Designation: D4280 – 15

Standard Specification for Extended Life Type, Nonplowable, Raised Retroreflective Pavement Markers[1]

This standard is issued under the fixed designation D4280; 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 specification covers nonplowable, retroreflective raised pavement markers for nighttime lane marking and delineation.

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

1.3 The following precautionary caveat pertains only to the test methods portion, Section 9, of this specification: *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:*[2]

D5 Test Method for Penetration of Bituminous Materials

D36 Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)

D71 Test Method for Relative Density of Solid Pitch and Asphalt (Displacement Method)

D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester

D113 Test Method for Ductility of Bituminous Materials

D1785 Specification for Poly(Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120

D3111 Test Method for Flexibility Determination of Hot-Melt Adhesives by Mandrel Bend Test Method

D4402 Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rotational Viscometer

D5329 Test Methods for Sealants and Fillers, Hot-Applied, for Joints and Cracks in Asphaltic and Portland Cement Concrete Pavements

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E284 Terminology of Appearance

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E808 Practice for Describing Retroreflection

E809 Practice for Measuring Photometric Characteristics of Retroreflectors

E811 Practice for Measuring Colorimetric Characteristics of Retroreflectors Under Nighttime Conditions

2.2 *Federal Specifications:*[3]

TT-T-291 Thinner, Paint, Mineral Spirits, Regular and Odorless

2.3 *AASHTO Standards:*[4]

AASHTO M237 Epoxy Resin Adhesive for Bonding Traffic Markers to Hardened Concrete

3. Terminology

3.1 *Definitions:*

3.1.1 *cleanability*—the ability of a raised retroreflective marker to keep its optical surfaces clean under traffic and environmental conditions.

3.1.2 *coefficient of luminous intensity, R_I*—the ratio of the luminous intensity (I) of the retroreflector in the direction of observation to the illuminance (E) at the retroreflector on a plane perpendicular to the direction of the incident light, expressed in candelas per lux (cd/lx) (see Practice E808 and Terminology E284).

3.1.2.1 *Discussion*—The values presented for the coefficient of luminous intensity are presented in SI units, which are the accepted worldwide norm for expressing this value, rather than in inch-pounds. When values are low, the coefficient of

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[2] 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] Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, http://www.access.gpo.gov.

[4] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, http://www.transportation.org.

(retroreflected) luminous intensity may be given in millicandelas per lux. In inch-pound units, R_I is given in candelas per footcandle (cd/fc). Historically, the term "specific intensity" and symbol ("SI") have been used to designate this term but "R_I" is preferred.

3.1.3 *color*—chromaticity, according to the CIE (Commission Internationale de l'Eclairage) 1931 colorimetric system.

3.1.4 *horizontal entrance angle*—the angle in the horizontal plane between the direction of incident light and the normal to the leading edge of the marker.

3.1.4.1 *Discussion*—This angle corresponds to the entrance angle β2 when the marker is positioned for photometry. The direction given in Practice E808 should be used when designating this angle.

3.1.5 *observation angle*—the angle between the illumination axis and the observation axis. (See also Practice E808.)

3.1.6 *retroreflection*—reflection in which radiation is returned in directions close to the direction from which it came, this property being maintained over wide variations of the direction of incident radiation.

3.1.7 *retroreflective element*—a minimal optical unit that produces retroreflection, for example, a cube corner or a biconvex structure.

4. Classification

4.1 Markers should be classified as to type, color, and abrasion resistance.

4.1.1 *Types of Markers:*

4.1.1.1 *Type A*—Two-way reflective markers, one color.

4.1.1.2 *Type B*—One-way reflective markers, one color.

4.1.1.3 *Type E*—Two-way reflective markers, two colors.

4.1.2 *Retroreflected Color of Markers:*

4.1.2.1 *W*—White.

4.1.2.2 *Y*—Yellow.

4.1.2.3 *R*—Red.

4.1.2.4 *B*—Blue.

4.1.2.5 *G*—Green.

4.1.3 *Abrasion Resistance:*

4.1.3.1 *Designated H*—Marker with hard, abrasion-resistant lens surface.

4.1.4 *Flexural Strength:*

4.1.4.1 *Designated F*—Marker with sufficient longitudinal strength for application to flexible, asphaltic concrete pavement.

4.2 Show classification in the order detailed in 4.1.1 – 4.1.3.1: type, color, abrasion resistance, and flexural strength. For example, ERWF is a two-way red-and-white marker without abrasion resistant surface and with sufficient flexural strength for application to flexible pavement.

5. Ordering Information

5.1 Orders for material under this specification should include the following information:

5.1.1 Quantity,

5.1.2 Type of marker: retroreflective one way, or retroreflective two way,

5.1.3 Color of marker,

5.1.4 Abrasion resistance, if needed, and

5.1.5 Flexural strength, if needed.

NOTE 1—Flexural strength is not critical when application is to portland cement concrete pavement, but is critical when application is to some soft asphaltic concrete pavements.

6. Requirements for Retroreflective Markers

6.1 *Construction:*

6.1.1 The marker shall be comprised of materials with adequate chemical, water, and UV resistance for the intended use.

6.1.2 Marker height shall not exceed 0.80 in. (20.3 mm).

6.1.3 Marker width shall not exceed 5.1 in. (130 mm).

6.1.4 The angle between the face of the marker and the base shall be no greater than 45°, except as provided in 6.1.4.1.

6.1.4.1 If the angle between the face of the marker and the base is greater than 45°, or if the marker front has protuberances of more than 0.04 in. (1 mm). then as part of type acceptance, the marker shall be subjected to a six-month road test during the time of the year when weather and traffic conditions are most critical to cleanability. Cleanability is determined by measuring coefficient of luminous intensity before and after washing the marker lens.

6.1.5 The base of the marker shall be substantially free from gloss or substances that may reduce its bond to adhesive.

6.1.6 The base of the marker shall be flat within 0.05 in. (1.3 mm). If the bottom of the marker is configurated, the protruding faces of the configurations shall not deviate more than 0.05 in. (1.3 mm) from a plane.

6.1.7 Construction not meeting the requirements of 6.1.2, 6.1.3, 6.1.4, 6.1.6, or 6.1.7, but meeting the performance requirements of 6.2, will be acceptable following a twelve-month road test to determine cleanability, durability, and adhesion to the road.

6.2 *Performance Requirements:*

6.2.1 *Retroreflectivity:*

6.2.1.1 For new markers, coefficient of luminous intensity (R_I) measured in accordance with 9.1 shall be not less than the values in Table 1.

