Designation: E670 – 09 (Reapproved 2015)

Standard Test Method for Testing Side Force Friction on Paved Surfaces Using the Mu-Meter[1]

This standard is issued under the fixed designation E670; 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 measurement of the side force friction of paved surfaces utilizing a device commonly called a Mu-Meter.[2]

1.2 This test method utilizes a measurement obtained by pulling the Mu-Meter, containing two freely rotating test wheels angled to the direction of motion, over a pavement surface at a constant speed while the test wheels are under a constant static load. This method provides data of the side force friction (and other data) along the whole length of the test surface being tested which is applied to a variety of computerized algorithms enabling the production of results including (but not limited to) rolling averages, numeric and graphical representations, friction mapping and reports formatted in the layout approved by a wide variety of national airport regulators.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

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.* See also Section 6.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D297 Test Methods for Rubber Products—Chemical Analysis

D412 Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension

D1054 Test Method for Rubber Property—Resilience Using a Goodyear-Healey Rebound Pendulum (Withdrawn 2010)[4]

D1765 Classification System for Carbon Blacks Used in Rubber Products

D2240 Test Method for Rubber Property—Durometer Hardness

D3182 Practice for Rubber—Materials, Equipment, and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets

E178 Practice for Dealing With Outlying Observations

E303 Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester

E1551 Specification for Special Purpose, Smooth–Tread Tire, Operated on Fixed Braking Slip Continuous Friction Measuring Equipment

3. Summary of Test Method

3.1 The Mu-Meter consists of a trailer similar to the one in Fig. 1, which is towed by a vehicle.[2]

3.2 The test tires are positioned in the test mode. The Mu-Meter is brought to the desired test speed. Water (if applicable) is delivered ahead of the test tires and the beginning of the test is marked. The resulting sideways friction force acting between the test tires and the pavement surface is digitized and recorded in the volatile memory of the processor

[1] This test method is under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee E17.21 on Field Methods for Measuring Tire Pavement Friction.

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[2] The sole source of supply of the apparatus known to the committee at this time is Douglas Equipment Ltd, Douglas House, Village Road, Arle, Cheltenham, Gloucestershire UK GL51 0AB and Douglas Equipment International, 8305 Cherokee Boulevard, Douglasville, Douglas County, Atlanta, Georgia 30134 USA. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[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.

[4] The last approved version of this historical standard is referenced on www.astm.org.

