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Standard Practice for Radial Light Truck Tires to Establish Equivalent Test Severity Between a 1.707-m (67.23-in.) Diameter Rotating Roadwheel and a Flat Surface[1]

This standard is issued under the fixed designation F2869; 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 practice describes the procedure to identify equivalent test severity conditions between a 1.707-m diameter laboratory roadwheel surface and a flat or highway surface for radial pneumatic light truck (LT) tires.

1.1.1 Tire operational severity, as defined as the running or operational temperature for certain specified internal tire locations, is not the same for these two test conditions. It is typically higher for the laboratory roadwheel at equal load, speed and inflation pressure conditions due to the curvature effect.

1.1.2 The practice applies to specific operating conditions of light truck tires up through load range E for such tires used on vehicles having a gross vehicle weight rating (GVWR) ≤4536 kg (10000 lb).

1.1.3 The specific operating conditions under which the procedures of the practice are valid and useful are completely outlined in Section 6, (Limitations) of this standard.

1.1.4 It is important to note that this standard is composed of two distinct formats:

1.1.4.1 The usual text format as published in this volume of the Book of Standards (Vol. 09.02).

1.1.4.2 A special interactive electronic format that uses a special software tool, designated as prediction profilers or profilers. This special profiler may be used to determine laboratory test conditions that provide equivalent tire internal temperatures for the belt edge region for the two operational conditions, that is, the curved laboratory roadwheel and flat highway test surfaces.

1.2 The prediction profilers are based on empirically developed linear regression models obtained from the analysis of a large database that was obtained from a comprehensive experimental test program for roadwheel and flat surface testing of typical radial light truck (LT) tires. See Section 7 and the research report[2] for more details.

1.2.1 For users viewing the standard on CD-ROM or PDF, with an active and working internet connection, the profilers can be accessed on the ASTM website by clicking on the links in 7.5 and 7.6.

1.2.2 For users viewing the standard in a printed format, the profilers can be accessed by entering the links to the ASTM website in 7.5 and 7.6 into their internet browsers.

1.3 For this standard, SI units shall be used, except where indicated.

1.4 *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:*[3]

F414 Test Method for Energy Absorbed by a Tire When Deformed by Slow-Moving Plunger
F538 Terminology Relating to the Characteristics and Performance of Tires
F551 Practice for Using a 67.23-in. (1.707-m) Diameter Laboratory Test Roadwheel in Testing Tires
F1922 Test Method for Tires, Pneumatic, Vehicular, Highway
F2779 Practice for Commercial Radial Truck-Bus Tires to Establish Equivalent Test Severity Between a 1.707-m (67.23-in.) Diameter Roadwheel and a Flat Surface
IEEE/ASTM SI 10 American National Standard for Use of the International System of Units (SI): The Modern Metric System

[1] This practice is under the jurisdiction of ASTM Committee F09 on Tires and is the direct responsibility of Subcommittee F09.30 on Laboratory (Non-Vehicular) Testing.

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[2] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: F09-1002.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3. Terminology

3.1 *Definitions:*

3.1.1 *belt edge (BE) temperature, n— in the cross section of a radial tire*, the temperature at the edge of the stabilizer plies or belts, for example, in the rubber region of the two belt edges.

3.1.2 *contained air temperature, n*—the temperature of the air contained within the tire cavity when the tire is mounted and inflated on the proper rim.

3.1.3 *curved equivalent test severity, n—in tire testing*, the test conditions (load, rotational speed, tire inflation pressure) on the flat or highway surface that will provide equivalent internal tire temperatures, for example, at the belt edge, to a known set of curved 1.707-m roadwheel surface test conditions.

3.1.4 *endurance, n—of a tire*, the ability of a tire to perform as designed in its intended usage conditions such as load, inflation pressure, speed, time, and environmental conditions.

3.1.5 *high speed performance, n—of a tire*, the rotational speed capability of a tire to perform as designed in its intended usage conditions such as load, inflation pressure, speed, time, and environmental conditions.

3.1.6 *highway equivalent test severity, n—in tire testing*, the test conditions (load, rotational speed, tire inflation pressure) on the 1.707-m roadwheel that will provide equivalent internal tire temperatures, for example, at the belt edge, to a known set of highway or flat surface conditions.

