Designation: E 670 – 94 (Reapproved 2000)

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

This standard is issued under the fixed designation E 670; 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 wetted pavement surface at a constant speed while the test wheels are under a constant static load. This method provides a continuous graphical record of the side force friction along the whole length of the test surface and enables averages to be obtained for any specified length.

1.3 The values stated in inch-pound units are to be regarded as the 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.* Safety precautionary information is contained in Section 6.

2. Referenced Documents

2.1 *ASTM Standards:*

D 297 Test Methods for Rubber Products—Chemical Analysis[3]

D 412 Test Methods for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers-Tension[3]

D 1054 Test Method for Rubber Property Resilience Using a Rebound Pendulum[3]

D 1765 Classification System for Carbon Blacks Used in Rubber Products[3]

D 2240 Test Method for Rubber Property—Durometer Hardness[3]

D 3182 Practice for Rubber—Materials, Equipment, and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets[3]

E 178 Practice for Dealing with Outlying Observations[4]

E 303 Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester[5]

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 or incorporated into an automotive vehicle.[2]

3.2 The test tires are positioned in the test mode. The Mu-Meter is brought to the desired test speed. Water is delivered ahead of the test tires and the beginning of the test is marked. The resulting sideways or cornering friction force acting between the test tires and the pavement surface is recorded on a strip chart. The speed of the test vehicle is recorded with the aid of suitable instrumentation.

3.3 The side force friction is determined from analysis of the strip chart record and reported as Mu Number (MuN).[6]

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 centered 18 ± 0.5 in. (457 ± 13 mm) from the ground for Mu-Meters with unadjustable hitches. For Mu-Meters with adjustable hitches, the towing ball shall be placed so that the

[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] As manufactured by M. L. Aviation Co. Ltd., White Waltham Aerodrome, Maidenhead, Berkshire, England and distributed in the United States by Bison Instruments, 5708 W. 36th St., Minneapolis, MN 55416.

[3] *Annual Book of ASTM Standards*, Vol 09.01.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

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

[6] Refer to manufacturers instruction and servicing manual (MLH 148) for method of determining Mu number from strip chart.

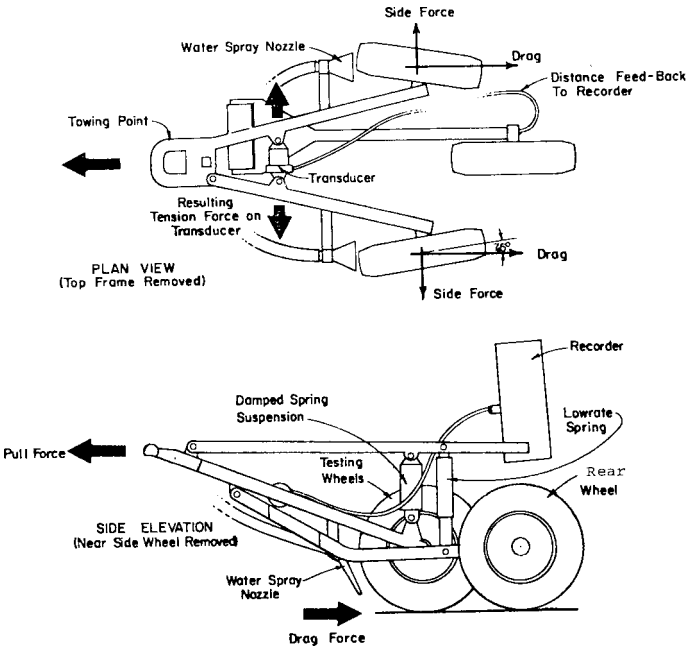

FIG. 1 Mu-Meter Schematic

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 7.50 ± 0.75° outward from the centerline of the Mu-Meter. The two test wheels shall have limited angular travel so the side force friction can be transmitted to the force cell mounted within the frame with a minimum angular difference. The test wheel major plane should tilt approximately 2° outward from the vertical when in the toe-out position. The rear stabilizing (third) wheel advances the strip chart record.

5.2.2 *Force Cell*—The force cell shall be 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 travel of the force cell during loading shall be sufficiently small so the total included angle between the test tires does not change by more than 0.5° during the test. The force 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 force 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*:

5.2.4.1 The general requirements for the Mu-Meter test tires for measuring side force friction are given in Annex A1. 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 *Recorder*—The recorder shall measure and record the force cell tensile force from 0 to 500 lbf (0 to 2225 N) linearly on the chart as 0 to 100 MuN and the advance of the chart shall be linear with distance. The recorder shall have at least one event marker, remotely controlled, to indicate the beginning and end of test runs or other events during the test. Other remote or digital readout capabilities are permissible.