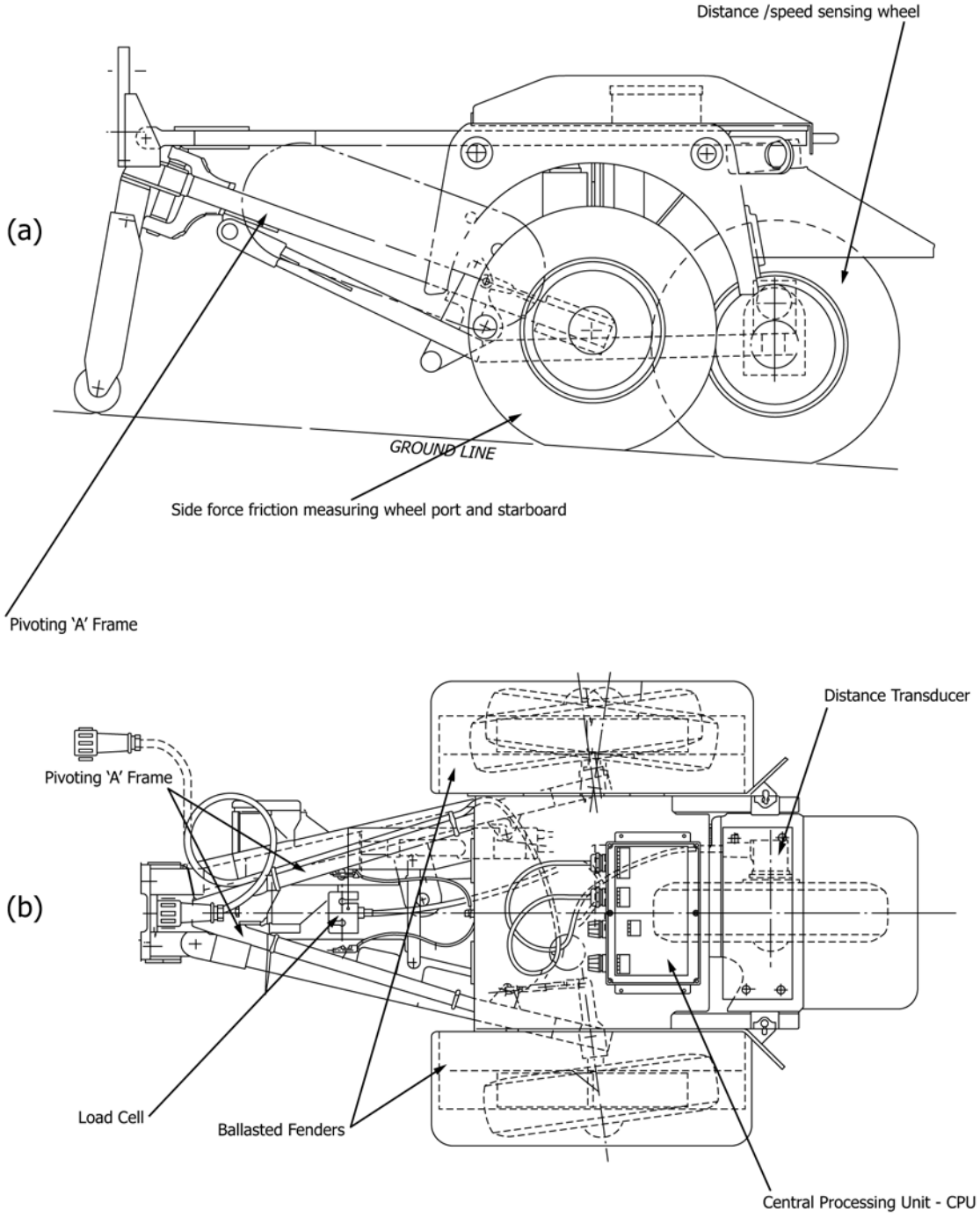

FIG. 1 Mu-Meter Schematics

mounted on the trailer and subsequently displayed on the in-cab monitor (usually a laptop or tablet computer) for subsequent display or downloading. The speed and distance traveled by the test vehicle is also recorded by integrated on-board systems.

3.3 The friction analysis is displayed on the in cab monitor and can be down loaded to other PCs as required by the client for analysis utilising the software provided. Results report the Mu Number (MuN).[5]

4. Significance and Use

4.1 The knowledge of side force friction serves as an additional tool in characterizing pavement surfaces. Side force friction data alone may be of limited value in determining the suitability of paving materials or finishing techniques. However, when used in conjunction with other physical and chemical tests, the side force friction may contribute to characterization of pavement surfaces.

4.2 The values measured with the equipment and procedures stated herein do not necessarily agree or correlate directly with those obtained by other paved surface friction measuring methods.

5. Apparatus

5.1 *Tow Vehicle*—The tow vehicle shall be capable of towing the Mu-Meter at a speed of at least 40 mph (65 km/h) and maintaining this speed within ±0.5 mph (0.8 km/h). If tests are conducted at speeds greater than 40 mph, the vehicle shall be capable of maintaining these speeds within ±1 mph (1.5 km/h). The vehicle shall have a suitable towing hitch of either ring eye or ball hitch design. The towing ball/hook shall be placed so that the standard datum line on the Mu-Meter is 12 ± 0.5 in. (305 ± 13 mm) from the ground. In either case the hitch height shall not vary more than 2 in. (51 mm) between the loaded and unloaded towing vehicle condition.

5.2 *General Requirements for Measuring System*—The instrumentation system shall conform to the following overall requirements at ambient temperatures between 40 and 100°F (4 and 38°C) as follows:

-Overall system accuracy ±3 % of full scale
-Time stability calibration 10 h minimum
-The exposed portions of the measuring system shall tolerate 100 % relative humidity (rain or spray) and all other adverse conditions, such as dust, shock, and vibrations that may be encountered in pavement test operations.

5.2.1 *Trailer*—The trailer configuration for testing shall be essentially as shown in Fig. 1 with the two test wheels, each mounted so that when the measuring position is selected the front of each wheel shall be splayed out to angle of 7.50° ± 0.75° (15.00° inclusive angle) relative to the centerline of the Mu-Meter. The two test wheels are mounted on frames joined at the towbar on a needle bearing which allows them to pivot relative to each other, such travel limited by sensitive strain gauge, which senses the side force friction, generated between the wheels. The rear-centralized wheel operates a distance encoder, which is utilized by the system to measure distance traveled and via an internal clock speed.

5.2.2 *Force Cell*—The geometry of the chassis structure within the measuring A frame fabrication ensures that the load cell is mounted in a position such that 500 lbf (2225 N) of tensile force is equivalent to the side force exerted by the wheels on a pavement having a MuN (Mu Number) of 100. The extension of the load cell during a test shall be sufficiently small to limit the movement of the measuring wheels in such a way that the total included angle between the test tires does not change by more than 0.5° during the test. The load cell shall provide an output directly proportional to the force with hysteresis less than 2 % of the applied load up to the maximum expected loading, and sensitivity to any expected cross-axis loading less than 2 % of the applied load. The load cell shall be mounted in such a manner as to experience less than 1° angular rotation from the horizontal plane at the maximum expected loading.

5.2.3 *Wheel Load*—The apparatus shall have the following vertical static loads when the unit is in the toe-out position ready for testing and when the tires are inflated to their proper pressures:

Each test wheel 171 ± 2 lbf (761 ± 9 N)
Rear wheel 118 to 138 lbf (525 to 614 N)
Towing hitch 80 lbf (360 N)

5.2.4 *Tires (see Annex A1 – Annex A3):*

5.2.4.1 The Mu-Meter will be fitted with tires manufactured to Specification E1551. The tire pressure in the two test wheels shall be 10 ± 0.5 psi (69 ± 3 kPa) measured at ambient temperature (cold).

5.2.4.2 The rear-stabilizing tire shall be treaded and shall be the same size as the test tires. Tire pressure in the rear-stabilizing tire shall be 30 ± 2 psi (207 ± 14 kPa) measured at ambient temperature (cold).

5.2.5 *Processor CPU*—The CPU shall record and interpret the data output of the load cell over the range 0 to 500 lbf (0 to 2225 N) and store the processed data within its volatile memory and on the cab laptop nominated drive. The CPU shall also store unlimited event markers (dependant on display definition and pixilation) The CPU will also store and process the start and end position of each run, the time of start and other information inputted manually by the operator for run referencing at a later date.

