Designation: D6991 – 05

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 4 and Note 5).

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 and health practices and to 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

D1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base[3]

D1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base[3]

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.

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

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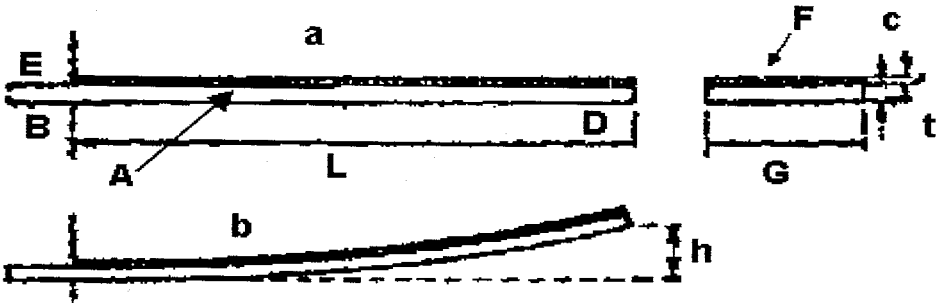
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn.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



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

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 called the fixed point at an exact known distance (L) from the edge clamping point. By moving the fixture under an optical microscope, the deflection of the cantilever is always measured at the fixed point.

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 1—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.[4,5]

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 2-3 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 thickness should not be greater than half the thickness of the cantilever panel (see Note 4). For example, if substrate thickness is 0.254 mm (0.01 in.) the recommended 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 coating thickness to 0.254 – 0.381 mm (0.01 – 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.

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

7.9 The thickness of the dry coatings should be measured in accordance with Test Methods D1186, Test Method D1400 or any other test method as agreed upon between the producer and the user.

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.

[4] 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.

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