6.2.1.2 For abrasion resistant markers, after abrading the marker in accordance with 9.5, coefficient of luminous intensity at 0° entrance angle measured in accordance with 9.1 shall be not less than the values in Table 1 multiplied by 0.5.

NOTE 2—No abrasion resistance test has been established for markers having biconvex optical elements.

NOTE 3—Some two-color markers may intentionally have only one of the retroreflective faces abrasion resistant, in which case, the second face should not be abraded.

NOTE 4—No laboratory abrasion test can be expected to model the full range of surface wear of pavement markers in use.

6.2.2 Because no practical laboratory procedures have been determined to provide complete, reliable, and predictive information on adhesive bond strength, the user is encouraged to seek information from alternative sources such as field tests. A field test of duration 12 months is recommended. A control marker is chosen with known satisfactory adhesion. The test markers may be required to experience no more than 1.5 times as great an adhesion failure rate as the controls. The test

TABLE 1 Coefficient of Luminous Intensity R_I

NOTE 1—The retroreflector axis and datum axis of the marker are as shown in Fig. 2 and Fig. 3.

NOTE 2—Entrance angle component β1 and rotation angle ε are 0°.

NOTE 3—The values presented for the coefficient of luminous intensity in the table are given in SI units, which are the accepted worldwide norm for expressing this value, rather than in inch-pounds. The values in *cd/fc* are provided for information.

Entrance Angle Component β2	Observation Angle α	Minimum Value R_I, mcd/lx				
		White	Yellow	Red	Green	Blue
0°	0.2°	279	167	70	93	26
+ 20°/–20°	0.2°	112	67	28	37	10
Entrance Angle Component β2	Observation Angle α	Minimum Value R_I, cd/fc				
		White	Yellow	Red	Green	Blue
0°	0.2°	3.0	1.8	0.75	1.0	0.28
+ 20°/–20°	0.2°	1.2	0.72	0.30	0.4	0.11

severity should be such that between 3 % and 20 % of the controls fail during the field test. There must be adequate numbers of test markers and controls for statistical validity.

6.2.3 *Physical Properties:*

6.2.3.1 *Flexural Strength* (designation F markers only)—When tested in accordance with 9.2.1, a marker shall withstand 2000 lbf (8914 N) without breakage.

NOTE 5—Method 9.2.1 tests longitudinal flexural strength, distinct from the flexural strength tested in previous editions of this specification.

6.2.3.2 *Compressive Strength*—When tested in accordance with 9.2.2, a marker shall support a load of6000 lb (2727 kg) without breakage or significant deformation of the marker. Significant deformation shall be understood to be 0.13 in. (3.3 mm).

6.2.4 *Color*—When the retroreflector is illuminated by CIE Standard Source A and when measured in accordance with 9.3, the color of the retroreflected light shall fall within the color gamuts given by the following corner points and shown in Fig. 1.

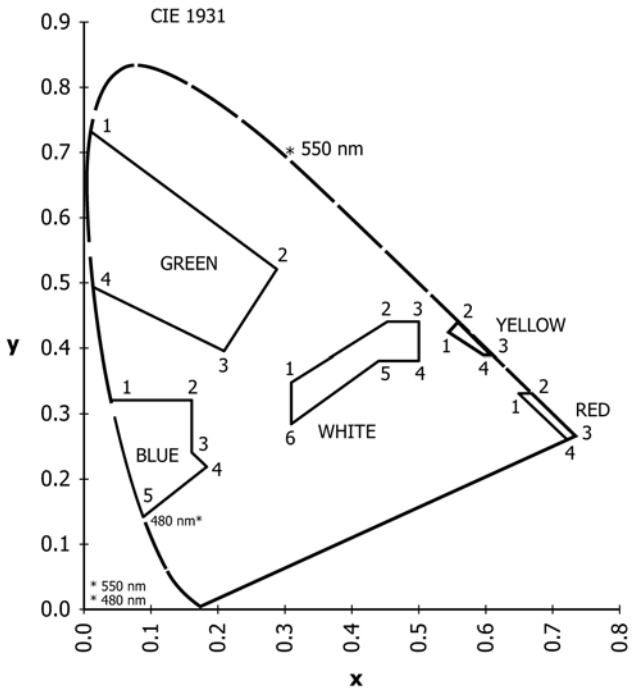

FIG. 1 Color Gamut in accordance with 6.2.4

6.2.4.1 *White:*

Point No.	x	y
1	0.310	0.348
2	0.453	0.440
3	0.500	0.440
4	0.500	0.380
5	0.440	0.380
6	0.310	0.283

6.2.4.2 *Yellow:*

Point No.	x	y
1	0.545	0.424
2	0.559	0.439
3	0.609	0.390
4	0.597	0.390

6.2.4.3 *Red:*

Point No.	x	y
1	0.650	0.330
2	0.668	0.330
3	0.734	0.265
4	0.721	0.259

6.2.4.4 *Blue:*

Point No.	x	y
1	0.039	0.320
2	0.160	0.320
3	0.160	0.240
4	0.183	0.218
5	0.088	0.142

6.2.4.5 *Green:*

Point No.	x	y
1	0.009	0.733
2	0.288	0.520
3	0.209	0.395
4	0.012	0.494

6.2.5 *Resistance to Lens Cracking:*

6.2.5.1 *Lens Impact Strength*—When impacted in accordance with 9.4.1, the face of the lens shall show no more than two radial cracks longer than 0.25 in. (6.4 mm). There shall be no radial cracks extending to the edge of the abrasion resistant area. There shall be no delamination.

6.2.5.2 *Temperature Cycling*—When subjected to temperature cycling in accordance with 9.4.2, there shall be no cracking or delamination.