5.2.6 *Vehicle Speed-Measuring Encoder*—The distance and speed encoders shall provide speed resolution and accuracy of ±1.5 % of the indicated speed or ±0.5 mph (±0.8 km/h), whichever is greater. The output shall be directly viewable by the operator. The speed shall be recorded.

5.3 *Pavement Wetting System:*

5.3.1 The water shall be applied to the pavement ahead of the test tires utilising a nozzle manufactured to the dimensions conforming to Fig. 2. For airport runways, the recommended quantity of water applied shall be proportional to test speed and to provide a depth of 0.020 in. (0.5 mm) over a width at least 1 in. (25 mm) wider than the toed-out test-tire pavement width and applied so the tire is centrally located between the wetted edges during the actual testing.

5.3.2 The nozzle configuration and position, shall ensure that the nozzle centerline is pointed toward the paved surface at an angle of 25 ± 2°. The water shall strike the paved surface 6 to 8 in. (150 to 200 mm) ahead of the vertical centerline of the Mu-Meter test tire. The nozzle shall be of such a height that it clears all obstacles that the Mu-Meter is expected to

[5] Refer to manufacturers operational manual (SEDP316 Iss.10) for method of interpreting Mu numbers from the data.

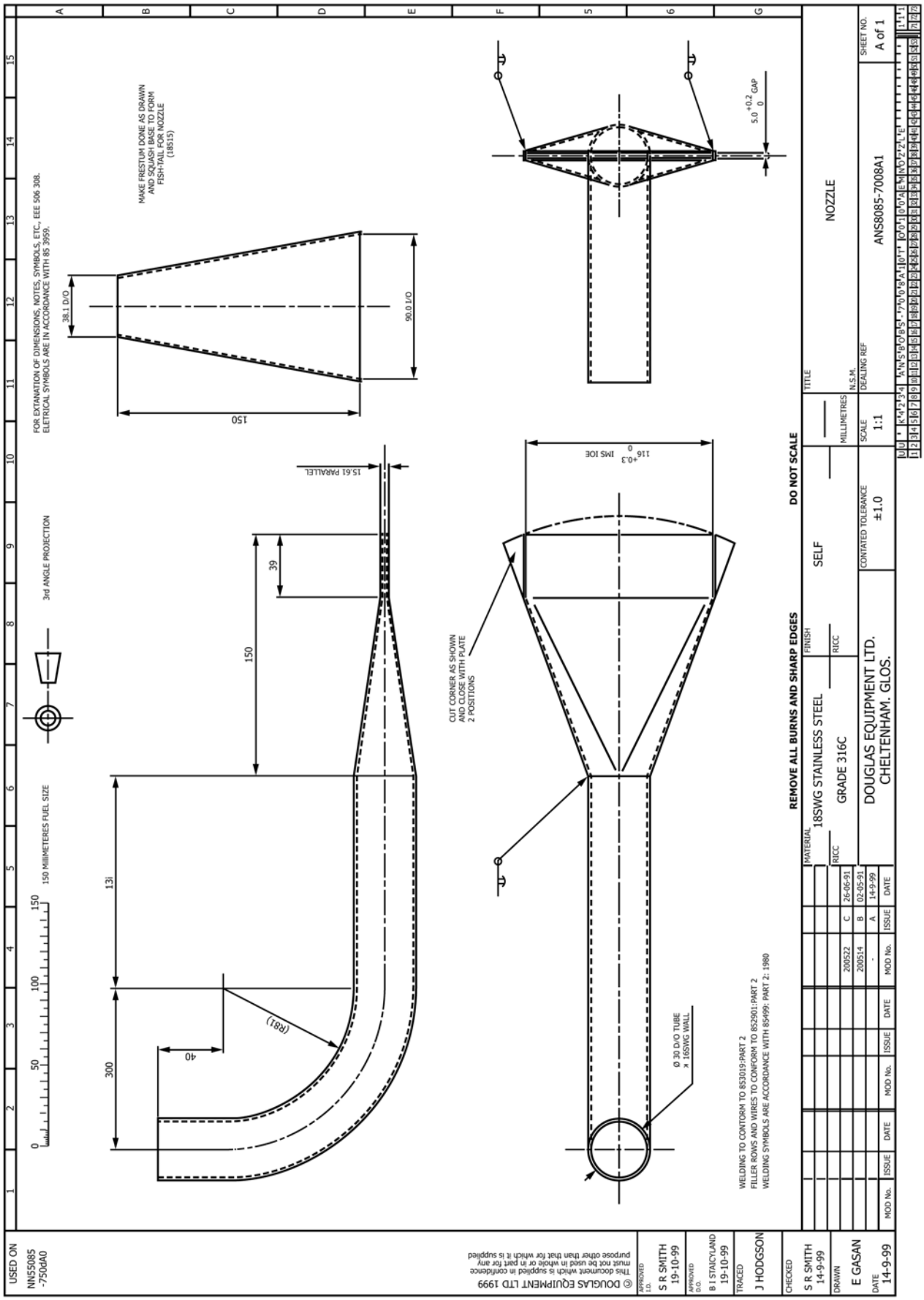

FIG. 2 Pavement Wetting

encounter and shall provide a water-wetted width as required in 5.3.1, but in no case shall the nozzle be more than 4 in. (100 mm) above the paved surface.

5.3.3 The water used shall be reasonably clean with no chemicals added, such as wetting agents or detergents.

6. Safety Precautions

6.1 The towing vehicle and Mu-Meter, as well as all attachments, shall comply with all applicable state and federal laws. All necessary precautions shall be taken to ensure the safety of personnel and other traffic. No tests shall be made if there is danger that the dispersed water may freeze on the pavement.

