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Standard Test Method for Measurements of Internal Stresses in Organic Coatings by Cantilever (Beam) Method[1]

This standard is issued under the fixed designation D6991; 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 procedure for measurements of internal stresses in organic coatings by using the cantilever (beam) method.

1.2 This method is appropriate for the coatings for which the modulus of elasticity of substrate (Es) is significantly greater than the modulus of elasticity of coating (Ec) and for which the thickness of substrate is significantly greater than thickness of coating (see Note 7 and Note 8).

1.3 The stress values are limited by the adhesion values of coating to the substrate and by the tensile strength of the coating, or both.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *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, health, and environmental practices and to determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

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

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. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *cantilever, n*—a beam or member securely fixed at one end and hanging free at the other end.

3.1.2 *deflection, n*—the displacement of a beam from its original position by an applied force.

3.1.2.1 *Discussion*—The deflection of the beam is used to measure that force acting on the tip.

3.1.3 *internal stress, n*—a stress system within a solid that is not dependent on external forces.

4. Test Method

4.1 Internal stresses in coatings are determined by the cantilever method (Fig. 1). Substrate A in the shape of a rectangular cantilever beam is clamped by its end B in a special fixture E. Coating (F) is applied to one side of the beam. Internal stresses occur in the film when it is being cured (drying, cross-linking, etc.). When there is sufficient adhesion between the coating and the substrate, the stresses bend the cantilever beam, forcing its free end D to be deflected from its original position by a distance of h. The deflection of the beam is measured under an optical microscope and internal stress is calculated using the equation for the cantilever method. See Eq 1 in Section 9, (Formula 1).

5. Significance and Use

5.1 Stresses in coatings arise as a result of their shrinkage or expansion if expected movements are prevented by coating adhesion to its substrate.

5.2 There are several causes leading to arrival of stresses in the coatings: film formation (cross-linking, solvent evaporation, etc.); differences in thermal expansion coefficients between coating and substrate; humidity and water absorption; environmental effects (ultraviolet radiation, temperature and humidity), and others.

[1] This test method is under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.23 on Physical Properties of Applied Paint Films.

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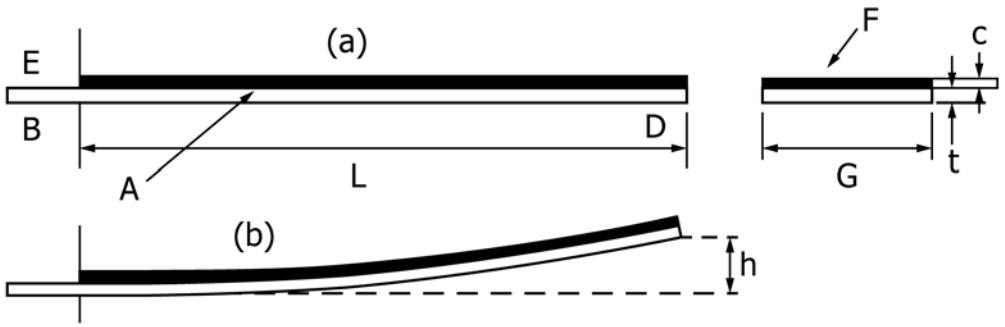
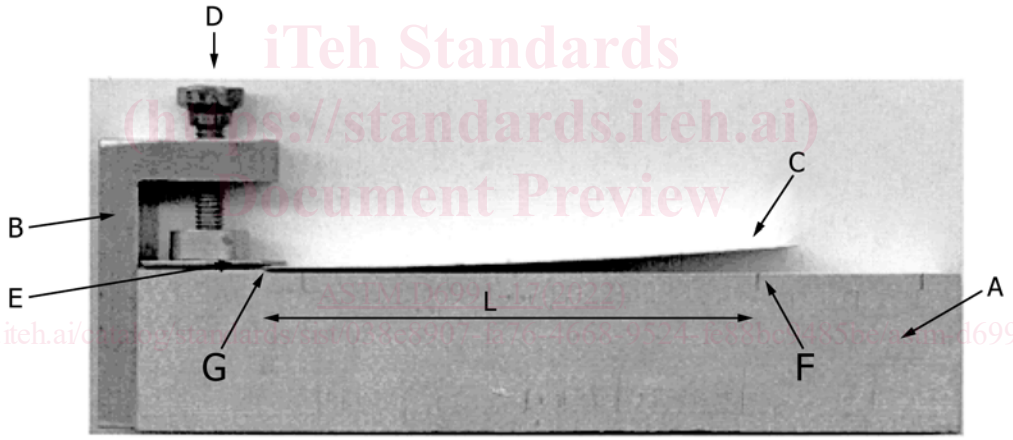
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



