Designation: E2431 – 06 (Reapproved 2011)

Standard Practice for Determining the Resistance of Single Glazed Annealed Architectural Flat Glass to Thermal Loadings[1]

This standard is issued under the fixed designation E2431; 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 practice covers a procedure to determine the resistance of annealed architectural flat glass to thermally induced stresses caused by exposure to sun and shadows for a specified probability of breakage (P_b). Proper use of this procedure is intended to reduce the possibility of thermal breakage of annealed glass in buildings.

1.2 This practice applies to vertical or sloped glazing in buildings.

1.3 This practice applies to monolithic and laminated glass of rectangular shape and assumes that all glass edges are simply supported.

1.4 This practice applies only to annealed flat soda-lime silica glass with clean cut, seamed, flat ground, or ground and polished edges that are free from damage. The glass may be clear or tinted as well as coated (not including coatings that reduce emissivity of the glass).

1.5 This practice does not apply to any form of wired, patterned, etched, sandblasted, drilled, notched, or grooved glass or glass with surface and edge treatments, other than those described in 1.4, that alter the glass strength.

1.6 This practice does not address uniform loads such as wind and snow loads, safety requirements, fire, or impact resistance.

1.7 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard. For conversion of quantities in various systems of measurements to SI units refer to IEEE/ASTM SI-10.

1.8 *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 Documents:*[2]

C162 Terminology of Glass and Glass Products

E631 Terminology of Building Constructions

IEEE/ASTM SI-10 Use of the International System of Units (SI) (the Modernized Metric System)

2.2 *Other Documents:*[3]

2005 ASHRAE Handbook Fundamentals

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminologies C162 and E631 for additional terms used in this practice

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *edge bite*, *n*—the width of the glass edge (measured perpendicular to the cut edge, in the plane of the glass) that is protected from direct exposure to solar irradiance by the window frame edge conditions expressed in mm (in.) [see Table 1].

3.2.2 *edge thermal stress factor* (TSF_{edge}), *n*—the ratio of induced thermal stress to the solar load, SL, as the result of the edge bite condition expressed in MPa/(W/m^2).

3.2.3 *frame type*, *n*—the manner in which the edges of the glass are supported in the window frame [see Table 1].

3.2.4 *glass dimensions*, *n*—the rectangular dimensions of the glass (not the daylight opening), with the width being the smaller dimension and the length being the larger dimension both expressed in mm.

3.2.5 *incident solar irradiance* (Insolation), (I_s), *n*—amount of solar energy per unit time per unit area normal to glass, to which the glass is exposed expressed in W/m^2.

3.2.6 *probability of breakage* (P_b), *n*—the number of lites per 1000 that would be predicted to break when exposed to the specified thermal loading conditions.

[1] This practice is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.51 on Performance of Windows, Doors, Skylights and Curtain Walls.

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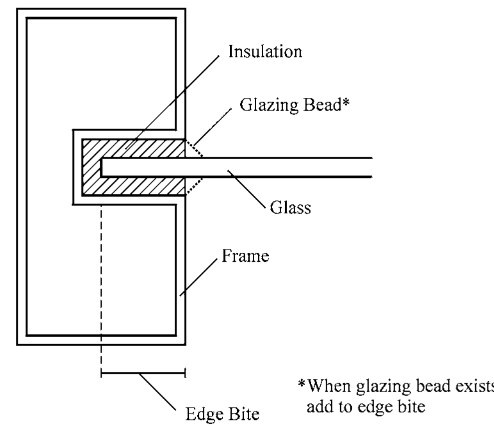
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 1791 Tullie Circle, NE, Atlanta, GA 30329, http://www.ashrae.org.