7. Sampling

7.1 *Test Sections*—Sharp curves and steep grades shall not be included in a test section with level tangent sections, nor shall passing lanes be included with traffic lanes. An attempt shall be made to keep test sections as uniform as possible so the resulting average of the recorded test shall be an average of a uniform surface. Normally, highway testing shall be accomplished with the left test wheel in the center portion of the left wheel wear path of a traffic lane. Normally, for monitoring purposes, airport testing shall be performed approximately 10 ft (3 m) from the centerline of the runway and should encompass the full length of the runway. Areas of the runway with rubber deposit buildup, paint markings, or other contaminants, shall be analyzed as separate sections.

8. Calibration

8.1 All aspects of calibration of the Mu-Meter are covered in Appendix X1 of this test method.

9. General

9.1 *Tire Preparation*—New test wheel tires must be conditioned by running them at their normal inflation pressures in the test position on the Mu-Meter, until such time as the running surface of the tire adopts a consistent smooth matt appearance, usually 4–6 miles. Inspect previously used tires for damage and other irregularities that may affect the test results and reject tires that have been damaged or worn to the extent that the underlying ply stranding has become to be exposed.

9.2 *Test Preparation*—Check the tires for flat spots, irregularities, or other damage before running a test. Check the inflation pressures in accordance with 5.2.4. Recheck the suspension to see that it is free to move with no binding or tight spots. Prior to each series of tests, warm up the tires by traveling at least 5 miles (8 km) at normal traffic speeds in the normal non toed-out position. Place the test wheels in the toe-out position and the third wheel in the down position. The test wheels shall be free to rotate but locked in the toe-out position. The rear wheel shall be free to move up and down, restrained only by its spring load.

9.3 *Test Speeds*—Run the standard test at 40 ± 0.5 mph (65 ± 0.8 km/h) or in accordance with the local national regulations. Maintain test speeds of 40 mph or less to ±0.5 mph and test speeds over 40 mph to ±1.0 mph (1.5 km/h). At all speeds other than 40 mph, record the speeding the screen position noted.

10. Procedure

10.1 Check the Mu-Meter as in 9.2. Bring the apparatus to the test speed. If required by local regulations, begin delivery of water to the test tires approximately 1 second before the test is initiated and continue until the test is completed or water supply depleted, whichever occurs first.

10.2 Mu numbers will be displayed on the in cab laptop display, along with other reported data as defined necessary for the selected national standard.

11. Faulty Tests

11.1 Tests that are faulty or give Mu Numbers differing by more than 5 MuN from the average of all tests of the same test section shall be treated in accordance with Practice E178.

12. Report

12.1 *Field Report*—The field report for each test section shall contain data on the following items:

12.1.1 Location and identification of test section,

12.1.2 Date and time of day,

12.1.3 Weather conditions (principally temperature, cloud cover, and wind),

12.1.4 Lane and section tested,

12.1.5 Speed of test vehicle and water depth (for each test),

12.1.6 Average Mu Number for each test section,

12.2 *Summary Report*—The summary report shall include, for each test section, data on the following items insofar as they are pertinent to the variables or combinations of variables under investigation:

12.2.1 Location and identification of test section,

12.2.2 Number of lanes and presence of lane separators,

12.2.3 Pavement type (mix design of surface course, condition, and aggregate type, if available),

12.2.4 Age of pavement,

12.2.5 Average daily traffic,

12.2.6 Average traffic speed (or speed mix as in the case of grade with heavy truck traffic),

12.2.7 Date and time of day,

12.2.8 Weather conditions,

12.2.9 Lane and section tested,

12.2.10 Average Mu Number for test section, and

12.2.11 Highest and lowest values entered into the average.

13. Precision and Bias

13.1 The relationship of observed MuN units to some “true” value of side force friction has not been studied at this time. As a result, only repeatability is given for the method.

13.2 The acceptable precision of MuN units can be stated in the form of repeatability. As there is no significant correlation between standard deviation and arithmetic mean of sets of test values, it appears that standard deviations are applicable to this test regardless of the average side force friction of the surface.

Pooling data from different Mu-Meters and peer testing derived an acceptable standard deviation of 2.0 MuN units, each tested on different surfaces.

13.3 The number of tests required to assure that the average of the measured values stays within the allowable error 95 % of the time can be determined by the following equation:

$$n = \left[\frac{t\sigma}{\varphi}\right]^2 \quad (1)$$

where:

φ = allowable error,
t = normal curve value of 1.96 for 95 % confidence,
σ = standard deviation of test results (MuN units), and
n = number of tests.

ANNEXES

(Mandatory Information)

A1. SPECIFICATION FOR MU-METER TIRE

A1.1 Scope

A1.1.1 This specification covers the general requirements for the Mu-Meter standard tire for measuring the side-force friction coefficient generated between the pavement surface and the smooth tread tires on the two measuring wheels toed-out to the line of drag.

A1.2 Materials and Manufacture

A1.2.1 The individual standard tires shall conform to the design standards of Section A1.4. Fig. A1.1 is a photograph of the Mu-Meter tire. Dimensions, weights and permissible variations are given in Section A1.4 and in Fig. A1.2.

