chi Square Distribution Table value (x^2) for $x^2_{95\%,n-1}$ to test the following hypothesis:

H_o: $SD^2_{sample} \leq SD^2_{Historical}$
(Sample SD is at least as good as Historical SD)

H_i: $SD^2_{sample} > SD^2_{Historical}$
(Sample SD is worse than Historical SD)

A1.7. If the calculated Chi Square value is less than or equal to the Chi Square Table value at 95% confidence level, then accept H_o. Accepting the H_o hypothesis implies that the test variability of the test sample is at least as good as historical testing and that additional testing will not likely affect the test sample mean or reduce variability. Therefore, the candidate tire should be rejected because there is a high probability that additional testing will not influence the results. At this point, the tire supplier has the option to run additional tests to enhance further statistical analysis, however the probability of overall acceptance is low.

A1.8. In the second situation, if the calculated Chi Square value is greater than the Chi Square Table value at the 95% confidence level, then reject H_0. Accepting H_i implies that the sample test variability is worse than historical test variability and additional testing will probably affect the test sample mean or reduce variability. If the H_i hypothesis is accepted, additional tests should be conducted and the Student "t" analysis and Chi Square analysis repeated until the candidate tire is either accepted (adequate performance) or rejected based on the analysis of variance.

A1.9. A sample calculation for the Chi Square analysis might be:

Wet Peak @ 32 kph

98% (tire 1)

86% (tire 2)

105% (tire 3)

Average = 96%

Std. Dev. = 9.6%

Samples = 3

GM Passenger Car Rating Test Variability for Wet Peak @ 32 kph = 5.1%

Calculated Chi Square Distribution:

$$\frac{(3 - 1) \times (9.6)^2}{(5.1)^2} = 7.086$$

Chi Square Table A2 Value $x^2_{95,n-1}$ = 5.991

Table A2
Reference Values for Chi Square Analysis

SAMPLE SIZE (n)	CHI-SQUARE VAUE (for n-1)
5	9.488
4	7.815
3	5.991

Result: 7.086 > 5.991 therefore, reject H_0

A1.10. If the H_0 hypothesis is accepted, then the probability that additional testing will affect the performance results is small and the tire should be rejected.

A1.11. If the H_0 hypothesis is rejected, the analysis indicates the probability that additional testing will influence the performance results, and additional testing should be conducted. The results of the follow-up testing should be combined with the initial results and the Student "t" Analysis process repeated.

A1.12. This process can be continued for two (2) additional tires; five (5) total. If after a total of five tests are conducted without specification compliance being met, and the sample test variability still exceeds historical; proceed to evaluate the test process for potential rating outliers.

A1.13. Outlier Test Criteria: If after the fifth test replication for a given construction, the Chi-square analysis indicates excessive variability for a particular test condition (i.e. 32 kph wet) the following steps should be followed to evaluate data for potential outliers.

A1.13.1. Obviously Defective Control: Determine if the variation of suspected ratings can be explained due to a deviation from prescribed test procedures or a test condition problem.

A1.13.2. Obvious Instrument Malfunction: Determine if improperly functioning test equipment or data processing errors could have contributed to suspected data.

A1.13.3. Exceeding a Statistical Criteria: If no obvious physical explanation can be found for suspected rating variability, a statistical test for outliers can be applied and the statistical compliance process repeated. The outlier process should only be executed ONCE.

A1.13.3.1. A recommended statistical process for determining outliers is as follows:

$$Critical\ Test\ Value = \frac{ABS(X_{bar} - X_{sus})}{S}$$

Where:

X_{bar} = Average of all ratings for the test condition

X_{sus} = Individual rating suspected of being an outlier

S = Historical Standard Deviation for applicable test condition

ABS = Absolute value

As with the Chi-square test, the calculated values are compared with the "reference values" shown in Table A3 at 95% confidence. X_{sus} is an outlier if the calculated Critical Test Value exceeds the "reference value".

