



Standard Test Methods for Mandrel Bend Test of Attached Organic Coatings¹

This standard is issued under the fixed designation D522/D522M; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 These test methods cover the determination of the resistance to cracking (flexibility) of attached organic coatings on substrates of sheet metal or rubber-type materials.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.3 *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

D823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels

D1005 Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers

D7091 Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals

3. Summary of Test Method

3.1 The coating materials under test are applied at uniform thickness to panels of sheet metal or rubber-type materials. After drying or curing the coated panels are bent over a

mandrel and the resistance to cracking of the coating is determined. In Test Method A the coated panels are bent over a conical mandrel. In Test Method B the coated panels are bent over cylindrical mandrels of various diameters.

4. Significance and Use

4.1 Coatings attached to substrates are elongated when the substrates are bent during the manufacture of articles or when the articles are abused in service. These test methods have been useful in rating attached coatings for their ability to resist cracking when elongated. They have been useful in evaluating the flexibility of coatings on flexible substrates.

5. Test Specimen

5.1 Substrates:

5.1.1 If the purpose of the test is to determine the percent of elongation of the coating material, the substrate shall be cold-rolled steel strip 0.8 mm [$\frac{1}{32}$ in.] (22 gage) thick.

5.1.2 If the purpose of the test is to rate the coated material for resistance to cracking, the substrate may be any type of sheet metal or rubber-type material (for example, steel, aluminum, tinplate, or synthetic rubber). The thickness of the sheet metal may be less than 0.8 mm [$\frac{1}{32}$ in.] and the thickness of the rubber-type materials may be as great as 13 mm [$\frac{1}{2}$ in.].

5.1.3 The recommended panel size is 100 mm [4 in.] in width and 150 mm [6 in.] in length. The maximum size that the conical mandrel can accommodate is 115 mm [$4\frac{1}{2}$ in.] wide and 190 mm [$7\frac{1}{2}$ in.] long.

5.1.4 The surface preparation of the substrate shall be agreed upon between the purchaser and the seller. Prior to the application of the coating, round slightly the edges of metal panels to remove burrs in order to eliminate anomalous edge effects.

NOTE 1—If elongations are to be determined for coatings applied to substrates other than 0.8 mm [$\frac{1}{32}$ in.] thick cold-rolled steel, they must be measured with a special mandrel jig as described in Appendix X1.2.

5.2 Coated Panels:

5.2.1 Apply uniform coatings of the materials under test to the substrates in accordance with Practices **D823** and air dry or bake under conditions mutually agreeable to the purchaser and the seller. If percent elongation is to be measured, a minimum thickness of 25.4 μ m [1.0 mil] is required on 0.8 mm [$\frac{1}{32}$ in.]

¹ These test methods are under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and are the direct responsibility of Subcommittee D01.23 on Physical Properties of Applied Paint Films.

Current edition approved Nov. 1, 2013. Published December 2013. Originally approved in 1939. Last previous edition approved in 2008 as D522 – 93a (2008). DOI: 10.1520/D0522_D0522M-13.

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.

thick cold-rolled steel. Perform a minimum of three determinations of coating thickness on each of the specimens in accordance with Test Methods **D1005** or **D7091**.

5.2.2 From precoated sheets cut at least three specimens of the size given in **5.1.3**. Use only plane (flat) sheets and round the edges of the panels slightly as in **5.1.4**. The coating surface shall be free of oil and other foreign matter that might increase the flexibility of the coating or interfere with the observation for cracking. Measure the film thickness as in **5.2.1**.

6. Conditioning and Number of Tests

6.1 Condition the test specimens for at least 24 hours at $23 \pm 2^\circ\text{C}$ [$73.5 \pm 3.5^\circ\text{F}$] and $50 \pm 5\%$ relative humidity, and test in the same environment or immediately on removal therefrom unless otherwise specified by the purchaser and seller.

6.2 Test at least three replicate specimens in Test Method A and at least two replicate specimens in Test Method B at each mandrel diameter of interest.

TEST METHOD A—CONICAL MANDREL TEST

7. Apparatus

7.1 *Conical Mandrel Tester*, consisting of a metal cone, a rotating panel-bending arm, and panel clamps, all mounted on a metal base as illustrated in **Fig. 1**.