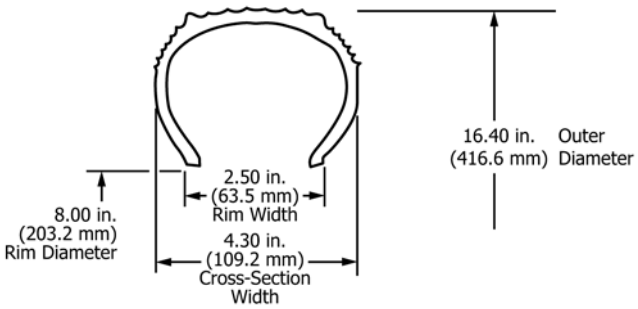

FIG. A1.2 Mu-Meter Test Tire Dimensions

FIG. A1.1 Mu-Meter Test Tire

A1.2.2 Tread compounding, fabric processing, and all steps in tire manufacturing shall be certified to ensure that the specifications are met.

A1.2.3 There are "no-wear" indicators as such to determine when the maximum wear level for testing has been reached. However, there are six curb ribs on each side of the tire. As soon as the tire has worn to the first curb rib, more frequent observations of wear should be made. The tire should be removed from service soon after it has worn to the first curb rib and before the tire cord is exposed.

A1.2.4 When a new tire is placed on one of the two wheels, a new tire must be placed on the other wheel also.

A1.3 Chemical Requirements

A1.3.1 The compounding requirements are given in Table A1.1.

NOTE A1.1—Certain proprietary products have been specified since exact duplication of properties of the finished tire may not be achieved with other similar products. This inclusion does not in any way comprise a recommendation for these proprietary products nor against similar products of other manufacturers, nor does it imply any superiority over any such similar products.

A1.4 Physical Requirements

A1.4.1 The physical and mechanical test requirements are given in Table A1.2.

A1.5 Dimensions, Weights, and Permissible Variations

A1.5.1 *General*—Details of dimensions are shown in Fig. A1.2. All tire dimensions are subject to the manufacturer's normal tolerances.

A1.5.2 *Construction:*

TABLE A1.1 Compounding

Material	Parts by Mass
SBR 1712	100.0
N375 black	56.0
40 mesh crumb	14.0
Aromatic oil	9.5
Zinc oxide	3.0
Stearic acid	1.0
Nonox ZA	2.5
Paraffin wax	2.0
Sulfur	1.6
Santocure MOR	1.0

TABLE A1.2 Physical Requirements

Tensile sheet cure at 140°C	60 min @ 140°C
Tensile strength, psi (kPa)	2200 (15.2)
300 % modulus, psi (kPa)	1100 (7.6)
Elongation at break, %	500
Hardness (Shore A)	65
Resilience, %	50
Specific gravity	1.160

A1.5.2.1 The tire shall be a size 4.00-8 (16 by 4) by 6 ply tube type tire. The outside diameter shall be 16.40 in. (417 mm), cross section 4.30 in. (109 mm), and rim width 2.50 in. (64 mm).

A1.5.2.2 The RL 2 tire currently being used has a shallow tread pattern of seven grooves of 0.04 in. (1 mm) depth. For the Mu-Meter application, the tire is considered to be of plain pattern. When a new set of tires is put on, no readings are taken until the tires are run at the set slip angle and the ribs worn away.

A1.6 Workmanship

A1.6.1 Tires shall be free of defects in workmanship and materials.

A1.7 Certification

A1.7.1 Upon request, the manufacturer shall furnish the purchaser certification that the tire meets this specification.

A1.7.2 All tires under certification shall be subject to the manufacturers normal variation.

A1.8 Preservation

A1.8.1 The tires should be kept dry under ordinary atmospheric conditions in subdued light.

A1.9 Recommendations for Tire Use and Operational Requirements

A1.9.1 The RL 2 Mu-Meter tire is considered broken in when the 0.04-in. (1-mm) shallow tread pattern is worn off as described in A1.5.2.2.

A1.9.2 Tire pressure in the two measuring wheels shall be 10 ± 0.5 psi (69 ± 3 kPa) measured at ambient temperature (cold).

Suggested Marking on Tire:

4.00-8 plus all DOT Requirements.
Mu-Meter Test Tire—Not for General Highway Use.
Manufacturer's Name or Trademark.

A2. SPECIFICATION FOR AN ALTERNATE MU-METER TIRE

A2.1 Scope

A2.1.1 This specification covers the general requirements for an alternate Mu-Meter tire for measuring the side-force friction coefficient generated between the pavement surface and the smooth tread tires on the two measuring wheels toed-out to the line of drag.

A2.2 Materials and Manufacture

A2.2.1 The individual standard tires[6] shall conform to the design standards of Section A2.4. Fig. A2.1 is a photograph of the alternate Mu-Meter tire. Dimensions, weights and permissible variations are given in Section A2.5 and in Fig. A2.2.

A2.2.2 Tread compounding, fabric processing, and all steps in tire manufacturing shall be certified to ensure that the specifications are met (See Section A2.7, Test Methods).

A2.2.3 There are "no wear" indicators as such to determine when the maximum wear level for testing has been reached. Before the tire has worn to the fabric, the tire shall be removed from service.