Table A3

Reference Values for Outlier Test

SAMPLE SIZE (n)	REFERENCE VALUE
5	2.08
4	1.94
3	1.74

A1.13.4. Each individual rating value should be used to calculate a critical value and evaluated against the appropriate "reference value". All ratings that meet the outlier criteria should be rejected. If more than two rating values are rejected, than the entire data set should be rejected and the program repeated with different tires. Example cases are shown in Section A2 and A3 that illustrate the Chi Square analysis of variance and outlier procedure.

A2 Example of the Chi Square Analysis of Variance Procedure

H_o: $SD^2_{sample} \leq SD^2_{Historical}$

(Sample SD is at least as good as Historical SD)

H_i: $SD^2_{sample} > SD^2_{Historical}$

(Sample SD is worse than Historical SD)

A2.1 Case 1 : Initial Three Tire Sample

Wet Peak @ 32 kph
Test Data = 106% (tire 1)
= 89% (tire 2)
= 91% (tire 3)

Average = 95%
Std. Dev. = 9.3%
Samples = 3

Compare sample variability to historical variability:

GM Passenger Car Rating Test Variability
for Wet Peak @ 32 kph = 5.1%

Calculated Chi Square Distribution: 6.651
Chi Square "Reference Value" (table A2) $x^2_{95,n-1}$ = 5.991

Result: 6.651 > 5.99 therefore, reject H_0
Additional tire test required.

A2.2 Case 2 : Addition of Fourth Tire Test

Wet Peak @ 32 kph
Test Data = 106% (tire 1)
= 89% (tire 2)
= 91% (tire 3)
= 85% (tire 4)

Average = 93%
Std. Dev. = 9.2%
Samples = 4

Compare sample variability to historical variability:

GM Passenger Car Rating Test Variability
for Wet Peak @ 32 kph = 5.1%

Calculated Chi Square Distribution: 9.762
Chi Square "Reference Value" (table A2) $x^2_{95,n-1} = 7.815$

Result: 9.762 > 7.815 therefore, reject H_0
Additional tire test required.

A2.3 Case 3 : Addition of Fifth Tire Test

Wet Peak @ 32 kph
Test Data = 106% (tire 1)
= 89% (tire 2)
= 91% (tire 3)
= 85% (tire 4)
= 100% (tire 5)

Average = 94%
Std. Dev. = 8.6%
Samples = 5

Compare sample variability to historical variability:

GM Passenger Car Rating Test Variability
for Wet Peak @ 32 kph = 5.1%

Calculated Chi Square Distribution: 11.374
Chi Square "Reference Value" (table A2) $x^2_{95,n-1} = 9.488$

Result: 11.374 > 9.488 therefore, reject H_0
Five individual tire tests are completed and the sample test variability still exceeds historical.

A3 Example of the Outlier Procedure

Since the above Chi-square analysis indicates excessive variability for this set of test data, proceed with the Outlier Test for each rating value. Start with rating values at either end of the sample distribution.

A3.1 Case 1 : 85% Performance Rating

$$CriticalTestValue = \frac{ABS(94 - 85)}{5.1}$$

Calculated Critical Value for 85% = 1.76
Outlier Reference Value for Five Samples (table A3) = 2.08

Calculated Value (1.76) < Outlier Reference Value (2.08)

Therefore: 85% is not a statistical outlier.

A3.2 Case 2 : 106% Performance Rating

Calculated Critical Value for 106% = 2.35
Outlier Reference Value for Five Samples (table A3) = 2.08

Calculated Value (2.35) > Outlier Reference Value (2.08)

Therefore: 106% is a statistical outlier.

A3.3 Case 3 : Reject 106% Rating

Wet Peak @ 32 kph
Test Data = 89% (tire 2)
= 91% (tire 3)
= 85% (tire 4)
= 100% (tire 5)

Average = 91%
Std. Dev. = 6.3%
Samples = 4

Compare sample variability to historical variability:

GM Passenger Car Rating Test Variability
for Wet Peak @ 32 kph = 5.1%

Calculated Chi Square Distribution: 4.578
Chi Square "Reference Value" (table A2) $x^2_{95,n-1}$ = 7.815

Result: 4.578 < 7.815 therefore, reject H_i
No additional tire tests required.
Repeat specification compliance process

A3.4 Case 4 : Five Tire Tests Conducted with More Than Two Outliers.