7.1.1 *Cone*, smooth steel, 200 mm [8 in.] in length, with a diameter of 3 mm [$\frac{1}{8}$ in.] at one end and a diameter of 38 mm [$1\frac{1}{2}$ in.] at the other end.

8. Procedure

8.1 With the operating lever of the apparatus in a horizontal position, slip the test specimen between the mandrel and the drawbar with the finish side towards the drawbar. Rigidly clamp the specimen in a vertical position adjacent to the mandrel by placing the long edge behind the clamping bar in such a manner that the panel is always set up to the narrow end of the mandrel. Slip two sheets of No. 1 brown Kraft wrapping paper, substrate 30, thoroughly lubricated on each side with talc, between the specimen and the drawbar and hold in position only by the pressure of the drawbar against the paper.

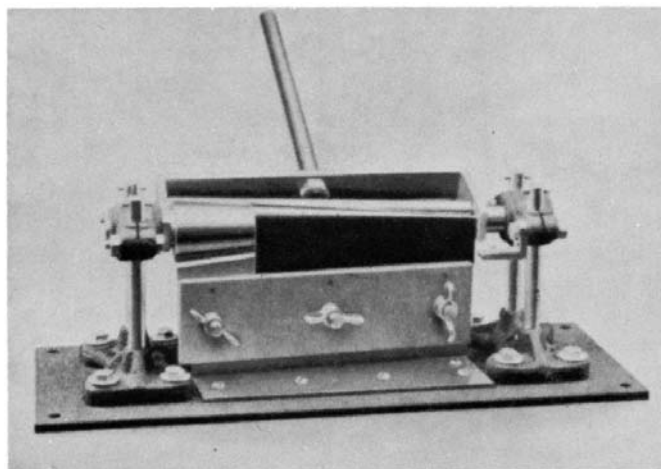


FIG. 1 Conical Mandrel Test Apparatus

8.2 Move the lever through about 180° at uniform velocity to bend the specimen approximately 135° . If the purpose of the test is to measure elongation, the bend time should be 15 seconds. To determine crack resistance under more simulated use conditions, the bend time should be about 1 second unless an alternative time is agreed upon between the producer and the user.

8.3 Examine the bent surface of the specimen immediately with the unaided eye for cracking. Having determined and suitably marked the end of the crack farthest from the small end of the mandrel, which shall be considered as the end point, bring the drawbar to the starting position and remove the panel from the mandrel. Measure the distance from the farthest end of the crack to the small end of the mandrel. This distance is used to compute the elongation. The mandrel diameter at which cracking ceased is taken as the resistance to cracking value.

NOTE 2—In some cases, the measured distance is used as a measure of crack resistance.

9. Calculation

9.1 When required, determine the elongation of the finish from the plotted curve in **Fig. 2**. This curve represents the relationship between the percent elongation and the diameter of the conical mandrel for a $25.4\ \mu\text{m}$ [1.0 mil] coating thickness. The relation between the distance along the conical mandrel and the corresponding diameter has also been plotted on this curve.

9.2 Adjust the percent elongation value obtained from **Fig. 2** for coating thickness by adding the correction obtained from **Fig. 3**.

NOTE 3—*Example*—Suppose visual examination of the finish on the bent cold-rolled steel specimens $0.8\ \text{mm}$ [$\frac{1}{32}$ in.] in thickness shows that the end of the first crack in the coating is at a distance of 75 mm [3 in.] from the small end of the cone. From **Fig. 2** determine the percent elongation of the film from the measured crack distance, in this example 5.2 %. To correct for coating thickness add the value obtained in **Fig. 3**. At a crack distance of 75 mm [3 in.] the correction per $25\ \mu\text{m}$ [1 mil] of coating thickness is 0.3 %. If the film thickness in the example is $50\ \mu\text{m}$ [2 mils], the actual percent elongation is $5.2 + (2 \times 0.3) = 5.8\%$.