7. Sampling

7.1 For markers not resistant to abrasion, sample size shall be 20 markers for each lot of 10 000 markers or less and 40 markers for each lot of more than 10 000 markers. For markers

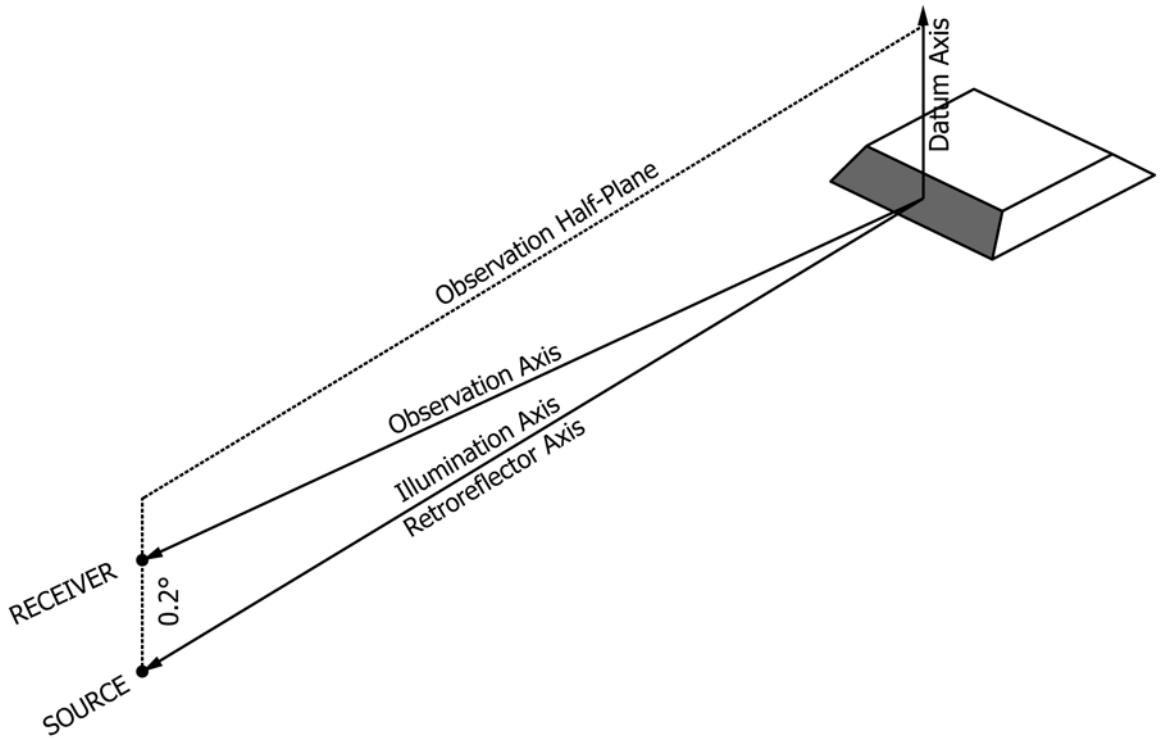

FIG. 2 Position of Marker for Photometry, 0° Entrance Angle

with an abrasion-resistant surface, ten additional samples shall be required. Lot size shall not exceed 25 000 markers.

8. Number of Tests and Retests

8.1 For coefficient of luminous intensity (9.1.1), the entire sample of retroreflective pavement markers shall be tested. Failure of more than 10 % of the reflective faces shall be cause for rejection of the entire lot represented by the sample. For abrasion resistant markers, in addition to the test of 9.1.1, four reflective faces passing the photometric requirements of 9.1.1 shall be subjected to abrasion (9.1.2) and remeasured; failure of more than one sample shall be cause for rejection of the entire lot.

8.2 For longitudinal flexural strength (9.2.1), compressive strength (9.2.2), and color (9.3), three specimens shall be tested. Specimens previously subjected to photometry (9.1.1), color (9.3), and the abrasion specified for 9.1.2 are acceptable for tests of longitudinal flexural strength (9.2.1) and compressive strength (9.2.2). Failure of more than one specimen shall be cause for rejection of the entire lot.

8.3 For lens impact strength (9.4.1) and resistance to temperature cycling (9.4.2), ten specimens shall be tested for each requirement. Failure of more than one of the specimens in either test shall be cause for rejection of the entire lot.

8.4 In the event of failure that would result in rejection of a lot, and at the discretion of the purchaser, a resample may be taken consisting of double the number of samples originally tested. Tolerances for resamples shall be in the same ratio as specified above.

9. Test Methods

9.1 *Coefficient of Luminous Intensity:*

9.1.1 *Procedure*—Measure coefficient of luminous intensity in accordance with Practice E809. Angular aperture of the source and angular aperture of the receiver shall each be no larger than 0.1°. Angular aperture of the retroreflective elements shall be no larger than 0.02°. If the retroreflective elements are no larger than 0.21 in. (5.3 mm) in diameter, suggested test dimensions are 50-ft (15.2-m) distance, 1.0-in (25.4-mm) diameter receptor, and 1.0-in. (25.4-mm) diameter source. Other test distances are acceptable provided that the stated angular aperture requirements are met and that the marker subtends no more than 1° at the source. Measure the distance from the light source exit pupil to the center of the retroreflective face of the marker. The base of the marker shall lie on a plane parallel to the illumination axis and perpendicular to the observation half-plane. Refer to Fig. 2, Fig. 3, and Practice E809. Any vertical surfaces on the marker, for example, on its leading edge, that could specularly reflect the source into the receiver shall be covered. The tolerance on entrance angle shall be ±0.5°. Maintain laboratory and condition markers to 72 ± 3ºF (23 ± 2°C), 50 ± 25 % RH.

9.1.1.1 Before photometry, gently wipe the face of the marker with a soft damp towel, then dry with a soft towel.

9.1.2 *Interlaboratory Study of Precision:*[5]

9.1.2.1 The calculations, results, and terminology used to prepare this statement are in accordance with Practice E691.

[5] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D04-1026.