5.2.6 *Vehicle Speed-Measuring Transducers*—Transducers such as "fifth wheel" or transmission-coupled tachometers 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 being applied to the pavement ahead of the test tires shall be supplied by a nozzle conforming to the dimensions of Fig. 2. For airport runways, the recommended quantity of water applied at 40 mph (65 km/h) shall be 8 gal/min ± 10 %/in. (1.20 L/min ± 10 %/mm) of wetted width. The water layer shall be 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. The volume of water per inch (millimetre) of wetted width shall be directly proportional to the test speed.

NOTE 1—For highway use, the alternative recommended flow rate of 4 gal/min± 10 %/in. (0.60 L/min ± 10 %/mm) of wetted width may be used. Since friction on paved surfaces is dependant upon water depth, the calculated surface water depth produced by this reduced flow shall be reported as required in 12.1.5 and 12.2.11.

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 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.

NOTE 2—The nozzle design and water distribution system required to

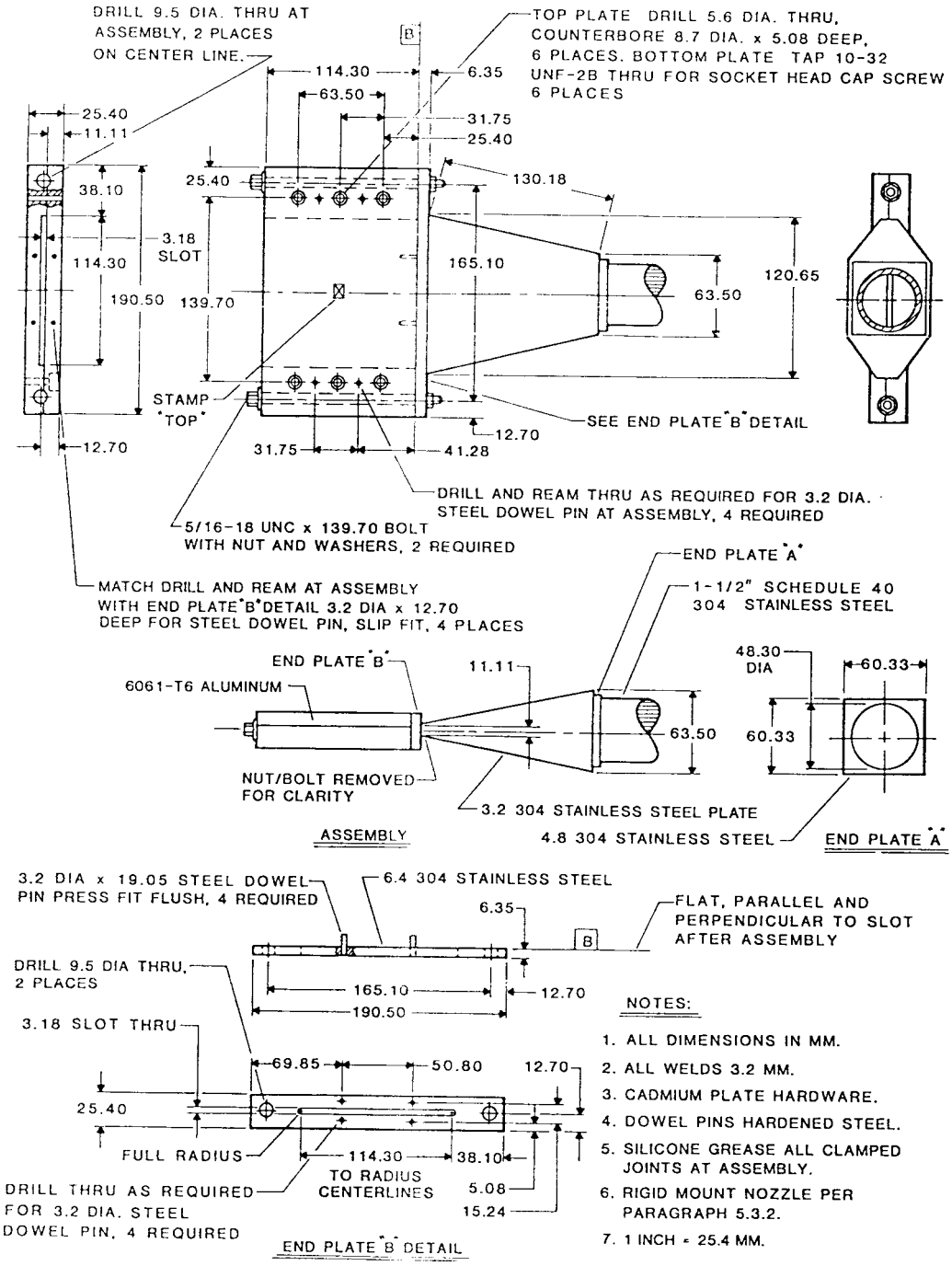

FIG. 2 Pavement Wetting System

provide desired pavement water depth(s) are currently undergoing evaluation, and experimental validation has not been completed.