A- Cantilever beam (substrate)
B- Beam end clamped in Fixture E
c- Coating thickness
D- Free end deflected under stress
E- Fixture
F- Coating
G- Width of beam
h- Deflection
L- Distance between the deflecting point and the clamping point
t- Substrate thickness

FIG. 1 Diagram of the Cantilever Method for Measurements of Internal Stresses in Organic Coatings
(a) – Original position (b) – Free end deflected from its original position as a result of stress



A- Support
B- Stop
C- Coated cantilever beam
D- Screw clamp
E- Pressure shim
F- Engraved mark
G- Edge clamping point
L- Distance between end of pressure shim to the engraved point where the deflection is measured

FIG. 2 Fixture with the Clamped Coated Cantilever Sample for the Measurements of Internal Stresses in Organic Coatings

5.3 Knowledge of the internal stresses in coatings is very important because they may effect coating performance and service life. If the internal stress exceeds the tensile strength of the film, cracks are formed. If stress exceeds adhesion between coating and substrate, it will reduce adhesion and can lead to delamination of coatings. Quantitative information about stresses in coatings can be useful in coating formulation and recommendations for their application and use.

5.4 This method has been found useful for air-dry industrial organic coatings but the applicability has not yet been assessed for thin coatings (thickness <0.0254 mm (.001 in.), for powder and thermally-cured coatings.

6. Apparatus

6.1 *Measurement Fixture* (Fig. 2)—The fixture consists of the support A and the stop B to which the cantilever substrate

C is clamped with the screw D and shim E. On the side of the support there is an engraved mark F called the fixed point at an exact known distance (L) from the edge clamping point G. By moving the fixture under an optical microscope, the deflection of the cantilever is always measured at the fixed point.

NOTE 1—Other similar fixture configurations may be used as long as the key elements of the setup are present. Key elements include clamping of shim E on top of substrate C against the support A such that the edge of the substrate C is in the same plane as the edge of the support A and clamping point G is at a distance L away from the engraved mark F.

6.2 *Optical Microscope*—Capable of measuring deflection with resolution 0.0254 mm (0.001 in.).

7. Test Specimen

7.1 Use stainless strips (stainless steel 304SS is acceptable) as a cantilever substrate with the following dimensions: width, 12 mm (0.5 in.); length, 102 mm (4 in.); and thickness, 0.254 mm (0.01 in.).

NOTE 2—Other dimensions could be used. However, to reduce effect of clamping, the length of cantilever strip between the edge point at which it is clamped and the point at which deflection is measured (see Fig. 1) should be greater than 80 mm.[3,4,5]Excessive thickness of steel substrate should be avoided to reduce error associated with measurement of deflection since deflection decreases drastically as substrate thickness increases.

Stainless steel was selected to avoid corrosion of the strips. However, in cases where the coating can not adhere to the stainless steel, the other materials can be used (carbon steel, aluminum, etc.).

7.2 Cantilever substrates are selected with a slight cylindrical curvature with a "concave" side to be coated. If the strips are flat the "slight curvature" can be made by gently bending them with hand to achieve 2 to 3 mm deflection.

7.3 Install the cantilever in the fixture and measure using microscope the deflection at fixed point before coating application.