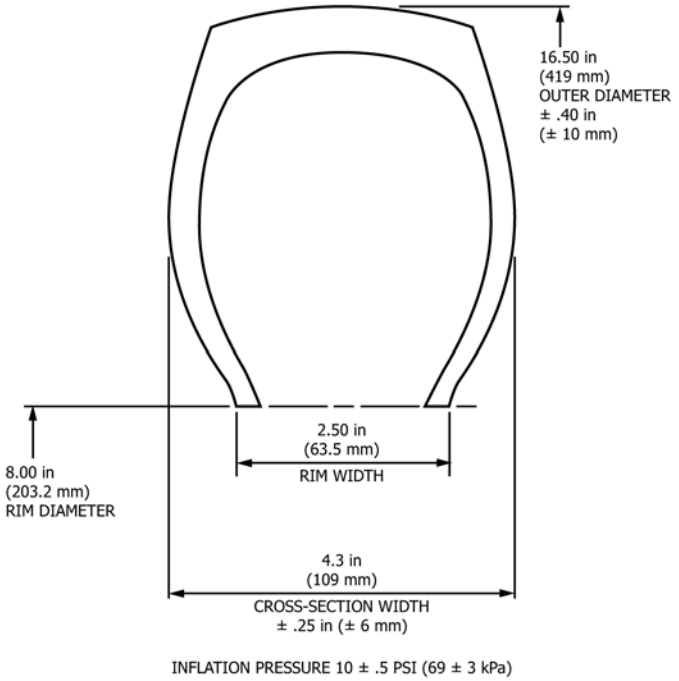

FIG. A2.2 Alternate Mu-Meter Tire Dimensions

[6] ASTM E670 tire is available from Dico Tire, Inc., 520 J.D. Yarnell Industrial Parkway, Clinton, TN 37716.

FIG. A2.1 Alternate Mu-Meter Tire

A2.2.4 When a new tire is placed on one of the two wheels, a new tire must be placed on the other wheel also.

A2.3 Material Requirements

A2.3.1 The compounding requirements are given in Table A2.1. See Note A2.1.

NOTE A2.1—Certain proprietary products have been specified since exact duplication of properties of the finished tire may not be achieved with other similar products. This inclusion does not in any way comprise a recommendation for these proprietary products nor against similar products of other manufacturers, nor does it imply any superiority over any such similar products.

A2.4 Physical Requirements

A2.4.1 The physical and mechanical test requirements are given in Table A2.2.

A2.5 Construction, Dimensions, and Permissible Variations

A2.5.1 *Construction*—The tire shall be a size 4.00–8 (16 by 4) by 6 ply tube type tire.

A2.5.2 *Dimensions*—Tread width shall be 2.9 ± 0.1 in. (74± 2.5 mm); the tread radius shall be 8.0 ± 2.0 in. (203 ± 51 mm); the cross-sectional width shall be 4.1 ± 0.25 in. (104 ± 6.0 mm); and the outside diameter at the tread centerline shall be 16.5 ± 0.40 in. (419 ± 10 mm) and a rim width of 2.50 in. (63.5 mm) at an inflation pressure of 10 ± 0.5 psi (69 ± 3 kPa). See Fig. A2.2 which shows the inflated dimensions of the tire. The tread rubber at the centerline measures 0.45 in. (11 mm) in thickness.

A2.5.3 *Tread*—For Mu-Meter application, the alternate tire is considered to have no tread pattern. To break-in a new set of tires, it is only necessary to remove the gloss on the tread surface.

A2.6 Workmanship

A2.6.1 Tires shall be free of defects in workmanship and materials.

TABLE A2.1 Compounding of Tread Rubber[A]

Material	Parts by Mass
SBR	55.0
Natural Rubber[B]	40.0
Polybutadiene[C]	20.0
N330 Carbon Black[D]	39.9
N339 Carbon Black[D]	24.0
Aromatic Oil	2.5
Zinc Oxide	2.0
Fatty Acid	1.4
Petroleum Wax	3.2
UOP 562[E]	2.0
Santocure NS	1.2
Sulfur[F]	1.3

[A] See Practice D3182.
[B] Styrene Butadiene Rubber (23.5 % Styrene) with 37.5 PHR of High Aromatic Oil.
[C] Cis Polybutadiene.
[D] See Classification D1765.
[E] Blend of N-(1,3-Dimethylbutyl)-N'-Phenyl/N-(1-Methylheptyl)-N,Phenyl/N, N'-Bis91-Methylheptyl) *p*-Phenylenediamine.
[F] t-Butyl Benezothiazole Sulfenamide.

TABLE A2.2 Physical Requirements

Tensile Sheet Cure at 298°F (147.8°C)	20 min
Tensile strength, min psi (MPa) (Test Method D412)	2200 (15.7)
300 % modulus, psi (MPa) (Test Method D412)	1100 (7.6) ± 200
Elongation at break min % (Test Method D412)	500
Hardness (Shore A) (Test Method D2240)	56 ± 2
Specific gravity (Test Method D297)	1.13± 0.02

A2.7 Test Methods

A2.7.1 *Tensile Sheet Cure*—Practice D3182.

A2.7.2 *Modulus (300 %)*—Test Methods D412.

A2.7.3 *Tensile Sheet Durometer*—Test Method D2240, using Type A Shore Durometer.

A2.7.4 *Restored Energy (Rebound or Resilience)*—Test Method D1054.

A2.7.5 *Specific Gravity*—Test Methods D297.

A2.7.6 *Tensile Strength*—Test Methods D412.

A2.7.7 *Elongation*— Test Methods D412.

A2.7.8 *Tire Tread Durometer*—Test Method D2240, in addition to the following procedures:

A2.7.8.1 Use Type A Durometer. (A 0.5 in. (12.7 mm) diameter presser foot, Shore, code XAHAF is recommended.)

A2.7.8.2 The durometer shall be calibrated at a reading of 60 hardness.