10. Report

10.1 Report the following information:

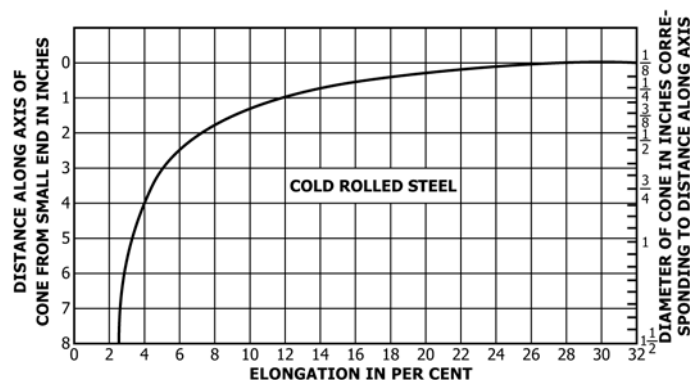


FIG. 2 Distance Along Cone and Corresponding Mandrel Size versus Percent Elongation for Specimens on Cold-Rolled Steel $0.8\ \text{mm}$ [$\frac{1}{32}$ in.] in Thickness

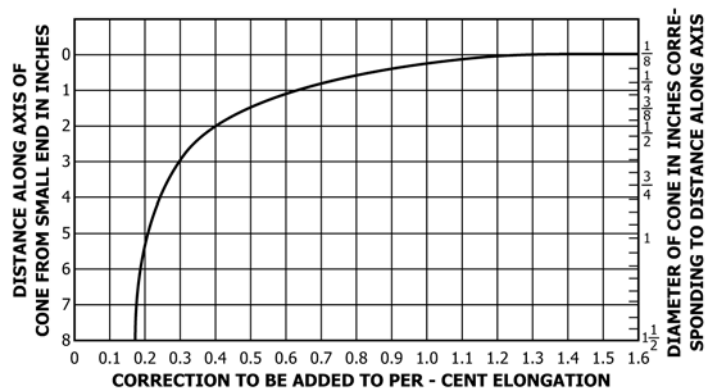


FIG. 3 Correction for Thickness of Film

10.1.1 Mean and range of coating elongation or resistance to cracking values for each specimen,

10.1.2 Mean and range of coating film thickness for each specimen,

10.1.3 Specimen preparation procedures used,

10.1.4 Test conditions,

10.1.5 Mean and range of elongation or resistance to cracking, and film thickness for the replicate specimens, and

10.1.6 Substrate material.

11. Precision and Bias³

11.1 *Precision*—On the basis of an interlaboratory test of limited scope³ in which two coatings differing in their flexibility were tested at two different times by operators in three laboratories, the intralaboratory standard deviation was found to be 1.5 % elongation, and the interlaboratory standard deviation was found to be 4.0 % elongation. Based on these standard deviations, the following criteria should be used for at the 95 % confidence level judging the acceptability of results:

11.1.1 *Repeatability*—Two determinations each the mean of duplicates obtained by a single operator should be considered to be suspect if they differ by more than 6 % in elongation.

11.1.2 *Reproducibility*—Two determinations each the mean of duplicates obtained by operators in different laboratories should be considered to be suspect if they differ by more than 15 % in elongation.

11.1.3 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in these test methods for measuring flexibility, bias cannot be determined.

TEST METHOD B—CYLINDRICAL MANDREL TEST

12. Apparatus

12.1 *Elongation Test Equipment*, consisting of rods or surfaces, including cylindrical steel diameters of 25 mm [1 in.], 19 mm [$\frac{3}{4}$ in.], 12.7 mm [$\frac{1}{2}$ in.], 9.5 mm [$\frac{3}{8}$ in.], 6.4 mm [$\frac{1}{4}$ in.], and 3.2 mm [$\frac{1}{8}$ in.], mounted on a metal base. An example of an acceptable form of this device is illustrated in Fig. 4.