TABLE 1 Frame Types

<table>
<tr><th>Frame Type</th><th>Sketch</th></tr>
<tr><td>Insulated edge -- This condition should only be used in the analysis if it can reasonably be assumed that the heat loss from the glass to the glazing pocket is negligible.</td><td>
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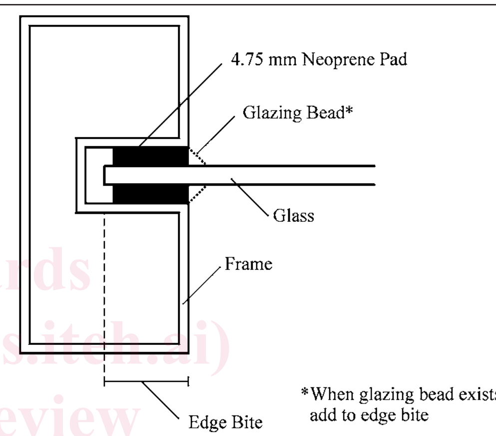
<tr><td>Conventional edge -- This condition should be used in the analysis only when the glazing pocket is fabricated with thin walled members and the glass is cushioned with gasket materials as shown.</td><td>
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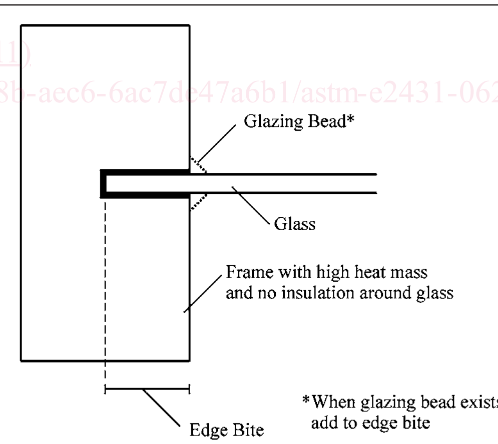
<tr><td>High heat mass edge -- This condition should be used in the analysis when the glazing is encapsulated in a material with a high heat mass such as concrete, heavy metal, and so forth.</td><td>
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</table>

3.2.7 *shadow thermal stress factor* (TSF_{shadow}), *n*—the ratio of induced thermal stress to the solar load, SL, as the result of shadow condition expressed in MPa/(W/m^2) (psi/Btu/hr·ft^2).

3.2.8 *solar load* (SL), *n*—the total amount of solar irradiance absorbed by the glass expressed in W/m^2.

3.2.9 *solar load adjustment factor for interior shading devices* (SLA), *n*—nondimensional factor that is used to account for the increase in thermal stress caused by the reflection of solar irradiance from an interior shading device.

TABLE 2 Shadow Thermal Stress Factors to be Used with Fig. 2

Shadow Condition	Maximum TSF_{shadow} kPa/(W/sq m)
Linear shadow	15.3
Angular shadow	31.9
L-Shaped shadow	20.8
Corner shadow	23.0

3.2.10 *solar reflectance of shading device* (R_s), *n*—decimal fraction of incident solar irradiation reflected from the device used as an interior shade.

3.2.11 *solar transmittance* (T_s), *n*—the amount of solar irradiance transmitted by the glass expressed as a fraction that ranges between 0.00 and 1.00.

3.2.12 *thermal stress*, *n*—edge tensile stress (MPa) induced in glass by solar irradiance.

3.2.13 *total solar absorptance* (A_s), *n*—the amount of solar irradiance absorbed by the glass expressed as a fraction that ranges between 0.00 and 1.00.

3.2.14 *total thermal stress factor* (TSF_{tot}), *n*—the ratio of total thermal stress induced in the glass by the combination of edge conditions and shadow conditions to the solar load expressed in MPa/(W/m^2).

4. Summary of Practice

4.1 The specifying authority shall provide the glass width, length, and nominal thickness; solar absorption of the glass construction (can be obtained from manufacturer's data); incident solar irradiance (can be determined from 2005 ASHRAE Handbook Fundamentals or other documented source); the frame type and edge bite; description of exterior shading conditions; and interior shading devices.[4]

4.2 The procedure described in this practice shall be used to determine if the glass can resist the calculated thermal stresses for a specified probability of breakage.

