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Designation: ~~C1652/C1652M – 06~~ C1652/C1652M – 14

Standard Test Method for Measuring Optical Distortion in Flat Glass Products Using Digital Photography of Grids[1]

This standard is issued under the fixed designation C1652/C1652M; 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.

INTRODUCTION

Transmitted and reflected distortion in annealed, heat strengthened, and tempered glass can be measured by several methods.(**1**, **2**, **3**, **4**~~,~~))[2] Qualitative methods are based on the observation of waviness in the glass as viewed in of reflected or transmitted images in a set of equidistant lines, called Zebra Lines. Quantitative measuring techniques are based on several methods, some of which are:
(*1* ~~1)~~) Measuring local curvature using mechanical radius gages ((**1**, **5**, **6**, and Test Method C1651)
~~2)~~(*2* ~~Moire~~) Moiré Fringe analysis (**7**, **8**)
~~3)~~(*3*) Double exposure of transmitted grid images (Practice F733)
(*4* ~~4)~~) Projection of an array of round dots (**9**)
(*5* ~~5)~~) Dual laser beams (**10**)
The user should be familiar with techniques that are available so as to select the most suitable after considering the precision, speed, and test specification requirements. The test method described in this document uses a digital camera to capture a transmitted or reflected image of a set of equidistant lines. Changes in the spacing of lines are used to quantifying the distortion.

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1. Scope

1.1 This test method covers the determination of optical distortion of heat-strengthened and fully tempered architectural glass substrates which have been processed in a heat controlled continuous or oscillating conveyance oven. See Specifications C1036 and C1048 for discussion of the characteristics of glass so processed. In this test method the reflected image of processed glass is photographed and the photographic image analyzed to quantify the distortion due to surface waviness. The test method is also useful to quantify optical distortion observed in transmitted light in laminated glass assemblies.

1.2 The values stated in either SI units or inch-pound units are 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 nonconformance with the standard.

1.3 There is no known ISO equivalent to this standard.

1.4 *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:*[3]
C162 Terminology of Glass and Glass Products
C1036 Specification for Flat Glass
C1048 Specification for Heat-Strengthened and Fully Tempered Flat Glass

[1] This test method is under the jurisdiction of ASTM Committee C14 on Glass and Glass Products and is the direct responsibility of Subcommittee C14.11 on Optical Properties.

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[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[3] 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.

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C1651 Test Method for Measurement of Roll Wave Optical Distortion in Heat-Treated Flat Glass
F733 Practice for Optical Distortion and Deviation of Transparent Parts Using the Double-Exposure Method
2.2 *Other Standards:*
U.S. Patent 7 345 698 Optical System for Imaging Distortions in Moving Reflective Sheets (2003)

3. Terminology

3.1 See Terminology C162 ~~Terminology~~ of Glass and Glass ~~Products~~Products.

3.2 *Definitions:*

3.2.1 *focal length, F*—The focal length of a specular reflector, due to the curvature at a point equals R/2. (See 3.2.3.) In transmitted light, local thickness changes introduce a convergence or divergence, equivalent to a lens with a focal length F.

3.2.2 *optical power, D*—The optical power due to the curvature at a point is D = 1/F. The optical power is expressed in diopters, (Units 1/m), or as is typical, in millidiopters. The optical power is also used to quantify optical distortion, the deformation of images reflected from flat glass, or transmitted by laminated or bent glass, or both.

3.2.3 *radius of curvature, R*—The local radius of curvature at a point on the surface, in meters. R_x and R_y are respectively measured in planes x (usually horizontal) and y (usually ~~vertical)~~vertical).

3.2.4 *roll wave*—A repetitive, wave-like departure from flatness in otherwise flat glass that results from heat-treating the glass in a horizontal conveyance system. Roll wave excludes edge effects such as edge kink, and distortion induced by assembly or installation.