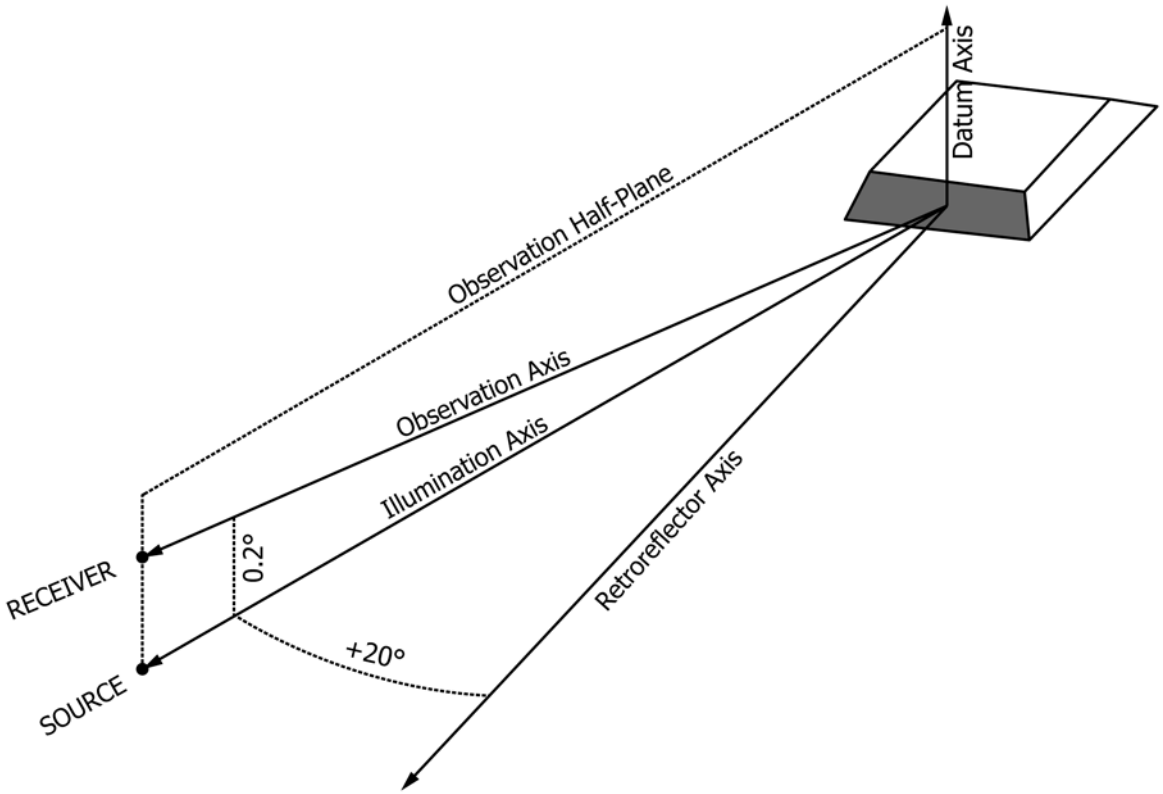

FIG. 3 Position of Marker for Photometry, +20° Entrance Angle

9.1.2.2 A set of markers conforming to this specification was photometered at six laboratories. The set comprised 150 lenses, equally divided among the five colors of 6.2.4 and also equally divided among three optical types: those having prisms approximately 0.1 in. (2.5 mm) in diameter; those having prisms approximately 0.012 in. (0.3 mm) in diameter; and those having discrete biconvex elements.

9.1.2.3 Each laboratory photometered each lens at 0.2° observation angle at each of 0°, +20°, and −20° entrance angles in accordance with 9.1.1, and the measurements were repeated on a second day.

9.1.2.4 The precision statistics are given in Table 2. For each lens, precision statistics were calculated as percentages of the interlaboratory mean R_I value for that lens. The precision statistics were averaged over the ten specimens of like color and optical type. The precision statistics for +20° entrance angle and for −20° entrance angle were averaged for the reported ±20° entrance angle. The differences in precision statistics among the five colors were small enough to allow average values to be reported. The differences in precision statistics among the three optical types were small enough to allow average values to be reported.

TABLE 2 Precision for Coefficient of Luminous Intensity

Entrance Angle	s_r Repeatability Standard Deviation	s_R Reproducibility Standard Deviation	r 95 % Repeatability Limit	R 95 % Reproducibility Limit
0°	1.5 %	6.7 %	4.1 %	18.5 %
±20°	4.0 %	9.0 %	11.1 %	25.0 %

9.1.2.5 There is no estimate of bias. There is no reference laboratory in North America by which to establish bias for this measurement.

9.2 *Physical Properties:*

9.2.1 *Longitudinal Flexural Strength:*

9.2.1.1 Condition markers at 73.4 ± 3.6°F (23.0 ± 2.0°C) for 4 h prior to testing.

9.2.1.2 Place two 0.5 by 1.0 in. (12.7 by 25.4 mm) steel bars, each longer than the width of the marker base, on their 0.5 in. (12.7 mm) faces, onto the platen of the compression apparatus. Place durometer 70 Shore A elastomeric pads approximately 0.12 in. (3 mm) thick onto the bars. Place marker base down onto the pads. Marker shall have its lengthwise (roadway) direction perpendicular to the two bars. Spacing of bars shall depend on length of marker base, being as great as possible without bars protruding beyond the extreme lengthwise points of the marker base. Place a durometer 70 Shore A elastomeric pad approximately 1 in. (25 mm) thick and larger than the marker top on top of marker. Place a third 0.5 by 1.0 in. (12.7 by 25.4 mm) steel bar, longer than the width of marker top, on its 0.5 in. (12.7 mm) face onto the top of the pad, positioned parallel to the other bars and centered over the marker top (see Fig. 4).

9.2.1.3 Apply load to the top of the marker at a rate of 0.2 in. (5.0 mm)/min through the top steel bar until the marker breaks. Breakage shall constitute complete rupture or other loss of integrity evidenced by a sudden decrease in load. Record load at break to the nearest lbf (N).