A2.7.8.3 Condition the tire and durometer to equilibrium at 73.4 ± 3.6°F (23 ± 2°C) before determining tread hardness.

A2.7.8.4 The tire tread hardness is to be determined by averaging at least one set of six readings. A set should consist of readings taken at equally spaced intervals across the tread. It is recommended that additional sets of readings be taken around the tread circumference.

A2.7.8.5 Apply presser foot to the tire tread as rapidly as possible without shock, keeping the foot parallel to the tread surface. Apply just sufficient pressure to obtain firm contact between presser foot and tire tread surface. Read the durometer scale within 1 s after presser foot is in contact with the tire tread, but after initial maximum transient which may occur immediately after contact is made.

A2.8 Certification

A2.8.1 Upon request, the manufacturer shall furnish the purchaser certification that the tire meets the specification.

A2.8.2 All tires under certification shall be subject to the manufacturers normal variation.

A2.9 Packaging and Preservation

A2.9.1 The tires should be stored in a dry area, at a temperature not exceeding 90°F (32.2°C) and in subdued light. Tires must not be stored near electric motors, welders, or other ozone generating equipment. The tire is not to be used as a standard test tire after more than one year storage by the consumer nor if it has been stored at more than 85°F (29.4°C) for more than 60 days.

A2.10 Recommendation for Tire Use and Operational Requirements

A2.10.1 The tire is used for measuring tire-pavement friction forces only and is not designed for general highway service.

A2.10.2 A new tire break-in sufficient to only remove the glossy tread surface is recommended before using the tire for testing. This break-in time will vary with pavement surface condition, speed, and test tire operating mode.

A2.10.3 The tire shall be operated on a Mu-Meter side-force friction measuring device.

A2.10.4 The tire pressure in the two measuring wheels shall be 10 ± 0.5 psi (69 ± 3 kPa) measured at ambient temperature (cold).

A2.10.5 The recommended static test load on the tire shall be 171 ± 2 lbf (761 ± 9 N) with loading to a maximum of 205 ± 2 lbf (912 ± 9 N) permissible, at 10 ± 0.5 psi (69 ± 3 kPa) inflation pressure.

A2.10.6 When any irregular wear or damage results from testing, or when the tread wear indicator is no longer visible, the use of the tire as a standard test tire shall be discontinued.

Suggested Marking on Tire:
ASTM (Designation of specification)
4.00-8 NHS
4 PLY RATING
TUBE TYPE
Manufacturer's Name or Trademark.

A3. TESTING THE E670 TIRE FOR RELIABILITY, PERFORMANCE AND CONSISTENCY

A3.1 Scope

A3.1.1 This specification describes the test procedures for establishing the reliability, performance, and consistency of the tire from batch to batch.

A3.2 Certification

A3.2.1 The manufacturer of the tire will certify that testing has been completed on each batch of tires.

A3.2.2 A certified testing company may be sub-contracted by the manufacturer to accomplish the testing and certification according to these procedures.

A3.2.3 Testing will be conducted on a properly calibrated continuous friction measuring device, such as the Mu-Meter. (See Section 8.)

A3.3 Tire Sampling

A3.3.1 The number of tires randomly selected from each batch is determined from Table A3.1.

A3.3.1.1 To ensure random selection of test tires, the tire manufacturer shall divide the batch into as many equal sublots as the number of test tires required by Table A3.1. One tire is then randomly selected from each sublot.

A3.3.1.2 In addition to the current tires selected for comparative testing with the previous batch tires, the manufacturer shall also retain and properly store the required number of randomly selected tires from the current batch for future comparative testing with the next batch of tires produced. This will always double the random sample size requirement given in Table A3.1.

A3.3.2 Each tire selected shall be properly labeled according to sequential batch number and marked accordingly to the order of their selection.

TABLE A3.1 Random Sampling of Tires from Tire Batch Size to Determine Acceptance/Failure

Tire Batch Size	Random Tire Sample Size For Testing		Accept if Number of Failed Tires Equals		Reject if Number of Failed Tires Equals	
	Tires	Pair	Tires	Pair	Tires	Pair
51 to 150	10	5	2	1	4	2
151 to 500	16	8	4	2	6	3
501 to 1200	26	13	6	3	8	4

A3.4 Test Surfaces

A3.4.1 Four test surfaces will be required as follows:
A3.4.1.1 *Test Surface A*— Mu[7] values ranging from 0 to 16.
A3.4.1.2 *Test Surface B*— Mu values ranging from 28 to 44.
A3.4.1.3 *Test Surface C*— Mu values ranging from 56 to 72.
A3.4.1.4 *Test Surface D*— Mu values 84 and above.

A3.4.2 The averaged Mu value for each of the test surfaces identified in A3.4 are based on a minimum of ten passes conducted at 40 mph (65 km/h).

A3.4.2.1 The averaged Mu value shall be as close to the middle of the respective ranges (see A3.4.1) as possible and the continuous friction trace produced by the friction device shall be consistently within a band width of ±3 Mu numbers.

A3.4.2.2 In addition, the averaged Mu value for each test surface shall not vary more than ±3 Mu numbers from the averaged Mu value obtained for that surface (A, B, C or D) for the previous batch of tires.

A3.4.3 The physical length of each test surface shall not be less than 250 ft (75 m) or greater than 500 ft (152 m).

A3.4.4 The data acquisition shall be taken within the physical length of each test surface where the friction values are stabilized and are representative of the test surface.