7.4 Substrate should be degreased or solvent-cleaned; in some cases, surface can be slightly and uniformly abraded using abrasive paper.

7.5 The clamped area and the uncoated side of the cantilever substrate are masked with tape during the application of coating.

7.6 Apply uniform coatings of the material to be tested to the "concave" side of the cantilever strip at specified thickness in accordance with Practices D823. The dry thickness should not be greater than half the thickness of the cantilever panel (see Note 7). For example, if substrate thickness is 0.254 mm (0.01 in.) the recommended dry coating thickness should be not greater than 0.127 mm (0.005 in.). Due to the slower process of curing in very thick coatings it is recommended to limit the dry coating thickness to 0.254 to 0.381 mm (0.01 to 0.015 in.).

7.7 Remove any paint from the uncoated side by sharp razor blade if necessary. Prepare a minimum of three coated panels for the material.

NOTE 3—If the coating thickness measurement and/or reinstallation of the panel to the base are expected to introduce unacceptable errors in deflection measurements, an extra panel which will not be mounted should be coated as a reference panel for coating thickness measurement during subsequent deflection measurements. The relative change in coating thickness on the reference panel should be applicable to the mounted panels with the same environmental history and degree of curing provided that the initial average DFT of the panels within the group are within ±10 %.

7.8 Cure the coated panels under humidity and temperature conditions as agreed upon between the producer and the user.

7.9 As soon as the coating is dry enough to be handled, the thickness of the dry coatings should be measured, in at least three locations evenly spaced along the length of the coating, in accordance with Practice D7091 or any other test method as agreed upon between the producer and the user.

NOTE 4—If a reference panel was prepared as mentioned in Note 3, this measurement should be used as the initial thickness for calculating the coating thickness during subsequent deflection measurements according to Note 6. Care should be taken to avoid deformation of coating during measurement. The location of thickness measurement on the reference panel should be marked such that the same locations will be measured as testing progresses over time.

7.10 Take any precautions in handling of the cantilever beam during preparation for application, masking, application, mask removal, etc., to avoid any deformation or damage.

8. Measurement Procedure

8.1 As soon as the coating is dry enough to be handled, the coated beam is clamped finger tight to the support with coated side up. The masking tape should be removed before installation.

8.2 The first deflection measurement taken under microscope should be made as soon as the coating is dry enough to handle, at which point there should be minimal or no measurable deflection. This measurement is used as a "zero" reference point.

NOTE 5—If coating rapidly cures and develops stress, the reference position of the cantilever substrate cannot be correctly determined. For such cases the deflection obtained with the uncoated substrate is taken as the "zero" point.

8.3 The difference between current values taken at the specified time intervals and "zero" values is the deflection to be used in stress calculations.

8.4 The stress (deflection) can be measured as a function of time and of difference variables (temperature, humidity, coating thickness, etc.). Coated samples can be clamped in the fixture for the period of testing, or can be removed for various exposures and reinstalled again.

NOTE 6—Sample reinstallation may increase the error of measurement. If reinstallation or physical contact with the panel are to be avoided, the DFT on the panel can be calculated based on the relative change in DFT of the reference panel from the initial DFT (see Note 3 and Note 4) to the time when deflection was measured as a function of time. This can be calculated based on Eq 3. The reference panel must receive the same environmental history as the mounted panel it is reference to.

[3] Perera, D., Y., Eynde, D. V., "Considerations on a Cantilever (Beam) Method for Measuring the Internal Stress in Organic Coatings," *Journal of Coatings Technology*, Vol. 53, No. 677, June 1981.

[4] Korobov, Y., Salem, L., "Stress Analysis as a Tool in Coatings Research," *Materials Performance*, Vol. 29, No. 4, April 1990.

[5] Koleske, Joseph V., *Paint and Coating Testing Manual Fourteenth Edition of the Gardner-Sward Handbook*, Chapter 49, Philadelphia, PA: ASTM, 1995.