9.2.1.4 *Precision and Bias:*

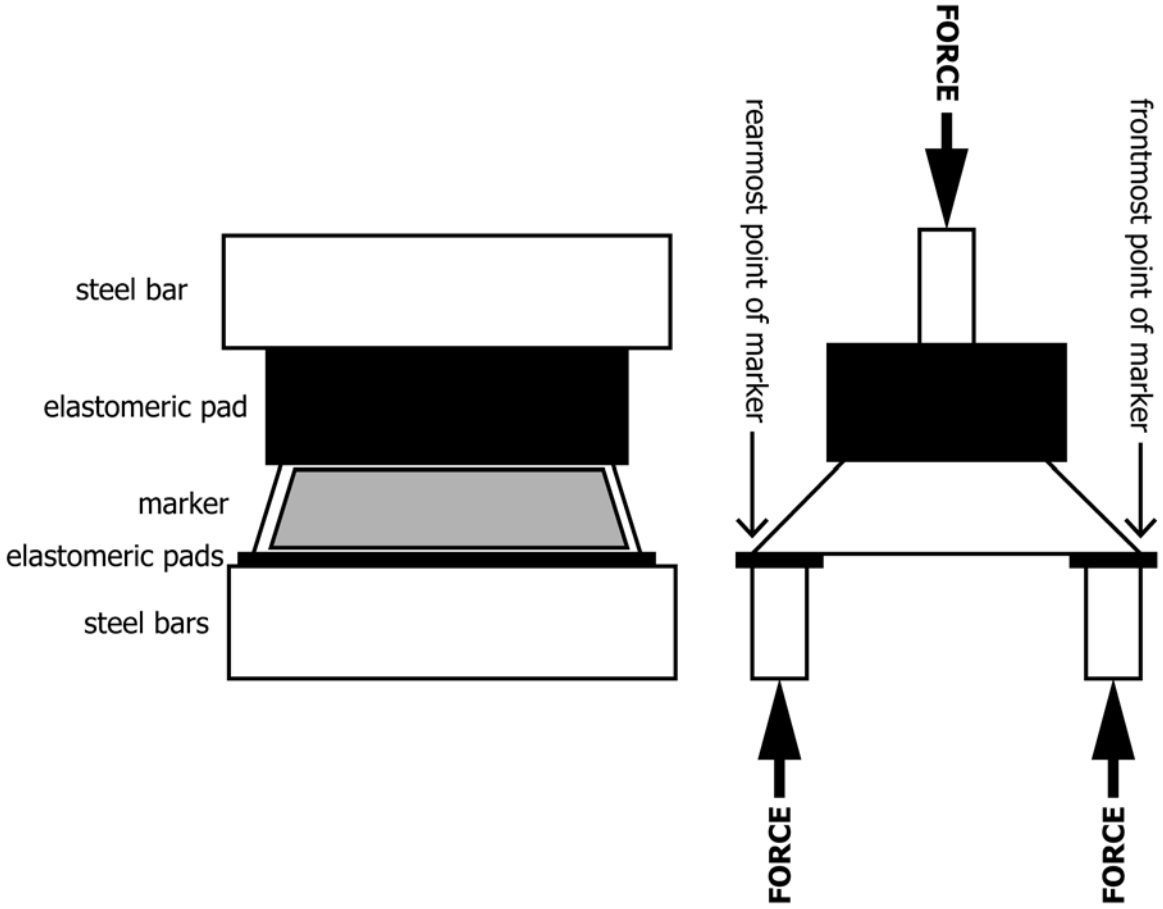

FIG. 4 Longitudinal Flexural Strength Test

(a) Interlaboratory Test Program—An interlaboratory study of longitudinal flexural strength for nonplowable raised pavement markers for extended life was conducted in accordance with Practice E691 in eight laboratories using four marker models with ten nearly identical specimens of each model for each laboratory. The four marker models were of the following constructions:

1. marker with molded ABS body
2. marker with molded polycarbonate shell and interior
3. marker with molded acrylic shell and urethane potting
4. marker with molded acrylic shell and urethane potting

(1) Mean measurement values for the four models varied from 990 kg to 1370 kg.

(2) The individual statistical results for each set were averaged to obtain one set of repeatability and reproducibility results.

(3) The terms repeatability limit and reproducibility limit are used as specified in Practice E177.

(4) The precision statistics are given in Table 3.

TABLE 3 Precision for Longitudinal Flexural Strength

Material	Repeatability Std. Dev. (%)	Reproducibility Std. Dev. (%)	Repeatability Limit (%)	Reproducibility Limit (%)
4 by 4 in. RPM	4.54	6.94	12.72	19.44

(*b*) *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method for measuring longitudinal flexural strength, no statement on bias is being made.

9.2.2 *Compressive Strength:*

9.2.2.1 Condition markers at 73.4 ± 3.6°F (23.0 ± 2.0°C) for 4 h prior to testing.

9.2.2.2 Position marker base down at the center of a 0.5-in. (13-mm) thick flat steel plate larger than the marker.

9.2.2.3 On top of the marker, place a 0.37-in. (9.5-mm) thick elastomeric pad larger than the marker and having a Shore A durometer of 60.

9.2.2.4 On top of the elastomeric pad, place a 0.5-in. (13-mm) thick flat steel plate larger than the marker.

9.2.2.5 Apply a load at a rate of 0.1 in. (2.5 mm)/min.

9.3 *Color*—Measure color in accordance with Practice E811 at 0.2° observation angle and 0° entrance angle. The source and receptor angular apertures shall each be 6 min of arc.

9.4 *Resistance to Lens Cracking:*

9.4.1 *Lens Impact Strength*—Condition the markers in a convection oven at 130°F (55°C) for 1 h.

9.4.1.1 While at the elevated temperature, impact the reflective face of the marker by allowing a 0.42-lb (0.19-kg) dart fitted with a 0.25-in. (6.4-mm) radius semi-spherical head to drop 18 in. (457 mm) perpendicularly onto the approximate

center of the reflective surface. For impact testing, set the marker on a steel fixture designed to hold the reflecting face horizontal, and place the fixture on a solid surface, such as a concrete floor.

9.4.1.2 Inspect for cracking and delamination.

9.4.2 *Resistance to Temperature Cycling*—Subject samples to three cycles of 140°F (60°C) for 4 h followed by 20°F (-7°C for 4 h.

9.4.2.1 Inspect for cracking and delamination.

9.4.3 *Precision and Bias*—No statement is made about either the precision or bias of the test for resistance to lens cracking, since the result merely states whether there is conformance to the criteria for success specified in the procedure.

9.5 *Abrasion Resistance:*

9.5.1 The abrasion resistance test method is only applicable to markers having a smooth continuous lens surface.

9.5.2 Sand shall fall 9.8 ± 0.1 ft (3.00 ± 0.03 m) uniformly onto the front of a marker having its retroreflector axis vertical. Distance shall be measured to the marker's leading edge.

9.5.3 Sand shall be natural silica sand from the St. Peters or Jordan sandstone deposits (located in the central United States).

9.5.3.1 *Discussion*—This sand is characterized by its roundness of grains and its exceptionally high silicon dioxide content.

9.5.4 The sand particle distribution shall be such that not more than 10 % by weight is retained on a No. 20 (850-µm) sieve and not more than 10 % by weight passes a No. 30 (600-µm) sieve after 10 min of continuous sieving.

9.5.5 Sand shall not be reused.

9.5.6 Sand shall fall at least 9.4 ft (2.85 m) before reaching a calibration aperture, a horizontal rectangular opening 1.57 ± 0.04 in. (4.0 ± 0.1 cm) by 4.72 ± 0.04 in. (12.0 ± 0.1 cm), under which the marker is centered with the marker width in the 4.72 in. (12 cm) direction. See 9.5.10 for modifications for markers wider than 10 cm.

9.5.7 A total of 5.5 ± 0.1 lbs (2.5 ± 0.05 kg) of sand shall fall through the calibration aperture at a rate maintained in the range from 0.9 lb/min to 2.2 lb/min (0.4 kg/min to 1.0 kg/min). See 9.5.10 for modifications for markers wider than 10 cm.

9.5.8 The abrasion resistance test shall be performed at 77 ± 9ºF (25 ± 5°C) and 50 ± 25 % RH with the markers pre-conditioned to those ranges.