3.1.7 *light truck tire, n*—a tire that has a LT prefix or suffix in the tire size description: this indicates that the tire was primarily intended for service on light trucks with gross vehicle weights (GVWR) ≤4536 kg.

3.1.8 *load range, n—of a light truck tire*, a letter designation (B, C, D, E) used to identify a given size tire with its load and inflation limits when used in a specific type of service. **F414, F1922**

3.1.9 *maximum rated load, n*—the load corresponding to a maximum tire load capacity at the rated inflation pressure in accordance with the publications of tire and rim standards current at the time of manufacture.

3.1.10 *measured inflation pressure, n*—gauge pressure of a tire measured at a given time under ambient temperature and barometric pressure. **F538**

3.1.11 *rated inflation pressure, n*—the minimum cold inflation pressure specified at the maximum rated load of a tire in accordance with the publications of tire and rim standards current at the time of manufacture.

3.1.12 *rim, n*—specially shaped circular periphery to which a tire may be mounted with appropriate bead fitment. **F538**

3.1.13 *test inflation pressure, n*—specified gauge pressure of a tire mounted on a rim, measured at a given time under ambient temperature and barometric pressure for evaluation purposes.

3.1.14 *test load, n*—the force applied to a tire through the rim; it is normal to the metal loading plate onto which the tire is loaded. **F538**

3.1.15 *tire, pneumatic, n*—a hollow tire that becomes load-bearing upon inflation with air, or other gas, to a pressure above atmospheric. **F538**

3.1.16 *tire, radial, n*—a pneumatic tire in which the ply cords that extend to the beads are laid substantially at 90° to the center line of the tread, the tire being stabilized by a belt. **F538**

3.1.17 *tire speed rating, n*—the maximum speed for which the use of the tire is rated under certain conditions as designated by the speed symbol marked on the tire sidewall or maximum speed rating as determined by the manufacturer.

3.1.18 *tire test speed, n*—the tangential speed at the point of contact with the road curved surface of a rotating tire for evaluation purposes.

4. Summary of Practice

4.1 This practice provides a procedure to determine the 1.707-m diameter roadwheel tire test conditions (speed, load, and inflation pressure) for flat surface equivalent test severity. It also enables the user to determine the 1.707-m diameter roadwheel test conditions for a specific increase or decrease in severity with respect to flat surface test severity. The converse is also true, determining the flat surface test conditions that provide equal test severity to a selected set of 1.707-m diameter roadwheel test conditions.

4.2 This practice provides a prediction profiler procedure (see Section 7 and Annex A1) to establish equivalent test severity between a 1.707-m diameter rotating wheel (Practice F551) and a flat surface, by adjusting test speed, load and inflation pressure. The prediction profiler provides the ability to identify numerous test conditions and resultant belt edge temperature differentials within the confines of this practice as described in Section 6.

4.3 Equivalent test severity is defined as the set of test conditions (load, speed, and tire inflation pressure) that provide equivalent steady state tire internal operating temperatures at the belt edge (BE) for: *(1)* a conversion from flat surface conditions to a 1.707-m diameter roadwheel conditions or *(2)* a conversion from a 1.707-m diameter roadwheel conditions to a flat surface conditions.[2]

5. Significance and Use

5.1 Historically, tires have been tested for endurance by a variety of test methods. Some typical testing protocols have been: *(1)* proving grounds or highway testing over a range of speeds, loads, and inflations, *(2)* testing on fleets of vehicles for extended periods of time, and *(3)* indoor (laboratory) testing of tires loaded on a rotating 1.707-m diameter roadwheel; however, the curved surface of a 1.707-m diameter roadwheel results in a significantly different tire behavior from that observed on a flat or highway surface.

5.1.1 This practice addresses the need for providing equivalent test severity over a range of typical tire operating conditions between a 1.707-m diameter roadwheel surface (Practice F551) and a flat surface. There are different deformations of the tire footprint on curved versus flat surfaces resulting in different footprint mechanics, stress/strain cycles, and significantly different internal operating temperatures for the two types of contact surface. Since tire internal temperatures are key parameters influencing tire endurance or operating characteristics under typical use conditions, it is important to be able to calculate internal temperature differentials between curved and flat surfaces for a range of loads, inflation pressures and rotational velocities (speeds).