The 3rd test sample, 4th test sample, and 5th test sample all have test variability greater than historical. The Outlier procedure indicates that three rating values have exceeded a given variation from the mean (2 @ 106% and 80%). All rating values in this data set should be rejected, the test process examined, and another sequence rerun using different tires.

Wet Peak @ 32 kph
Test Data = 89% (tire 1)
= 91% (tire 2)
= 106% (tire 3) outlier
= 80% (tire 4) outlier
= 106% (tire 5) outlier

Average = 94%
Std. Dev. = 11.4%
Samples = 5

Compare sample variability to historical variability:

GM Passenger Car Rating Test Variability
for Wet Peak @ 32 kph = 5.1%

Calculated Chi Square Distribution: 19.986
Chi Square A2Value (table A2) $x^2_{95,n-1} = 9.488$

Result: 19.986 > 9.488 therefore, reject H_0

Appendix B: Electronic Data Format Specifications (XXBMDDSS.TPC)

LINE NO.	VARIABLE	CHAR. LIMIT	EXAMPLE (Comments) (Some example data have been fabricated)
			GENERAL INFORMATION
1	TPC File Name	12C	xxBxxxxx.TPC………(This file's name)
2	CMP File Name	12C	xxBxxxxx.CMP………(Associated CMP file name)
3	Image File	12C	None at this time
4	Tire Test Request Number.	8C	90-12345 (Supplied by GM)
5	Test Site	3C	XXX (Valid Codes Only)
6	Tester	3C	XXX (Valid Codes Only)
7	Test Date	10C	01/20/1991 (Month/Day/Year)
8	Comments	30C	Development
			TEST TIRE INFORMATION
9	Size	13C	LT225/75R16
10	Load Rating	2C	SL (Standard Load)
11	Supplier	3C	XXX (Valid Codes Only)
12	Construction No	12C	1234567890AB
13	Tire ID	10C	1234567890
14	Durometer	F3.0	123
15	DOT Serial	6C	AB1234 (First 2 + Last 4)
16	Rim Width	F5.2	12.34 (Inches)
17	Load	F5.0	12345 (Newtons)
18	Inflation Pressure	F3.0	123 (kPa)
			TEST CONDITIONS
19	Surface	12C	ConcreteABCD
20	Surface Condition	32C	Wet – on board applied
21	Water Depth	F5.3	12.34 (mm)
22	Ambient Temperature	F3.0	105 (Fahrenheit)
23	Surface Temperature	F3.0	140 (Fahrenheit)
24	Speed	F3.0	32 (km/h)
			TEST TIRE DATA
25	Test Tire Peak	F5.3	1.023
26	Test Tire Slide	F5.3	0.824
27	% Slip At Peak	F3.0	14
			CONTROL TIRE DATA
28	Designation	5C	SRTT
29	Load	F5.0	4586 (Newtons)
30	Inflation Pressure	F3.0	241 (kPa)
31	Durometer (Avg)	F3.0	55
32	Control Tire Peak	F5.3	0.864
33	Control Tire Slide	F5.3	0.663

Appendix C: Electronic Data Format (XXBMDDSS.CMP)
Coefficient Versus Percent Slip Composite Data