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 wheelpath of a traffic lane. Normally, 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. A Mu Number may be quoted without qualification

only if the Mu-Meter is so positioned. Test areas where the Mu-Meter deviates from its transverse roadway position shall be noted.

8. Calibration

8.1 *Speed*—Calibrate the test vehicle speed indicator at a constant test speed by determining the time for traversing a reasonably level, straight pavement, of a length appropriate for the method of timing. Accurately measure the pavement length. Load the test vehicle to its normal operating weight for this calibration. Record speed variations during a traverse with the recording system. Make a minimum of six speed determinations, including all speeds at which tests are to be run, to complete the calibration.

8.2 *Recorder Calibration*—Calibrate the recorder and load cell in the tension mode. Both increasing and decreasing tension forces of 0 to 500 lbf (0 to 2225 N) shall be proportional to a chart reading of 0 to 100 MuN within the following limits:

Force, lbf (N)	Chart Readings
0 (0)	0 to 3
100 (445)	18 to 22
200 (890)	38 to 43
300 (1335)	58 to 63
400 (1780)	78 to 84
500 (2225)	98 to 104

8.3 *Force-Calibration Procedure*—Calibrate the apparatus after the shallow tread pattern on the test tires has been worn away. The apparatus may require additional calibrations at intervals deemed necessary during the life of the tire. Perform the calibration by pulling the Mu-Meter over a standard test board (see Appendix X1 for calibration of a Mu-Meter standard test board). Prior to calibration, thoroughly clean and dry the tires and the standard test board surface. Brush the tires, the approach surface, and the standard test board surface by means of a bristled brush to remove loose particles and dust. The test tire pressure shall be in accordance with 5.2.4, and the ambient temperature shall be more than 45°F (7°C). Pull the Mu-Meter over the standard test board surface with the test wheels in the test position at a slow constant speed, less than 3 mph (5 km/h). Perform three tests, carefully cleaning the tires, approach surface, and test board surface between each test. The results for the three consecutive tests shall be within ±1 MuN of the average obtained and within ±2 MuN of the test surface MuN or refer to service manual.

NOTE 3—Cornering stiffness of the test tires has been found to change with tread wear. Due to this change, the Mu-Meter should be recalibrated as tire wear progresses.

9. General

9.1 *Tire Preparation*—Condition new test wheel tires by running them at their normal inflation pressures in the test position on the Mu-Meter, until such time as the shallow ribs on the contour are completely removed and a smooth rubber surface is obtained. Dynamically balance the wheel and tire assemblies after conditioning if it is anticipated that tests at speeds of more than 60 mph (97 km/h) will be made. Inspect the tires for damage and other irregularities that may affect the test results and reject tires that have been damaged or worn to the extent they are unlikely to complete any tests.

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. Prior to each series of tests, warm-up the tires by traveling at least 5 miles (8 km) at normal traffic speeds. 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 springload.

9.3 *Test Speeds*—Run the standard test at 40 ± 0.5 mph (65 ± 0.8 km/h). 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, note the speed when quoting the Mu Number. This may be accomplished by adding the speed that the test was run as a subscript to the Mu Number.

9.4 *Mu Number Speed Gradient Determination*—The change of Mu Number with speed is to be reported as MuN per mph (MuN per km/h) and should be obtained as the slope of the MuN versus speed curve which is plotted from at least three speeds in increments of approximately 10 mph (15 km/h). The standard speed gradient is defined as the slope of the MuN-speed curve at 40 mph (65 km/h) and shall be so indicated.

10. Procedure

10.1 Check the Mu-Meter as in 9.2. Bring the apparatus to the test speed. Deliver water to the test tires approximately 1 s before the test is initiated and continue until the test is completed. Indicate the beginning and the end of the test by means of the event marker. Stop the water delivery approximately 1 s after completion of the test.

10.2 Evaluate the recorded trace between the two event marks. The trace averaged between these two points is the Mu Number.

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 E 178.

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 calculated surface water depth (for each test), and

12.1.6 Average Mu Number for each test section; vehicle speed and calculated surface water depth at which the reported average was obtained.

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 Grade and alignment,
12.2.4 Pavement type (mix design of surface course, condition, and aggregate type, if available),
12.2.5 Age of pavement,
12.2.6 Average daily traffic,
12.2.7 Average traffic speed (or speed mix as in the case of grade with heavy truck traffic),
12.2.8 Date and time of day,
12.2.9 Weather conditions,
12.2.10 Lane and section tested,
12.2.11 Average Mu Number for test section; vehicle speed and surface water depth at which reported average was obtained,
12.2.12 Highest and lowest values entered into the average (if values are reported that were not used in computing the average, this fact shall be reported), and
12.2.13 Plot of speed gradient data (if obtained).

