



Designation: C1350M – 96 (Reapproved 2019)

# Standard Test Method for Measurement of Viscosity of Glass Between Softening Point and Annealing Range (Approximately $10^8$ Pa·s to Approximately $10^{13}$ Pa·s) by Beam Bending (Metric)<sup>1</sup>

This standard is issued under the fixed designation C1350M; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers the determination of glass viscosity from approximately  $10^8$  Pa·s to approximately  $10^{13}$  Pa·s by measuring the rate of viscous bending of a simply loaded glass beam.<sup>2</sup> Due to the thermal history of the glass, the viscosity may not represent conditions of thermal equilibrium at the high end of the measured viscosity range. Measurements carried out over extended periods of time at any temperature or thermal preconditioning will minimize these effects by allowing the glass to approach equilibrium structural conditions. Conversely, the method also may be used in experimental programs that focus on nonequilibrium conditions.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.

1.4 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.

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee C14 on Glass and Glass Products and is the direct responsibility of Subcommittee C14.04 on Physical and Mechanical Properties.

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<sup>2</sup> Hagy, H. E., "Experimental Evaluation of Beam Bending Method of Determining Glass Viscosities in the Range  $10^8$  to  $10^{15}$  Poises", *Journal of the American Ceramic Society*, Vol 46, No. 2, 1963, pp. 95–97.

## 2. Referenced Documents

2.1 *ASTM Standards*:<sup>3</sup>

C336 Test Method for Annealing Point and Strain Point of Glass by Fiber Elongation

C338 Test Method for Softening Point of Glass

C598 Test Method for Annealing Point and Strain Point of Glass by Beam Bending

C965 Practice for Measuring Viscosity of Glass Above the Softening Point

C1351M Test Method for Measurement of Viscosity of Glass Between  $10^4$  Pa·s and  $10^8$  Pa·s by Viscous Compression of a Solid Right Cylinder [Metric]

## 3. Terminology

3.1 *Definitions*:

3.1.1 *beam bending viscometer*—a device used to determine the viscosity of glass from approximately  $10^8$  Pa·s to approximately  $10^{13}$  Pa·s by measuring the deflection rate of a simply supported beam. The equation for calculating viscosity by this method is:

$$\eta = \frac{gL^3}{1440 I_c (dh/dt)} \left[ M + \frac{\rho AL}{1.6} \right] \left[ \frac{(1 + \alpha_s T)^3}{(1 + \alpha_g T)^4} \right] \quad (1)$$

where:

$\eta$  = viscosity, Pa·s,  
 $M$  = load (applied load + loading train), gms,  
 $dh/dt$  = midpoint deflection rate of test beam, cm/s,  
 $g$  = acceleration of gravity, 980 cm/s<sup>2</sup>,  
 $I_c$  = cross-sectional moment of inertia, cm<sup>4</sup>,  
 $\rho$  = density of glass, g/cm<sup>3</sup>,  
 $A$  = cross-sectional area of the beam, cm<sup>2</sup>,  
 $L$  = support span, cm, and  
 $\alpha_s$  and  $\alpha_g$  = mean coefficient of linear thermal expansion of support stand and glass, respectively, 25 °C to temperature of measurement, T, m/m/°C. See **Note 1**.

<sup>3</sup> 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.

NOTE 1—The term  $(1 + \alpha_s T)^3 / (1 + \alpha_g T)^4$  corrects for thermal expansion changes of room temperature dimensions. It can be ignored when  $\alpha_s$  and  $\alpha_g$  are approximately equal. A fused silica support stand in combination with a high expansion glass can make this term 3 % in magnitude. Only an estimate of  $\alpha_g$  is required, since the correction is small. Use 1.5 times the room temperature coefficient if data are unavailable.

#### 4. Significance and Use

4.1 This test method is well suited for measuring the viscosity of glasses in ranges higher than those covered by parallel plate (see Test Method C1351M) and rotational viscometry (see Practice C965) methods. This test method is useful for providing information related to the behavior of glass after it has been formed into an object of commerce and in research and development.

#### 5. Apparatus

5.1 The apparatus shall consist of a furnace, a means of controlling its temperature and heating rate, specimen holders and loading rod, and a means of observing the rate of viscous deflection of the glass specimen.

