Designation: ~~D6991 – 05 (Reapproved 2010)~~ D6991 – 17

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~~7 and Note ~~5~~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~~ safety, health, and ~~health~~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, Varnish, and Related Products on Test Panels

~~D1186~~D7091 ~~Test Methods~~ Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to ~~a Ferrous Base~~Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals ~~(Withdrawn 2006)~~

~~D1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base (Withdrawn 2006)[3]~~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.

[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.

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.

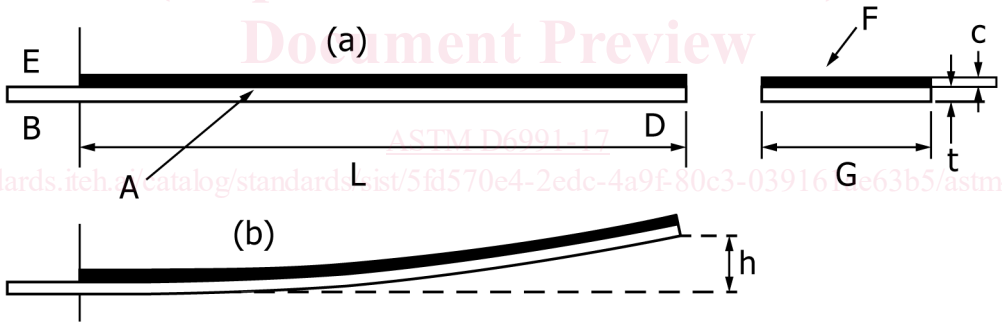
5.2 There are several causes leading to arrival of stresses in the coatings: film formation (cross-linking, solvent evaporation, etc.); differences in thermal expansion coefficients between coating and substrate; humidity and water absorption; environmental effects (ultraviolet radiation, temperature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



~~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~~

A- Cantilever beam (substrate)
B- Beam end clamped in Fixture E
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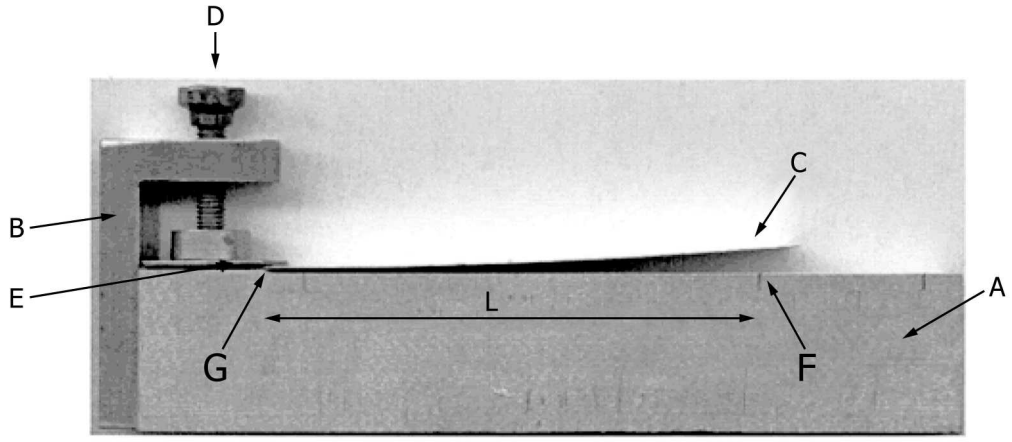
t- Substrate thickness

FIG. 1 Diagram of the Cantilever Method for Measurements of Internal Stresses in Organic Coatings
~~a~~(a) – Original ~~position b~~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~~
~~L- Distance between end of pressure shim to the engraved point where the deflection is measured~~

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

known distance (L) from the edge clamping ~~point.~~ 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] 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 ~~2-3~~ 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 ~~4~~7). For example, if substrate thickness is 0.254 mm (0.01 in.) the recommended dry coating thickness should be not greater than

[3] Perera, ~~D.~~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.