4. Summary of Test Method

4.1 This test procedure was designed to provide an accurate method of quantifying the optical distortion of glass as it is revealed in reflected or transmitted images. The optical distortion in reflected light can be related to a surface waviness, known as roll wave in tempered glass products, or, in transmitted light, related to curvature and local thickness variations in laminated glass products. The test method is based on the use of a digital camera which is used to record the appearance of an accurately printed grid pattern which has been reflected from or transmitted though ~~apiece~~ a lite of glass. Mathematical analyses performed on computer of the changes in the grid pattern along with the laws of optics and the geometrical arrangement makes it possible to quantify the lens power or optical distortion of each element of the glass surface defined by the grid.

4.2 A uniformly spaced set of parallel lines, usually set at 45° angle to horizontal, may be used instead of a grid. If such a set of lines is used, the mathematics of calculation will be slightly altered from those expressed in Appendix X1.

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5. Significance and Use

5.1 This test method provides accurate data for evaluation of the optical properties of the glass being inspected.

5.2 The procedure described is useful for measuring the roll wave introduced during the tempering process of flat architectural glass. (**1**)

5.3 This test method is also useful for inspection of laminated and tempered automotive glass in transmitted light, in both flat and curved geometries.

6. Apparatus

6.1 The items shown in Fig. 1 are required to practice this test method:

6.2 An accurately printed flat screen containing a pattern of equidistant black lines on a white background.

NOTE 1—The ruled area of the screen should have at least twice the dimensions of the area on the glass to be examined.

6.2.1 The line spacing or pitch p (center to center or corresponding edge to corresponding edge distance between adjacent lines) defines the spatial resolution of the system. A ~~50 mm~~ 50 mm [2 in] pitch in both horizontal and vertical directions provides satisfactory resolution for the examination of tempered glass in reflection mode. A smaller pitch can be used when examination of smaller deformations in laminated glass is carried out using this test method. The width of the black line is typically 6 mm [¼ in]. The line-to-line distance must be uniform, in both horizontal and vertical directions. The uniformity of the line-to-line spacing, p, is critical, because the system interprets a non-uniform spacing as optical distortion. A uniformity of the pitch of 0.2 mm [0.008 in] is satisfactory in reflective measurements.

6.3 A digital camera equipped with an a planar lens and an image pixel resolution compatible with the software requirements. ~~These requirements are met by most commercially available digital cameras.~~

6.4 A computer using an operating system compatible with the software and any peripherals needed to satisfy the data logging and reporting requirements.

6.5 A software program capable of performing the evaluation of changes in line-spacing, p, and computation of the optical distortion, D, throughout the inspected region.