9.5.9 *Abrasion Apparatus:*

9.5.9.1 The apparatus shall consist of a vertical pipe with a sieve at the top, a calibration aperture with deflectors at the bottom, a marker support, and a means for collecting the sand that passes through the calibration aperture.

9.5.9.2 Sand shall fall within the full unobstructed pipe from the sieve to the plane of the calibration aperture.

9.5.9.3 The pipe shall have an inner diameter of at least 5.9 in. (15 cm). See 9.5.10 for modifications for markers wider than 4 in. (10 cm). Smooth plastic pipe in accordance with Specification D1785 may be used. The pipe shall be within 0.2° of vertical.

9.5.9.4 The sieve shall be used to establish the beginning point of the sand drop and also to limit sand flow. Sand may fall no more than 1.2 in. (3 cm) onto the sieve.

9.5.9.5 The calibration aperture shall be formed from four sharp horizontal edges, which are the upper edges of angled deflectors. See Fig. 5. Sand falling within the calibration aperture is not deflected; sand falling outside the calibration aperture is deflected away from the aperture and cannot strike the marker.

9.5.9.6 The marker shall be mounted with its leading edge no farther than 5.9 in. (15 cm) from the plane of the calibration aperture. The marker shall be mounted with no fixturing within 1 cm of its front face. Fixturing must be such to allow free flow of sand around the marker. The plane of the marker base shall be within 1° of vertical. The marker leading edge shall be within 2° of horizontal.

9.5.9.7 All sand passing through the calibration aperture, including any that bounces off the marker, must be collected and weighed. Sand that does not pass through the calibration aperture must not be included in this weight.

9.5.9.8 Sand must flow equally through all parts of the calibration aperture. This shall be verified by placing at least ten vials having approximately 0.4 in. (1 cm) mouths at the height of the marker under the aperture. When enough sand has dropped through the apparatus that at least one of the vials has received at least 0.2 oz. (5 g), the least-filled vial shall have received at least 75 % as much weight of sand as the most-filled vial. After determining the flow stability of the apparatus, verify uniformity as often as necessary.

9.5.10 Markers may be as wide as 5.1 in. To accommodate markers up to X in. wider than 4 in. the following four modifications must be made. This width is measured on the marker front, including lens and surrounding body.

9.5.10.1 The calibration aperture shall be (4.7 + X) in. wide.

9.5.10.2 The pipe inner diameter shall be at least (6 + X) in.

9.5.10.3 The weight of sand falling through the calibration aperture shall be 5.5 + 0.458X lb (2.5 + 0.208X kg) ± 2 %.

9.5.10.4 The rate of sand falling through the calibration aperture shall be maintained within the range (0.88 + X/13.6) to (2.2 + X/5.45) lbs/min ((0.4 + X/30) to (1 + X/12) kg/min).

9.5.11 *Interlaboratory Study of Precision:*[5]

9.5.11.1 The calculations, results, and terminology used to prepare this statement are in accordance with Practice E691, except for minor modifications to accommodate the unequal numbers of samples tested at the participating laboratories.

9.5.11.2 The measured quantity is the unitless ratio of the coefficient of luminous intensity (R_I) at 0° entrance angle after abrasion to the coefficient of luminous intensity (R_I) at 0° entrance angle before abrasion. The repeatability of the measurement therefore depends on both the repeatability of the R_I measurement and the repeatability of the abrasion. The reproducibility of the measurement depends primarily on the reproducibility of the abrasion.

9.5.11.3 The sample markers were of three types, LPG, LPC, SPC, depending on their optics and front surface. "LP" denotes having prisms approximately 0.1 in. (2.5 mm) in diameter and "SP" denotes having prisms approximately 0.012 in. (0.3 mm) in diameter. "G" denotes glassed and "C" denotes