##### 5.2 Furnace:

5.2.1 The furnace shall be electrically heated by resistance elements. The dimensions and the details of the furnace construction are not critical; its cross-section can be circular of 75 mm (~3 in.) diameter or square with sides of 75 mm. The furnace should have a constant temperature zone that covers the specimen geometry, including the deflection range. Differences in temperature greater than 2 °C within that constant temperature zone are unacceptable.

##### 5.3 Temperature Measuring and Indicating Instruments:

5.3.1 For the measurement of temperature, there shall be provided a calibrated Type K, R, or S thermocouple. The thermocouple shall be housed in a double-bore alumina tube with its junction placed within 5 mm of the specimen near the axis of the furnace. The thermocouple shall be referenced to 0 °C by means of an ice bath, and its emf measured with a calibrated potentiometer that can be read with a sensitivity of 0.1 °C and an accuracy of  $\pm 0.5$  °C. Precautions shall be taken to ensure that the ice bath is maintained at 0 °C throughout the test. Alternately, the output of the thermocouple can be measured on a calibrated, direct reading meter (electronic thermometer) that can be read with a sensitivity of 0.1 °C and an accuracy of  $\pm 0.5$  °C. See Note 3 for temperature lag-lead corrections.

##### 5.4 Furnace Control:

5.4.1 Suitable means shall be provided for maintaining the furnace temperature at a fixed control point and for controlling the heating and cooling rates. Commercially available programming equipment provides excellent control. A variable transformer with manual control is an inexpensive, but less adequate means of accomplishing the required control.

##### 5.5 Specimen Holder and Loading Rod :

5.5.1 A diagram of the apparatus can be found in Test Method C598.

5.5.2 A ceramic support stand and a ceramic loading rod shall be provided for supporting the specimen and applying the load to it. The thermal expansion characteristics of both

members must be very similar so as to minimize motion of the loading rod due to expansion differences. A rectangular alumina muffle or circular tube that can be notched to define specimen position is a suitable support stand (see Note 2). The supporting surfaces of these notches shall be flat and lie in a plane perpendicular to the axis of the furnace. The inside edges of these notches define the support span once the specimen beam starts to deflect. A support span of about 5 cm ( $\pm 2$  in.) is recommended. A suitable loading rod can be provided by a single-crystal sapphire rod flame bent at one end in the form of a shepherd's crook.<sup>4</sup> This crook will contribute to the load on the specimen, so its weight should be kept to a minimum.

NOTE 2—Vitreous silica is a suitable material for both support stand and loading rod. It is not recommended for temperatures above 900 °C.

##### 5.6 Extensometer for Measuring Midpoint Deflection:

5.6.1 The means for observing the rate of deflection of the specimen shall allow reliable reading of total deflection of at least 10 mm. The extensometer shall permit direct reading of 0.010 mm and estimates of 0.0010 mm. Its accuracy shall be such that the error of indication will not exceed  $\pm 2$  % for any measured deflection. This will limit the minimum deflection that may be used in calculation. A linearly variable differential transformer (LVDT) is suitable for this purpose, as is any other device (for example, optical or capacitive), provided that deflection is reliably measured as specified.

##### 5.7 Weights:

5.7.1 A set of weights spanning the range from 1 to 500 g and accurate to 0.1 % relative is required.

##### 5.8 Micrometre Calipers:

5.8.1 Micrometre calipers which can be read to an accuracy of at least 0.01 mm are required for measuring specimen dimensions.

##### 5.9 Analytical Balance:

5.9.1 An analytical balance capable of weighing the shepherd's crook and loading train to an accuracy of 0.1 % relative.

#### 6. Preparation of Test Specimen

6.1 Specimens may either be flame drawn or centerless ground into cylindrical form or diamond-saw cut and mill ground into rectangular form. Nonuniformity of any dimension along the length of the specimen shall not exceed 2 %. When nonuniformity of any dimension exists, an average value shall be used.

6.2 The numerical ratio of beam span to moment of inertia shall not be less than 60. The thickness or diameter to span ratio shall be less than 0.1.

#### 7. Calibration

7.1 Direct calibration of the apparatus is accomplished by using standard glasses, such as those supplied and certified by the National Institute of Standards and Technology (NIST),

<sup>4</sup> The sole source of supply of flamebent hooks known to the committee at this time is Insaco Inc., P.O. Box 422, Quakertown, PA 18951. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.