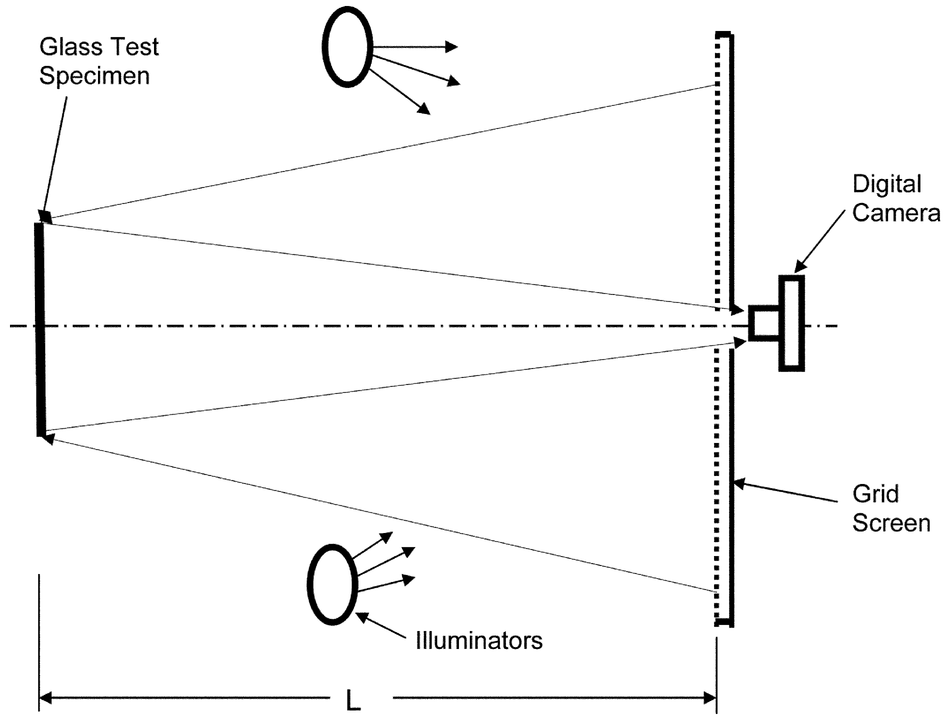

FIG. 1 Test Configurations of Reflective Analysis

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https://standards.iteh.ai/catalog/standards/sist/b6e2d87c-856b-4ea9-889c-ab985bea151c/astm-c1652-c1652m-14

6.6 Lighting sufficient to provide photographic contrast.

6.6.1 ~~A uniform illumination of the~~ The screen must be ~~ensured. In average lighting conditions, four Quartz-Halogen flood-lamps, 500 watt each, are satisfactory.~~ illuminated with uniform diffused background lighting with a minimum illuminance of 850 lux (80 candles), measured at the surface of the screen. Four Quartz-Halogen flood lamps, 500 watts each, can provide satisfactory results.

6.6.2 In a brightly illuminated area, two times higher illumination power is needed to assure good photographic contrast.

7. Sampling

7.1 The number of specimens and frequency of testing is to be determined by the user.

8. Calibration and Standardization

8.1 System calibration is a two-step procedure.

8.2 *Verification of System Zero*

8.2.1 Set the camera at a distance 2L from the screen. Capture the image of the screen without a glass panel in place and process the image through the analysis software. The image analysis should indicate small values of D throughout the inspection area, typically less than 5 mdpt.

8.3 *Verification of Calibration (Span Calibration)*

8.3.1 This system calibration is determined by the screen uniformity and distance, L, to the camera as shown in Fig. 1, Fig. 2, and Fig. 3.

8.3.2 Place a panel with known distortion in the test position. Record the screen image and process it through the software. The calculated distortion should not differ from the known value by more than 5 mdpt.

8.3.3 The known value of distortion should be established using traceable, curvature measuring methods. Dual laser beam and interferometry are suitable for this purpose.

9. Procedure

9.1 *Set up the grid screen:*

9.1.1 Ruled screen board should be vertical, in an upright position.

9.1.2 When used in reflective mode, the board should have a hole, sufficient for viewing through with a digital camera, cut in its center.