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. An acceptable standard deviation of 2.0 MuN units was derived by pooling limited data from different Mu-Meters, 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:

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

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.

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*:

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

FIG. A1.1 Mu-Meter Test Tire

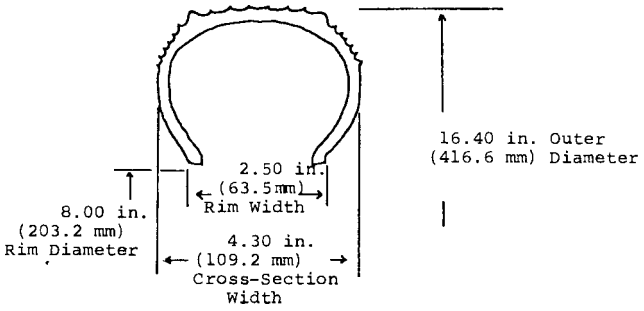

FIG. A1.2 Mu-Meter Test Tire Dimensions

TABLE A1.1 Compounding

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

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.

TABLE A1.2 Physical Requirements

Tensile sheet cure at 140°C	60 min @ 140°C
Tensile strength, psi (kPa)	2200 (15 200)
300 % modulus, psi (kPa)	1100 (7600)
Elongation at break, %	500
Hardness (Shore A)	65
Resilience, %	50
Specific gravity	1.160

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[7] 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.

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.

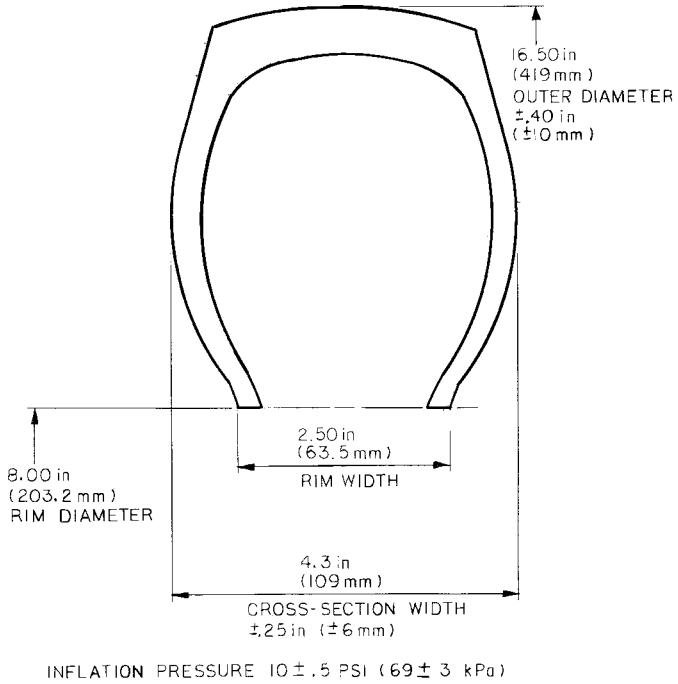

FIG. A2.2 Alternate Mu-Meter Tire Dimensions

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

[7] 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

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 D 3182.
[B] Styrene Butadiene Rubber (23.5 % Styrene) with 37.5 PHR of High Aromatic Oil.
[C] Cis Polybutadiene.
[D] See Classification D 1765.
[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.

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.

A2.7 Test Methods

A2.7.1 *Tensile Sheet Cure*—Practice D 3182.

A2.7.2 *Modulus (300 %)*—Test Methods D 412.

A2.7.3 *Tensile Sheet Durometer*—Test Method D 2240, using Type A Shore Durometer.

TABLE A2.2 Physical Requirements

Tensile Sheet Cure at 298°F (147.8°C)	20 min
Tensile strength, min psi (MPa) (Test Method D 412)	2200 (15.7)
300 % modulus, psi (MPa) (Test Method D 412)	1100 (7.6) ± 200
Elongation at break min % (Test Method D 412)	500
Hardness (Shore A) (Test Method D 2240)	56 ± 2
Specific gravity (Test Method D 297)	1.13± 0.02

A2.7.4 *Restored Energy (Rebound or Resilience)*—Test Method D 1054.

A2.7.5 *Specific Gravity*—Test Methods D 297.

A2.7.6 *Tensile Strength*—Test Methods D 412.

A2.7.7 *Elongation*— Test Methods D 412.

A2.7.8 *Tire Tread Durometer*—Test Method D 2240, 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 E 670 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.

A3.4 Test Surfaces

A3.4.1 Four test surfaces will be required as follows:

A3.4.1.1 *Test Surface A*— Mu[8] 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 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

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

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

±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 E 303, 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.