5.2 Data from lab and road tire temperature measurement trials were combined, statistically analyzed, and tire temperature prediction models derived.[2]

5.2.1 The fit of the models to the data is shown as the coefficient of determination, R^2, for the critical belt edge:

$$R^2 = 0.90$$

Two Standard Deviations (2-sigma) = 3.2°C
(that is, 95 % of the variation from the means
is within ±3.2°C)

5.2.2 These prediction models were used to develop the prediction profilers outlined in Section 7 and Annex A1.

6. Limitations

6.1 The procedures as given are valid for radial pneumatic LT tires up through load range E for the following ranges of test speed, tire inflation pressure and test load, for flat test surfaces and a 1.707-m diameter roadwheels:

6.1.1 Tire test speed in the range of 80 to 137 km/h (flat and curved surface).

6.1.2 Tire test inflation pressure in the range of 50 to 110 % of the inflation pressure associated with the maximum load capacity of the tire, for example, sidewall stamped.

6.1.3 Tire test load in the range of 41 to 143 % of the maximum load capacity of the tire, for example, sidewall-stamped maximum rated load.

6.2 The procedures described in Section 7 determine equivalent operating conditions between a flat surface and a 1.707-m diameter roadwheel by using empirical models to match tire internal belt edge temperatures. These empirical models are derived from a wide variety of tires tested within the above ranges and can be used to interpolate at any conditions within the constraints listed above. It is not recommended that the procedures be used for extrapolation beyond the constraints listed above.

7. Procedure

7.1 *Equivalent Test Severity Prediction Profilers:*

7.1.1 The flat-to-curved (FTC) prediction profilers are SAS JMP interactive displays based on algorithms developed from laboratory and highway tire temperature measurements. They provide 1.707-m diameter roadwheel tire test (rotational) speed, tire test load, and tire test inflation pressure conditions for equivalent test severity (as well as for lesser or more severe test severity) based upon the belt edge region temperatures. Before using the profilers, the user will have targeted a roadwheel "delta temperature" amount in degrees C for the tire running on a flat surface, that is, the targeted operating difference in temperature between the roadwheel and highway condition. By first identifying the desired "delta temperature(s)," the user will be able to identify (via the profilers) roadwheel test conditions to achieve the temperature "delta(s)." The equivalency determination is based upon a "delta" in rotational speed (km/h), % load, and/or % inflation from the known highway operating conditions within the limitations specified in Section 6.

7.1.2 The converse also applies for equivalent highway test conditions that can be identified from specified roadwheel test conditions by use of the curved-to-flat (CTF) prediction profilers.

7.2 When using either the 'FTC (or CTF) Delta DegC' prediction profilers, three variables are available for interactive modification:

Delta 1.7 m Dia RW KPH	The change in tire rotational speed for the roadwheel relative to the highway speed in km/h.
1.7 m Dia RW % Flat Surface Inflation	The percent change in roadwheel tire inflation relative to the highway tire inflation.
1.7 m Dia RW % Flat Surface Load	The percent change in roadwheel tire load relative to the highway tire load.

7.2.1 These variables appear along the *x*-axis of the prediction profiler and can be changed by clicking and dragging. Effects of changing these variables can be viewed as temperature changes in the belt edge region identified on the *y*-axis as:

"LT BE Flat Surface to 1.7 m Dia RW Delta DegC"

7.3 The curved-to-flat (CTF) prediction *y*-axis is labeled "LT BE 1.7 m Dia RW to Flat Surface Delta DegC" while the x-axis are labeled from the perspective of identifying the required changes from roadwheel conditions to flat conditions in order to achieve the targeted severity levels on the flat surface.