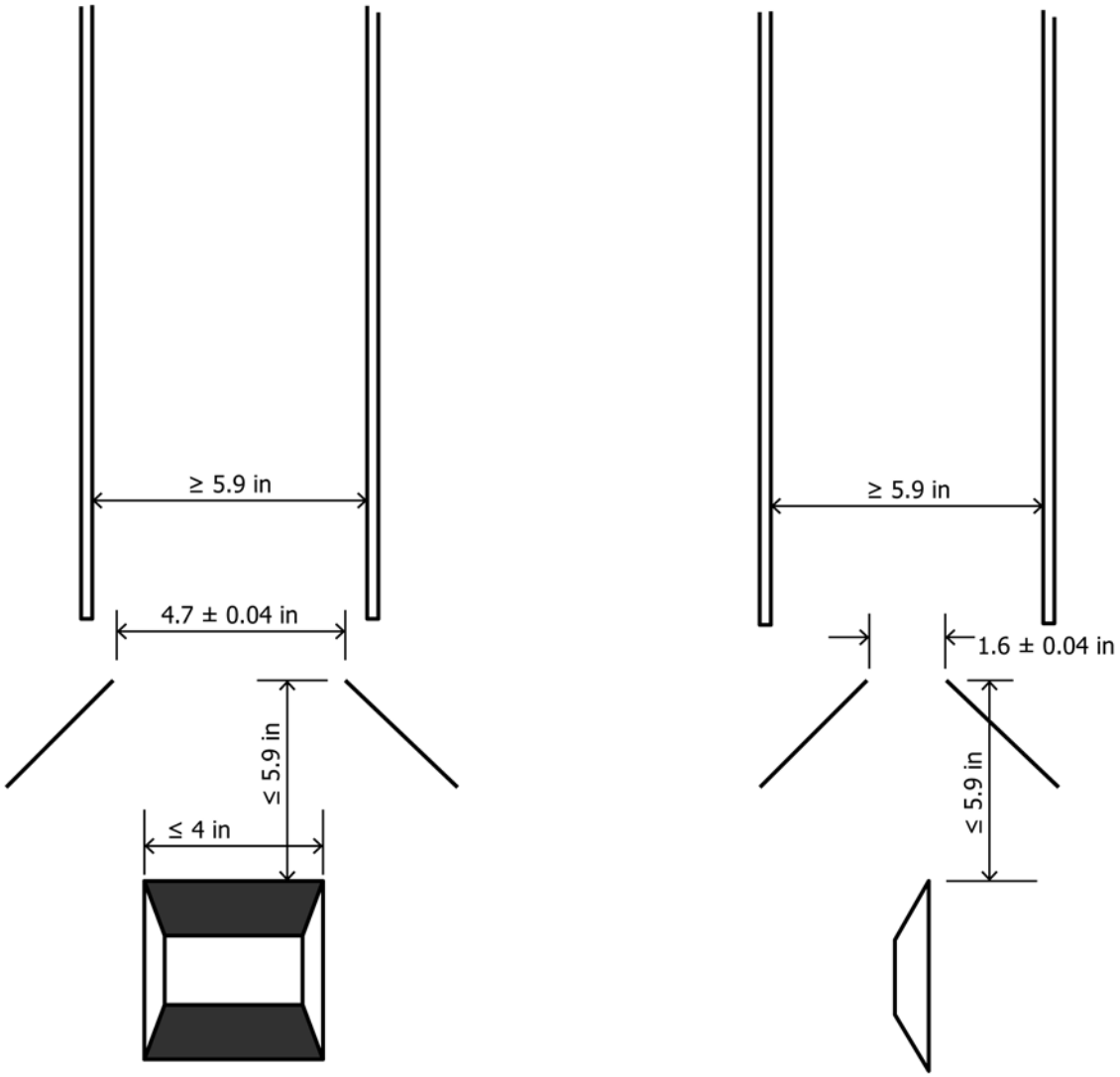

FIG. 5 Abrasion Resistance Test Apparatus

coated. The markers of each type were as identical as practical manufacturing allowed. All reflectors were white.

9.5.11.4 The study included four laboratories. Each laboratory photometered, abraded, and re-photometered between 10 and 20 markers of each type. Markers were conditioned to within 2°C for the pre-abrasion and post-abrasion photometry.

9.5.11.5 The precision statistics are given in Table 4.

9.5.11.6 The data given in Table 5 suggest upper limits to the contribution of manufacturing variation within the three types to the precision statistics.

TABLE 5 Sample Consistency for Abrasion Resistance

Marker Type	Lowest of Lab's Standard Deviations, s	Number of Samples, n, at that Lab
LPG	0.020	15
LPC	0.023	20
SPC	0.038	15

9.5.11.7 There is no estimate of bias. No reference abrasion apparatus exists by which to establish bias in the abrasion. Any photometric bias is expected to nearly cancel in the ratioing.

TABLE 4 Precision for Abrasion Resistance

Marker Type	$\bar{\bar{x}}$ Mean of Labs' Means	$s_{\bar{x}}$ Standard Deviation of Laboratory Means	s_r Repeatability Standard Deviation	s_L Standard Deviation of Assumed Normal Distribution of Laboratory Means	s_R Reproducibility Standard Deviation	r 95 % Repeatability Limit	R 95 % Reproducibility Limit
LPG	0.786	0.096	0.037	0.095	0.102	0.101	0.282
LPC	0.583	0.078	0.076	0.076	0.107	0.211	0.297
SPC	0.770	0.072	0.058	0.071	0.091	0.160	0.253

10. Packaging

10.1 Shipments shall be made in containers which are acceptable to common carriers and packaged in such a manner as to ensure delivery in perfect condition. Any damaged shipments shall be replaced by the contractor. Each package shall be clearly marked as to the name of the manufacturer, type, color, quantity enclosed, and date of manufacture.

11. Keywords

11.1 delamination; pavement markers; prismatic markers; raised pavement markers; retroreflective markers

ANNEX

(Mandatory Information)

A1. SPECIFICATION FOR ASPHALT ADHESIVE FOR PAVEMENT MARKERS

A1.1 Scope

A1.1.1 This specification establishes the requirements for asphalt adhesive to be used for placement of nonplowable, raised, retroreflective, pavement markers. The adhesive shall be suitable for bonding the above markers to portland cement concrete, asphaltic concrete, and chip sealed road surfaces and applicable when road surface and marker temperatures are in the range from 40 – 160°F (4.4 to 71°C). The adhesive properties will not deteriorate when heated to the application temperature recommended by the manufacturer.

A1.2 Classification

A1.2.1 *Type I*—A hot-melt asphalt adhesive without polymer, fibers, or GTR (ground tire rubber) modification.

A1.2.2 *Type II*—A hot-melt flexible asphalt adhesive modified with polymer excluding GTR.

A1.2.3 *Type III*—A hot-melt flexible asphalt adhesive containing GTR.

A1.3 Asphalt Adhesive Specifications

A1.3.1 Asphalt adhesive shall meet the requirements of Table A1.1.

NOTE A1.1—Penetration values represented in SI values provided in Table A1.1 are consistent with those found in Test Method D5.

A1.4 Packaging and Labeling

A1.4.1 The adhesive shall be packaged in self-releasing cardboard containers. The containers shall be divided into compartments that provide finished pieces with dimensions not exceeding 10 by 7.5 by 4 in. (254 by 191 by 102 mm). The label for the container shall clearly show the manufacturer, quantity, lot or batch number, and an indication that the material is asphalt adhesive for pavement markers.

TABLE A1.1 Asphalt Adhesive Properties

Property	Test Method	Type I	Type II	Type III
Softening point, °F (°C)	D36	200 – 264 (93 – 129)	200 (93) min	200 (93) min
Penetration at 77ºF, 3.5 oz, 5s, in (25°C, 100 g, 5s, mm × 10^{-1})	D5	0.04 – 0.07 (10 – 18)	0.12 (30) max	0.12 (30) max
Penetration at 140ºF, 3.5 oz, 5s, in (60°C, 100 g, 5 s, mm × 10^{-1})	D5	0.18 – 0.25 (45 – 65)	N/A	N/A
Viscosity at 400 ºF (204°C), #27 spindle, 20 rpm, lbf-sec/ft (Pa.s)	D4402	0.06 – 0.16 (3.0 – 7.5)	N/A	N/A
Viscosity at 376ºF (191°C), #27 spindle, 20 rpm, lbf-sec/ft (Pa.s)	D4402	N/A	0.04 – 0.13 (2.0 – 6.0)	0.04 – 0.13 (2.0 – 6.0)
Flow at 158°F, in. (70°C, mm)	D5329[A]	0.2 (5.1) max	0.2 (5.1) max	0.2 (5.1) max
Heat Stability Flow at 158°F, in. (70°C, mm)	D5329[B]	0.2 (5.1) max	N/A	N/A
Ductility at 77°F, 2 in./min, in. (25°C, 5 cm/min, cm)	D113	N/A	6 (15) min	3 (8) min
Ductility at 39°F, 0.4 in/min, in (4°C, 1 cm/min, cm)	D113	N/A	2 (5) min	0.8 (2) min
Flexibility at 19°F (– 7°C)	D3111[C]	N/A	No breaks, no cracks	No breaks, no cracks
Flash Point, °F (°C)	D92	550 (288) min	550 (288) min	550 (288) min
Specific Gravity at 77°F (25°C)	D71	1.6 – 1.85	1.10 – 1.35	1.25 – 1.50