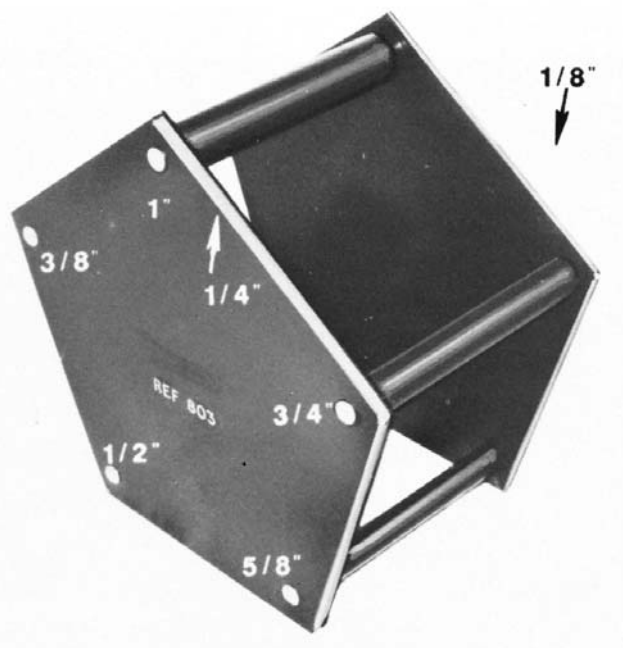


FIG. 4 An Illustration of a Cylindrical Mandrel Test Apparatus

13. Procedure

13.1 Place the test panel over a mandrel with the uncoated side in contact and with at least 50 mm [2 in.] overhang on either side. Using a steady pressure of the fingers, bend the panel approximately 180° around the mandrel at a uniform velocity in a time of 1 second unless an alternative time is agreed upon between the producer and the user. Remove and examine the panel immediately for cracking visible to the unaided eye. If cracking has not occurred, repeat the procedure using successively smaller diameter mandrels on previously untested areas of a specimen until failure occurs or until the smallest diameter mandrel has been used.

13.1.1 This procedure can be applied as a “pass/fail” test by determining whether cracking is produced by a specified mandrel size.

13.1.2 The resistance to cracking value for a coating is taken as the mandrel diameter at which cracking ceases.

³ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D01-1069. Contact ASTM Customer Service at service@astm.org.



TABLE 1 Elongation

Mandrel Diameter, mm [in.]	Elongation, %
25 [1]	3.3
19 [¾]	4.4
12.7 [½]	6.75
9.5 [⅜]	9.0
6.4 [¼]	14.0
3.2 [⅛]	28.0

TABLE 2 Correction for Film Thickness

Mandrel Diameter, mm [in.]	Correction Factor
25 [1]	0.21
19 [¾]	0.26
12.7 [½]	0.38
9.5 [⅜]	0.50
6.4 [¼]	0.71
3.2 [⅛]	1.40

13.2 To determine elongation of the applied coating, follow the procedure given in 13.1, using a bend time of 15 seconds.

14. Calculation

14.1 Determine the elongation range of the material from Table 1 in which the elongation of a 25 µm [1 mil] thick coating on 0.8 mm [⅓ in.] cold-rolled steel is given for each mandrel diameter.

14.2 If the coating thickness exceeds 25 µm [1 mil], correct the determined elongation for film thickness using the factors for each mandrel diameter given in Table 2. Calculate the total elongation of the coating as follows:

$$E = e_1 + tc_1$$

where:

E = total elongation, %,

e_1 = elongation from Table 1, %,

t = thickness, µm [mils], and

c_1 = correction factor from Table 2.

15. Report

15.1 Report the following information:

15.1.1 Mean and range of coating elongation or resistance to cracking values for each specimen,

15.1.2 Mean and range of coating thickness for each specimen,

15.1.3 Specimen preparation procedures used,

15.1.4 Test conditions,

15.1.5 Mean and range of elongation, resistance to cracking, and film thickness for the replicate specimens, and

15.1.6 Substrate material.

16. Precision and Bias

16.1 Results are not available to determine the precision of these test methods. These test methods have been in use for many years and are considered acceptable for evaluating the crack resistance of attached coatings.

17. Keywords

17.1 cracking; flexibility; resistance—cracking

APPENDIX

(Nonmandatory Information)

X1. RELATIONSHIP BETWEEN ELONGATION AND MANDREL SIZE

X1.1 In the mandrel test, the specimens are elongated considerably past their elastic limit. Therefore, the elongations obtained are considerably higher than elongation values calculated from a theoretical equation that is based on the assumption that the elastic limits of the specimens are not exceeded.

X1.2 The elongation values corresponding to mandrel diameters in Fig. 2 and Fig. 3 of these test methods were obtained by direct measurements with a special mandrel jig.

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