7.4 See Annex A1 for examples of prediction profilers outputs.

7.5 Flat-to-Curved (FTC) Prediction Profiler – Macro Button (available on electronic copy or ASTM F09 site):
http://www.astm.org/F2869_flat_to_curved.html

7.6 Curved-to-Flat Surface (CTF) Prediction Profiler – Macro Button (available on electronic copy or ASTM F09 site):
http://www.astm.org/F2869_curved_to_flat.html

8. Keywords

8.1 curved to flat surface; endurance; equivalency; flat to curved surface; high speed temperature; LT metric; highway equivalent; radial light truck tire; roadwheel; roadwheel testing; test severity; tire; tire temperature; 67.23-in.; 1.707-m

ANNEX

(Mandatory Information)

A1. PROCESS TO PREDICT EQUIVALENT TEST CONDITIONS AND PREDICTION PROFILER EXAMPLES

A1.1 To obtain highway equivalent test severity on a 1.70.7-m diameter roadwheel based upon the operational factors of tire rotational speed, tire load, and tire inflation pressure:

A1.1.1 A targeted severity level is first identified for the tire on the curved surface, that is, tire internal temperature delta(s) with respect to the same tire operated on a flat surface. For the first example that follows, the targeted test severity level is for the belt edge temperature as "equal to" (that is, Delta Deg C = 0). The prediction profilers have the capability to target a specific "Deg C delta" increase or decrease as well. The targeted severity level is based upon a known set of flat surface operating conditions (tire load, tire rotational speed, tire inflation pressure)

A1.1.2 For the targeted severity level (for example, "equal to") based upon the known highway (flat) conditions, the prediction profiler can determine the 1.707-m diameter road wheel test conditions of tire test load, tire test rotational speed, and tire test inflation pressure.

A1.1.3 This can be an iterative procedure to identify the required 1.707-m diameter road wheel test conditions of tire test load, tire test rotational speed, and tire test inflation pressure by specifying two of the three variables and using the profilers to identify the third, subject to the limitations specified in Section 6.

A1.2 *Example #1*—For any LT tire up through load range E with a specified set of flat surface operating conditions, predict the required 1.707-m diameter roadwheel load for equivalent belt edge temperature while keeping speed and inflation pressure equal to the flat surface speed and inflation pressure. The FTC prediction profiler yields the following results. See Fig. A1.1.

A1.2.1 *Step 1*—You will not move the speed bar because you want to maintain the same speed on the 1.707-m diameter roadwheel that you have on the flat surface, therefore, the differential should be zero.

A1.2.2 *Step 2*—You will not move the inflation pressure bar because you want to maintain the same inflation pressure on the 1.707-m diameter roadwheel that you have on the flat surface, therefore, the differential should be zero.

A1.2.3 *Step 3*—Move the load bar to the left to decrease the belt edge temperature (*y*-axis) differential to approximately zero.

A1.2.4 *Step 4*—For Equivalent Test Severity, it is desired to have the belt edge temperature difference to be approximately zero between the flat surface and the 1.707-m diameter roadwheel. While keeping speed and inflation pressure equal to the flat surface speed and inflation pressure, a reduction in load of approximately 12.3 % from the flat surface load is required to maintain equal belt edge temperatures in the transition from a flat surface to the 1.707-m diameter roadwheel.

A1.3 *Example #2*—For any LT tire up through load range E with a specified set of 1.707-m diameter roadwheel operating conditions, predict the required flat surface inflation pressure adjustment required for equivalent belt edge temperature while keeping speed and load equal to the 1.707-m diameter roadwheel speed and load. The CTF prediction profiler yields the following results. See Fig. A1.2.

A1.3.1 *Step 1*—You will not move the speed bar because you want to maintain the same speed on the flat surface that you have on the 1.707-m diameter roadwheel, therefore, the differential should be zero.

A1.3.2 *Step 2*—You will not move the load bar because you want to maintain the same load on the flat surface that you have on the 1.707-m diameter roadwheel, therefore, the differential should be zero.

A1.3.3 *Step 3*—Move the inflation pressure bar to the left to decrease the belt edge temperature (*y*-axis) differential to approximately zero.

A1.3.4 *Step 4*—For Equivalent Test Severity, it is desired to have the belt edge temperature difference to be approximately zero between the 1.707-m diameter roadwheel and the flat surface. While keeping speed and load equal to the 1.707-m surface speed and load, a reduction in inflation pressure of approximately 23.8 % from the 1.707-m surface inflation pressure is required to maintain equal belt edge temperatures in the transition from curved to flat