[A]Curing time: 1 h. Oven time: 5 h.
[B]Modification to Test Methods D5329: Section 8.4, Specimen Preparation—Heat 2.2 lb (1000 g) of adhesive in a covered quart can at 424°F (218°C) and maintain at this temperature for 4 h prior to preparing the sample panel according to Section 7.1 of Test Method D5.
[C]Modifications to Test Method D3111: Section 6, Apparatus—Mandrel diameter of 1 in. (25.4 mm). Section 7, Test Specimen—Test specimen dimensions of 1 in. (25.4 mm) wide, 0.125 in. (3.2 mm) thick, and 6 in. (152 mm) long. Section 8, Conditioning—Conditioning of sample at 19°F (–7°C) 4 h min. Section 10.5, Procedure—Bend the specimen to a 90° arch at a uniform rate in 10 s.

APPENDIX

(Nonmandatory Information)

X1. STORAGE, PLACEMENT AND APPLICATION OF NONPLOWABLE MARKERS

X1.1 *Storage*—Markers should be stored indoors and should be protected from any source of moisture both during shipment to the jobsite and at the jobsite. The markers should be maintained at a high enough temperature as to preclude moisture condensation, and, at the time of placement, both the markers and their containers should be dry.

X1.2 *Placement of Nonplowable Markers*—Before beginning pavement marker application, the contractor should accurately and adequately lay out, by reference points, the location of all pavement markers, to ensure their proper placement. Pavement markers should not be placed on pavement surfaces that show visible evidence of cracking, checking, spalling, or failure of underlying base material. If, during the preinstallation layout operation, it is determined that a marker would be placed at a point with one of the aforementioned pavement surface defects or at a pavement construction joint or within the intersection of a driveway or public street as the result of typical marker spacing, the affected marker should be relocated longitudinally a sufficient distance to a point approved by the engineer. The distance the marker may be relocated should not exceed 10 % of the typical marker spacing. Where it would be necessary to relocate the marker a distance greater than 10 % of the typical marker spacing, the affected marker should be deleted. The reflective face of the

marker should be perpendicular to a line parallel to the roadway centerline.

X1.3 *Application of Nonplowable Markers*—Markers should be cemented to the pavement with Rapid Set Type adhesive conforming to the provisions of AASHTO M237, Type I, or Standard Set Type adhesive conforming to AASHTO M237, Type II, or with asphalt adhesive.

X1.3.1 The engineer should be the judge as to when Rapid Set Type adhesive has set sufficiently to bear traffic.

X1.3.2 Regardless of the type of adhesive used, markers should not be placed under the following conditions:

X1.3.2.1 When either the pavement or the air temperature is 32°F (0°C) or less when using rapid set epoxy, 50°F (10°C) or less when using standard set epoxy or 40°F (4.4°C) or less when using asphalt,

X1.3.2.2 If the relative humidity of the air is greater than 80 %,

X1.3.2.3 If the pavement is not surface dry, and

X1.3.2.4 On new asphalt concrete surfacing, until the surfacing has been opened to public traffic for a period of not less than 14 days.

X1.3.3 The portion of the highway surface to which the marker is to be bonded by the adhesive should be free of dirt, curing compound, grease, oil, moisture, loose or unsound layers, paint, and any other material which would adversely affect the bond of the adhesive. A wire brush should be used, if necessary, to loosen and remove dirt, and the surface should be brushed or blown clean. New portland cement concrete should be blast cleaned. The adhesive should be placed uniformly on the cleaned pavement surface or on the bottom of the marker in a quantity sufficient to result in complete coverage of the area of contact of the marker with no voids present and with a slight excess after the marker has been lightly pressed in place; ideally there will be approximately 0.060 in. adhesive between the marker and the pavement.

X1.3.4 For epoxy installations, excess adhesive around the edge of the marker, excess adhesive on the pavement, and adhesive on the exposed surfaces of the markers should be immediately removed. Soft rags moistened with mineral spirits in accordance with Federal Specification TT-T-291 or kerosene may be used, if necessary, to remove adhesive from exposed faces of pavement markers. No other solvent should be used.

X1.3.5 For epoxy installations, the marker should be protected against impact until the adhesive has hardened to the degree designated by the engineer.

X1.3.6 The epoxy adhesive requires that the mixing operation and placing of the markers be done rapidly. When hand mixing the Standard Set Type adhesive, not more than 1 qt (1 L) should be mixed at one time, and the markers should be aligned and pressed into place within 5 min after mixing operations are started. Any mixed batch which becomes so viscous that the adhesive cannot be readily extruded from under the marker on application of slight pressure should not be used. Rapid Set Type adhesive should not be mixed by hand.

X1.3.7 The Rapid Set Type adhesive should be mixed by a 2-component type automatic mixing and extrusion apparatus. When machine mixing the Standard Set Type adhesive, or the Rapid Set Type adhesive, the markers should be placed within 60 s after the adhesive has been mixed and extruded and no further movement of the marker should be allowed. In addition, no more than 90 s should be permitted between the time the adhesive is in place on the roadway and not subject to further movement. The mixed adhesive should not remain in the mixing head for more than 45 seconds. Adhesive remaining in the mixing head longer than this period should be wasted before resuming the operation.

X1.3.8 Automatic mixing equipment for the epoxy adhesive should use positive displacement pumps and should properly meter the two components in the specified ratio, ±5 % by volume of either component. At the beginning of each day and at any other time ordered by the engineer, the ratio should be checked by the contractor in the presence of the engineer. This check should be made by disconnecting the mixing heads, or using suitable bypass valves, and filling two suitable containers with the unmixed components. The mixing head should properly mix the two components, so that there is no trace of black or white streaks in the mixed material.

X1.3.9 Voids in a cured, undisturbed sample of the mixed adhesive obtained from the extrusion nozzle should not exceed 4 %.

X1.3.10 Asphalt adhesive should be dispensed from a thermostatically controlled melter-applicator at a temperature of 375 to 425°F (191 to 218°C). The material should be stirred frequently to ensure even heating. The adhesive should be dispensed in a puddle larger than the bottom of the marker, and the marker should be dropped onto the puddle as quickly as possible, preferably within 5 s of adhesive placement. The marker should be pressed lightly onto the adhesive. The adhesive will set up in approximately 2 min and typically requires no protection from traffic.