LINE NO.	VARIABLE	CHAR. LIMIT	EXAMPLE (Comments) (Some example data have been fabricated)
		GENERAL INFORMATION	
1	Tire Test Request Number.	8C	90-102 (Supplied by GM)
2	Test Site *	3C	XXX (Valid Codes Only)
3	Tester *	3C	XXX (Valid Codes Only)
4	Test Date	8C	01/20/91 (Month/Day/Year)
5	Comments **	30C	Development
		TEST TIRE INFORMATION	
6	Size	13C	LT225/R16
7	Load Rating	2C	D (Load Range D)
8	Supplier *	3C	XXX (Valid Codes Only)
9	Construction No.	12C	12345
10	Tire ID	10C	121
11	Durometer	3.0	65
12	DOT Serial	5C	XX1700 (First 2 + Last 4)
13	Rim Width ***	5.2	6.50 (Inches)
14	Load	5.0	5001 (Newtons)
15	Inflation Pressure	3.0	241 (kPa)
		TEST CONDITIONS	
16	Surface	12C	Concrete
17	Surface Condition	32C	Wet – off board water
18	Water Depth	5.3	1.27 (mm)
19	Ambient Temperature	3.0	30 (Celsius)
20	Surface Temperature	3.0	30 (Celsius)
		TEST TIRE DATA	
21	Speed	3.0	32 (kph)
22	90 Total Points: Two Variables Coeff. Percent Slip x.xxx 1 - 90		Each Integer of Percent Slip

Appendix D: Sample Wet Traction Report

CONSTRUCTION: 123ABC **SUPPLIER**: XYZ **LOAD INDEX**: 90 **SPEED RATING**:G **TYPE**: PARPS **STATUS**: N

TEST TIRE ==> SIZE: P195/65R15 SL **TEST LOAD**: 4207 **PRESSURE**: 241 STD COND **SURFACE:** ASPH

CONTROL TIRE==> P195/75R14 SRTT **LOAD**: 4585 **PRESSURE**: 241 STD COND **TWS FILE NO**: 85 26

									CAND 32 KPH		CNTL 32 KPH		CAND 97 KPH		CNTL 97 KPH		<----TWS RATINGS--- 32 KPH		97
WORK REQ	**C**	**OBJ**	**BUILD**	**DATE**	**TIRE ID**	**REQ**	**LOC**	**TST**	**PEAK**	**SLIDE**	**PEAK**	**SLIDE**	**PEAK**	**SLIDE**	**PEAK**	**SLIDE**	**PEAK**	**SLIDE**	**PEAK**
06- XX	P	COMP	1234	04/03/2006	TIRE-A1	ABC	MPG	TWS	0.517	0.268	0.418	0.257	0.374	0.200	0.347	0.191	124	104	108
06- XX	P	COMP	1234	04/03/2006	TIRE-A2	ABC	MPG	TWS	0.500	0.273	0.418	0.257	0.375	0.210	0.347	0.191	120	106	108
						AVERAGES =			0.50 9	0.271	0.418	0.257	0.375	0.205	0.347	0.191	122	105	108

Appendix E: Sample Dry Traction Report

CONSTRUCTION: 123ABC **SUPPLIER**: XYZ **LOAD INDEX**: 90 **SPEED RATING**:G **TYPE**: PARPS **STATUS**: N

TEST TIRE ==> SIZE: P195/65R15 SL **TEST LOAD**: 4207 **PRESSURE**: 241 STD COND **SURFACE:** ASPH

CONTROL TIRE==> P195/75R14 SRTT **LOAD**: 4585 **PRESSURE**: 241 STD COND **TWS FILE NO**: 85 26

									CAND 64 KPH		CNTL 64 KPH		TWS RATINGS 64 KPH	
WORK REQ	**C**	**OBJ**	**BUILD**	**DATE**	**TIRE ID**	**REQ**	**LOC**	**TST**	**PEAK**	**SLIDE**	**PEAK**	**SLIDE**	**PEAK**	**SLIDE**
06- XX	P	COMP	1234	04/03/2006	TIRE-A1	ABC	MPG	TWS	0.995	0.767	0.926	0.730	107	105
06- XX	P	COMP	1234	04/03/2006	TIRE-A2	ABC	MPG	TWS	0.987	0.756	0.926	0.730	107	104
						AVERAGES =			0.991	0.762	0.926	0.730	107	105