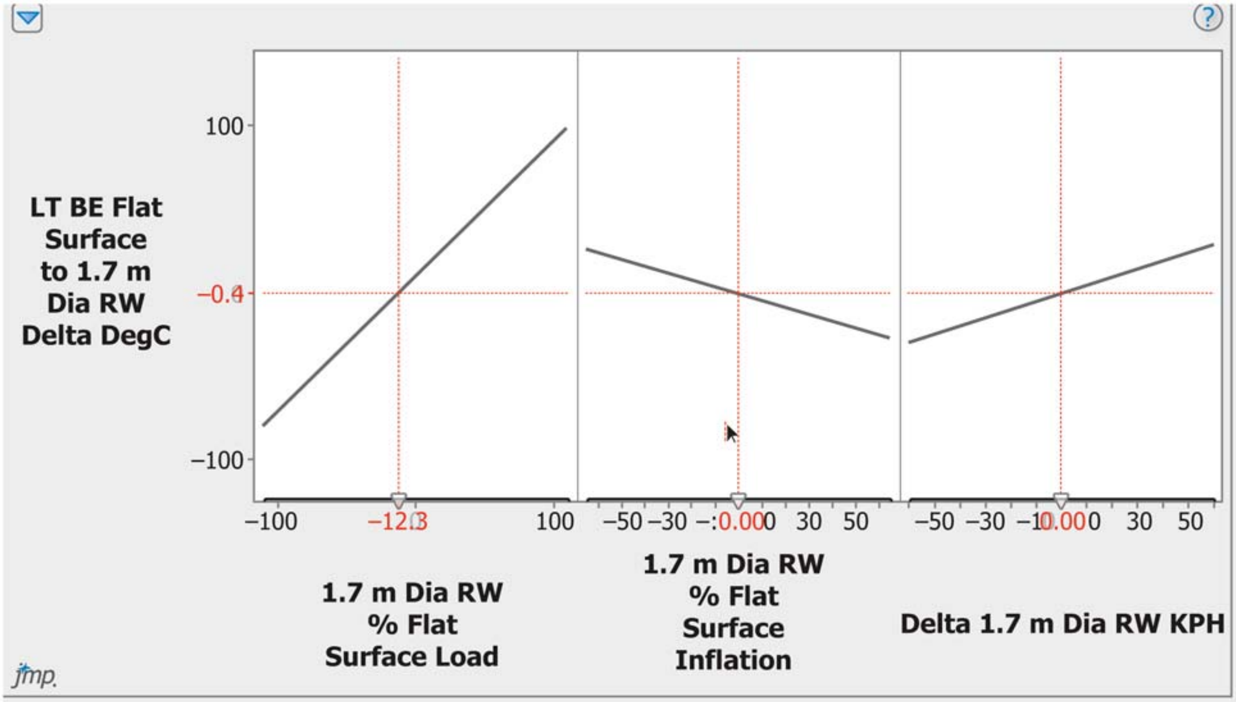

FIG. A1.1 Flat-to-Curved Prediction Profiler Results

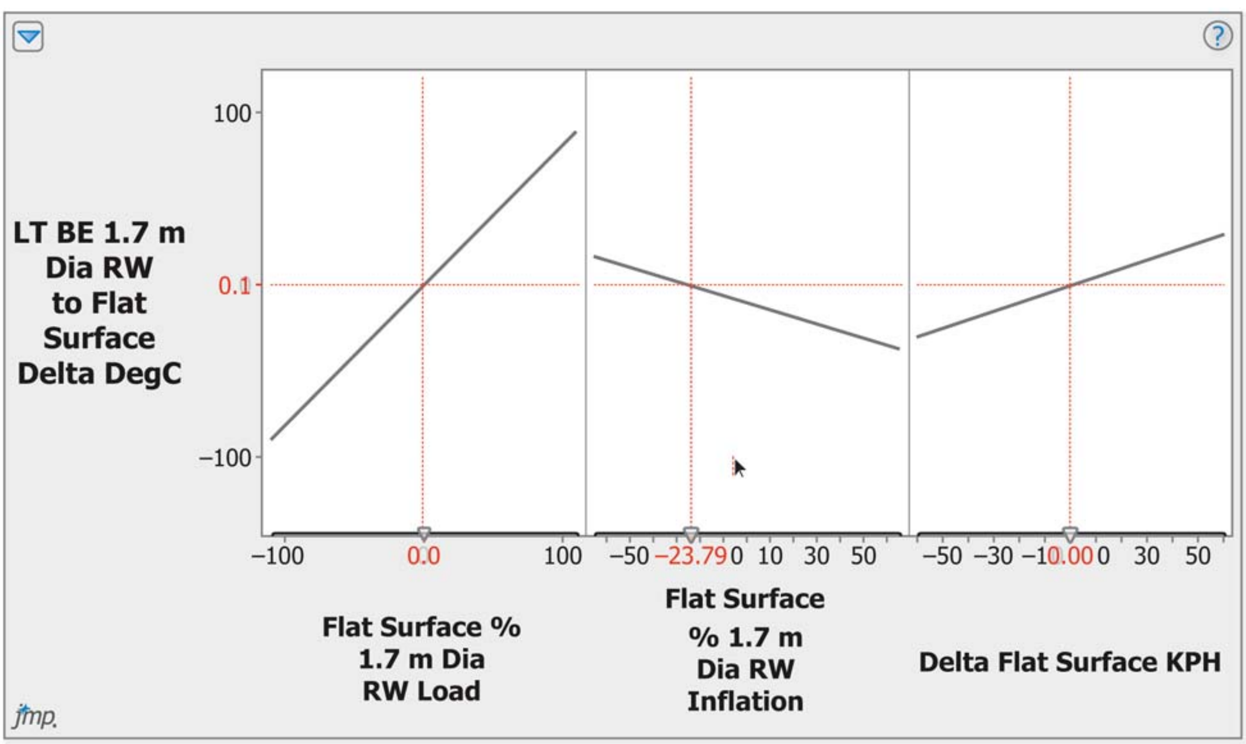

FIG. A1.2 Curved-to-Flat Prediction Profiler Results

APPENDIXES

(Nonmandatory Information)

X1. MEASURED TIRE TEMPERATURE LOCATIONS

X1.1 *Measured Tire Temperature Locations*—As defined in Section 3 (Terminology), the belt edge temperatures were measured (and predicted when using the developed model(s)) at the locations as shown within the tire cross section in Fig. X1.1.

NOTE X1.1—Shoulder and bead filler (at the top of rim flange) locations were also included in the analysis. Of all of the internal tire temperature locations, the belt edge consistently had the highest measured temperatures for all of the conditions tested after thermal equilibrium was established.

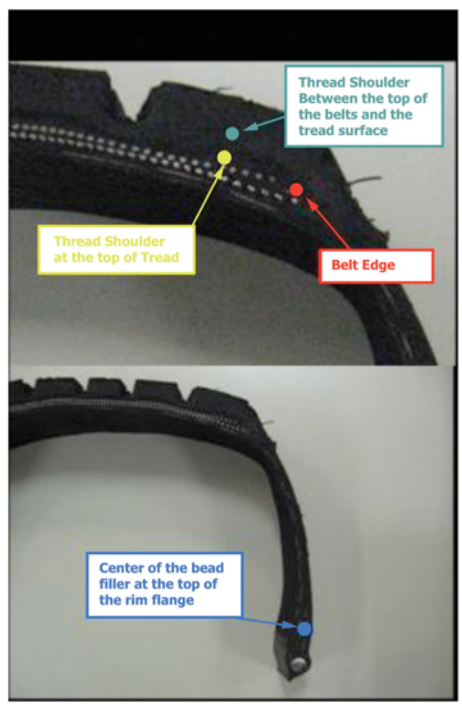

FIG. X1.1 Thermocouple Locations for Internal Tire Temperature Measurements

X2. RATIONALE

X2.1 A standard practice is needed to provide an industry standard for radial light truck tire laboratory temperature algorithms that equilibrate with highway (flat surface) operating temperatures and to determine equivalency for road versus laboratory operating conditions. Users of the new standard are expected to be government agencies, independent tire testing labs, and tire manufacturers.

X2.2 Therefore, it was necessary to develop the ASTM standard practice so that radial light truck tire performance can be evaluated through a standard industry method based upon internal tire temperatures that have been predicted using the algorithms developed by the radial light truck test development task groups of ASTM F09 Tire Committee.

X2.3 This practice describes the process to identify equivalent test severity, 1.707-m diameter laboratory, roadwheel test conditions for specific road operating conditions of load range radial light truck (LT) through load range E used on vehicles having a gross vehicle weight rating (GVWR) of ≤4536 kg.