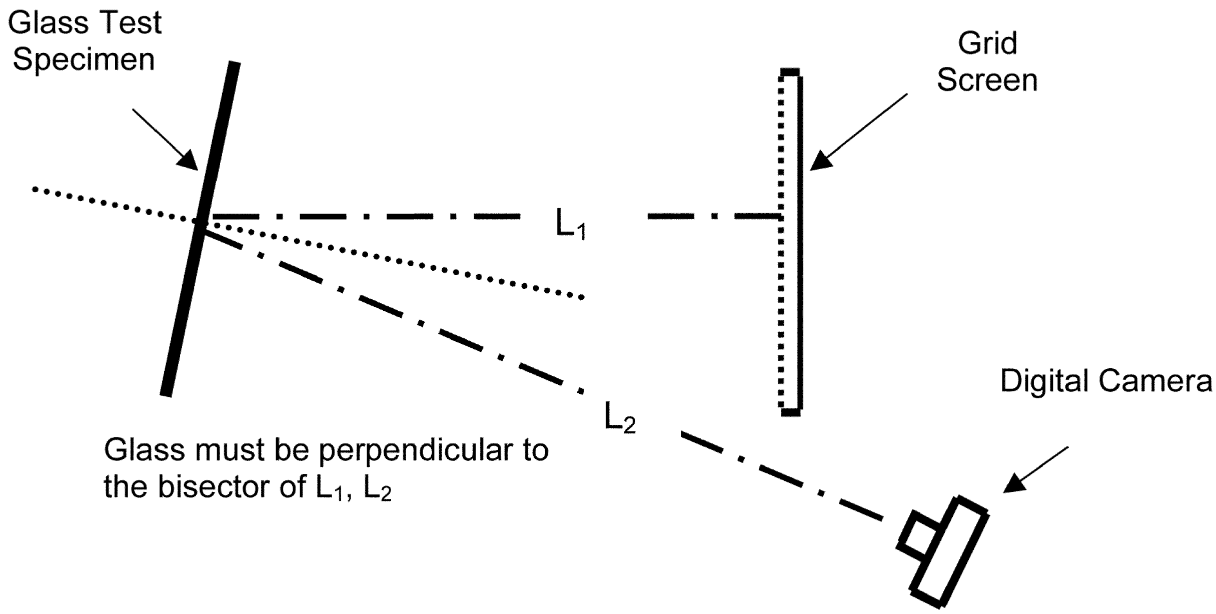

FIG. 2 Test Configuration for Off-Set Camera

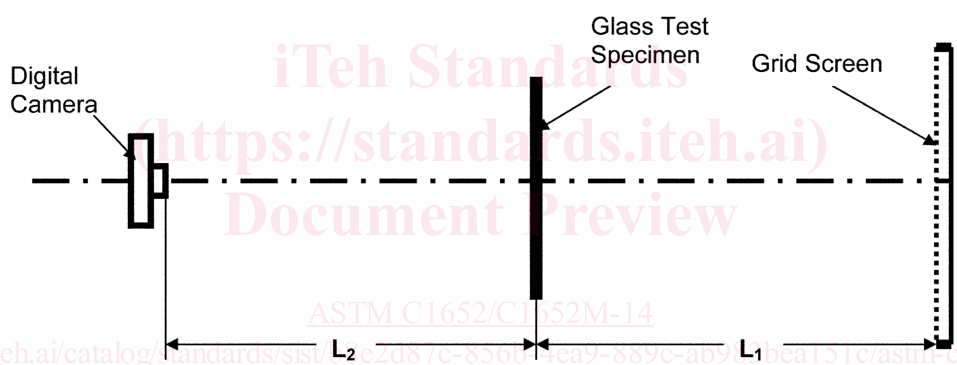

FIG. 3 Test Configuration in Transmitted Light

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9.1.3 When the screen is wall-mounted, so that viewing through a hole in its center is not possible, the camera can be mounted next to the screen or above it. In this configuration (see Fig. 2), a V-shaped line drawn from the center of the glass to the center of the screen (L_1), and from the center of the glass to the center of the camera lens (L_2) represents a geometric, specular reflection. The screen must be perpendicular to the bisector of line L_1 and L_2 and the camera back must be perpendicular to line L_2.

9.1.4 The grid board typically should be somewhat larger than twice the dimensions of the glass to be measured. For example, to analyze a 600mm by 1200 mm [24 in by 48 in] glass, use a 1500 mm by 2500 mm [60 in by 100in] grid board.

9.2 *Set up the glass sample:*

9.2.1 Place the glass parallel to the grid board as shown in Fig. 1, at a measured distance L. The distance should be the largest available, since the sensitivity of the measurement is directly proportional to the spacing, L. Four meters [160 in] yields satisfactory results.

9.2.2 For simplicity of computations, the overall distance between the screen and the camera should be L, so that, $L_1 = L_2 = L$. Nevertheless, the distances are not required to be equal.

9.2.3 Visually inspect the reflected image to assure that the roll wave is oriented horizontally or vertically. Fig. 3 illustrates the transmitted light set-up.

9.3 *Set up camera:*

9.3.1 Mount a digital camera on a suitable tripod, as shown in Fig. 2, and Fig. 3.

9.3.2 Set the camera to a resolution compatible with the software. Make sure that the image of the screen is in very sharp focus. In the image, the edges of the rectangular screen should be parallel to the edges of the camera frame.

9.4 *Illuminate grid screen:*