A3.5 Testing

A3.5.1 The manufacturer or testing facility shall select one tire pair from the current batch of provided samples and one

[7] Mu = μ; Coefficient of friction. Scale ranges from 0 to 100 and equates actual coefficient ratio value multiplied by 100.

tire pair from the previous batch of provided samples. The tires will be properly identified.

A3.5.2 Tests shall be conducted on originally dry pavement test surfaces using the friction device's self-watering system. The water depth shall be 0.04 in. (1 mm), applied in front of the friction measuring tires.

A3.5.3 To minimize ambient temperature influences on friction values, test trials shall be conducted when the temperature is within 80 ± 10°F (27 ± 6°C).

A3.5.4 A minimum of 6 passes shall be conducted at each of 2 speeds, 40 and 60 mph (65 and 95 km/h), on each test surface described in A3.4.1, using the tires selected under A3.5.1.

A3.5.5 The remaining randomly selected tire samples from each batch (see Table A3.1) shall be tested by conducting one pass over each test surface described in A3.4.1 at two speeds, 40 and 60 mph (65 and 95 km/h).

A3.6 Analysis of Test Data

A3.6.1 When the test trials have been completed, statistical analyses shall be conducted to develop the Linear Regression Line to establish the reliability, performance and consistency of the current tire batch with the previous tire batch. Paragraph A3.8 details the parameters for conducting the statistical analysis.

A3.6.2 The averaged Mu value for all tests conducted for each speed shall be within One Standard Error of Estimate or ±3 Mu numbers from the Linear Regression Line for each random tire sample of the previous tire batch versus the random tire sample of the current tire batch.

A3.6.3 The averaged Mu value shall be within One Standard Error of Estimate or ±3 Mu numbers from the statistical calculated Linear Regression Line for each of the remaining random tire samples, (see A3.5.5), for each test surface, and two test speeds.

A3.7 Retesting

A3.7.1 When any one tire pair fails to meet the parameters in one of the three sets given in statistical parameters of A3.8, the tire pair will fail to qualify. If the number of failed tire pairs equal or exceed the number given in the reject column of Table A3.1, the entire batch fails to qualify. No further testing will be conducted until the tire manufacturer completes a thorough check of the tire specification requirements. When the manufacturer is satisfied that the new batch produced meets the tire specification requirements, qualification trials will be rescheduled.

A3.7.2 When any tire pair fails to meet the requirements given in either A3.6.2 or A3.6.3, those tires will be retested. These additional tests are conducted to ensure that no unexplained inconsistency occurred either in the conduct of the test trials or testing procedures, equipment calibration, or in the performance of the statistical analyses.

A3.8 Parameters for the Statistical Analysis

A3.8.1 The three sets detailed in the following paragraphs must be met when conducting the statistical analysis. The data for the previous batch of tires shall be plotted on the *X*-axis and the current batch of tires shall be plotted on the *Y*-axis.

A3.8.2 *Intercept Set*—The parameters for this set are divided into three elements: Intercept at $X = 0$, Slope of Linear Regression Line, and Intercept at $X = 100$.

A3.8.2.1 *Intercept at X = 0*—The parameter for allowable variance at this intercept is ±3 Mu numbers for One Standard Error of Estimate.

A3.8.2.2 *Slope of Linear Regression Line*—A perfect correlation line is established when the Slope of the Regression Line equals 1.000. The parameter for the allowable variance from this line is ±0.080, or the slope range from 0.920 to 1.080.

A3.8.2.3 *Intercept at X = 100*—The parameter for allowable variance at this intercept is ±5 Mu numbers for One Standard Error of Estimate.

A3.8.3 *The Coefficient Set*—The parameters for this set are divided into two elements: the Coefficient of Correlation and the Coefficient of Determination.

A3.8.3.1 *The Coefficient of Correlation*—The minimum acceptable value for the Coefficient of Correlation is 0.980.

A3.8.3.2 *The Coefficient of Determination*—The minimum acceptable value for the Coefficient of Determination is 0.960. The Coefficient of Determination is calculated by squaring the Coefficient of Correlation.

A3.8.4 *Standard Error of Estimate Set*—Consists of only one element, the Standard Error of Estimate. The parameter for this set is± 3 Mu numbers for One Standard Error of Estimate.

A3.9 Precision and Bias

A3.9.1 The analysis of data obtained with several Mu-Meter devices operated by experienced personnel, indicates that duplicated tests show repeatability or agreement within ±3 Mu numbers of the averaged Mu value. Tire friction data obtained with the same operator and under identical test conditions should not be considered suspect unless they differ by more than 5 %.

APPENDIX

(Nonmandatory Information)

X1. CALIBRATION OF A MU-METER STANDARD TEST BOARD

X1.1 Calibration of the Mu-Meter Test Board shall be conducted in accordance with Method E303, with the exception that all tests shall be conducted under dry conditions.

X1.2 Three tests on the Mu-Meter test board shall be conducted on each of the two abrasive surfaces of the test board; one test at each end and one test at the center.

X1.3 New test boards shall provide a British Pendulum (Tester) Number (BPN) between 94 and 100 at 72 ± 2°F (22± 1°C), under dry conditions, for an average of the six test locations on the test board.

X1.4 The test board abrasive surface deteriorates with use. If the BPN of the test board is outside the limits of A1.3, the following correction factor may be applied:

$$MuN = 1.017\ BPN - 20.9 \quad \text{(X1.1)}$$

where:

MuN = Mu Number, and
BPN = British Pendulum (Tester) Number.