X2.4 The standard refers to prediction profilers to determine laboratory test conditions that provide equivalent tire temperatures for the belt edge region between curved (laboratory) and flat (highway) test surfaces. The profilers are empirically-based, linear-regression-modeling tools that are included within this standard.[2]

X2.5 *Radial Light Truck Tire Endurance Performance*:

X2.5.1 Tire endurance performance is not only dependent on the tire's design but also on certain operating conditions such as load, inflation pressure, and speed as well as the environment in which the tire operates.

X2.5.2 In service, tires are subjected to a variety of conditions:

X2.5.2.1 Ambient temperatures can range from –20°C to over 40°C.

X2.5.2.2 Highway speeds can rang fro 90 to 120 km/h.

X2.5.2.3 Vehicle tire loads can vary with respect to its gross vehicle weight rating.

X2.5.2.4 Inflation pressure can range from the vehicle manufacturer's recommended inflation pressure, to the sidewall-stamped inflation pressure, to a fleet service pressure, or to something less due to service related conditions.

X2.5.3 Certain combinations of these operating conditions can result in tires experiencing elevated temperatures when operated under high loads, high speed or low inflation pressure and have a bearing on tire performance and service life (**1**).[4]

X2.5.4 At highly elevated tire operating temperatures, thermally driven changes in tire material properties can occur and tire performance and service life may be negatively impacted. A properly maintained and operated tire will have temperatures that do not result in significant thermal changes in the tire material properties.

X2.5.5 Therefore, endurance testing is done by the tire manufacturer as part of the evaluation of tire performance.

X2.5.6 Testing for endurance, like many other tire tests, is usually performed in the laboratory on a 1.707-m diameter rotating roadwheel. The tire is rotated under load and speed on a surface that has a relatively high curvature compared to the highway, where the surface is nearly flat. Due to this difference in curvature between a flat surface and the roadwheel, several tire effects are created and must be considered:

X2.5.6.1 A foreshortening of the tire contact patch (or "footprint") resulting in higher overall footprint contact pressures and tire stresses.

X2.5.6.2 A change in shape of the footprint itself; that is, different from its optimal, flat surface shape that results increases in the centerline contact pressure and tire stresses.

X2.5.6.3 An overdeflection of the tire sidewall due to the reverse curvature of the footprint.

X2.5.6.4 An increase in the flex cycle severity.

X2.5.7 As a result, local heat generation rates increase and tire temperature will often be significantly higher when the tire is tested on the roadwheel compared to a tire used on the road at the same load, inflation pressure and rotational speed.

X2.5.8 Consequently, laboratory test conditions that are equal to road conditions can result in end-of-test (EOT) events that are not representative of typical highway tire removal conditions. For example, thermal reversion manifested as tread chunking, can be a laboratory EOT condition which is a consequence of the testing method. In such cases, the test termination does not correspond to what could have taken place during normal on-vehicle use. Occurrence of such non-representative EOT events effectively nullifies the validity of the test and prevents an evaluation of the endurance issues that may exist for the tire. Furthermore, if the test is required for compliance qualifications, tires that may have excellent endurance performance on the road can be removed prior to the required test completion as a result of the non-representative EOT event.

X2.5.9 Therefore, due to the significance of the tire operating conditions, e.g. speed, inflation pressure, and load on tire performance, and the increased severity of testing on a curved surface, it is critical to conduct laboratory roadwheel tire tests using test conditions that reflect temperature equivalency to specific road (flat surface) operating conditions if a meaningful measure of tire endurance is to be achieved.

X2.6 This standard practice describes the procedures of using the flat-to-curved (FTC) prediction profiler to identify the equivalent test severity conditions on a 1.707-m diameter

[4] The boldface numbers in parentheses refer to the list of references at the end of this standard.

laboratory roadwheel from specific flat or highway operating conditions for radial pneumatic light truck (LT) tires up through load range E tires used on vehicles having a gross vehicle weight rating (GVWR) of ≤4536 kg.

X2.7 The practice is applicable to the converse, as well, that is, highway test conditions can be identified from specific roadwheel test conditions by the curved-to-flat (CTF) prediction profiler.

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