5. Significance and Use

5.1 Use of this practice assumes:

5.1.1 the glass edges shall be free from damage,

5.1.2 the glass shall be properly glazed,

5.1.3 the glass shall not have been subjected to abuse, and

5.1.4 the glass edge support allows in-plane movement of the glass due to thermal expansion and contraction.

5.2 This practice does not address all factors that cause thermally induced stresses in annealed glass. Factors that are not addressed include: transient thermal stresses, HVAC registers, thermally insulating window coverings, drop ceilings and other heat traps, increased solar irradiance caused by exterior reflections, variations in heat transfer coefficients other than those assumed for the steady state analysis described herein, and stresses induced by thermal sources other than the sun. Factors other than those listed above may also induce thermal stress.

5.3 Many other factors shall be considered in glass selection. These factors include, but are not limited to, mechanically induced stresses, wind effects, windborne debris impacts, excessive deflections, seismic effects, heat flow, noise abatement, potential post-breakage consequences, and so forth. In addition, considerations set forth in building codes along with criteria presented in safety glazing standards and site specific concerns may control the ultimate glass type and thickness selection.

5.4 The proper use of this practice is intended to reduce the risk of thermally induced breakage of annealed window glass in buildings.

6. Procedure

6.1 Obtain the following information from the data supplied by the specifier:

6.1.1 The edge bite condition that most closely represents the project conditions from Table 1;

6.1.2 The total solar transmittance (T_s) of the specified glass;

6.1.3 The total solar absorptance (A_s) of the specified glass:

$$A_s = 1.00 - T_s - R_s \quad (1)$$

where:

R_s = total solar reflectance

6.1.4 The solar reflectance of the shading device (RSD), if used;

6.1.5 The incident solar irradiance (I_s) for this analysis; and

6.1.6 The specified acceptable probability of glass breakage (P_b) for this analysis.

6.2 Multiply the incident solar irradiance (I_s) by the solar absorptance (A_S) to determine the solar load (SL).

6.3 Determine the edge thermal stress factor (TSF_{edge}) from Fig. 1, given the edge bite and edge bite condition.

6.4 Determine the shadow thermal stress factor (TSF_{shadow}) using the common shadow patterns shown in Fig. 2 and the factors listed in Table 2.

6.5 Determine the total thermal stress factor (TSF_{total}) by summing the individual thermal stress factors given in 6.3 and 6.4.

6.5.1 If the calculated total thermal stress factor exceeds 39.4 kPa/(W/m^2) when the angular shadow pattern is assumed, that is, Fig. 2 b and d, then 39.4 kPa/(W/m^2) shall be used for the total thermal stress factor.

6.5.2 If the calculated total thermal stress factor exceeds 32.0 kPa/(W/m^2) when other shadow patterns, that is, Fig. 2 a and c, are assumed, then 32.0 kPa/(W/m^2) shall be used for the total thermal stress factor.

6.6 To determine the solar load adjustment factor (SLA) using Fig. 3, enter the vertical axis with the solar reflectance of the shading device (RSD) and the horizontal axis with total solar transmittance of the glass (T_S) to determine the solar load adjustment factor (SLA) for interior shading devices. If necessary use interpolation to estimate the solar load adjustment factor (SLA). If no shading device is used, the solar load adjustment factor (SLA) shall be taken to be 1.0.

6.7 Determine the calculated thermal stress, $\sigma_{calculated}$, by multiplying the total thermal stress factor (TSF_{total}) by the solar load (SL) and by the solar load adjustment factor (SLA).

[4] Beason, W.L., and Lingnell, A.W., "A Thermal Stress Evaluation Procedure for Monolithic Annealed Glass," *Use of Glass in Buildings*, ASTM STP 1434, V. Block, ed., ASTM International: West Conshohocken, PA, 2003.

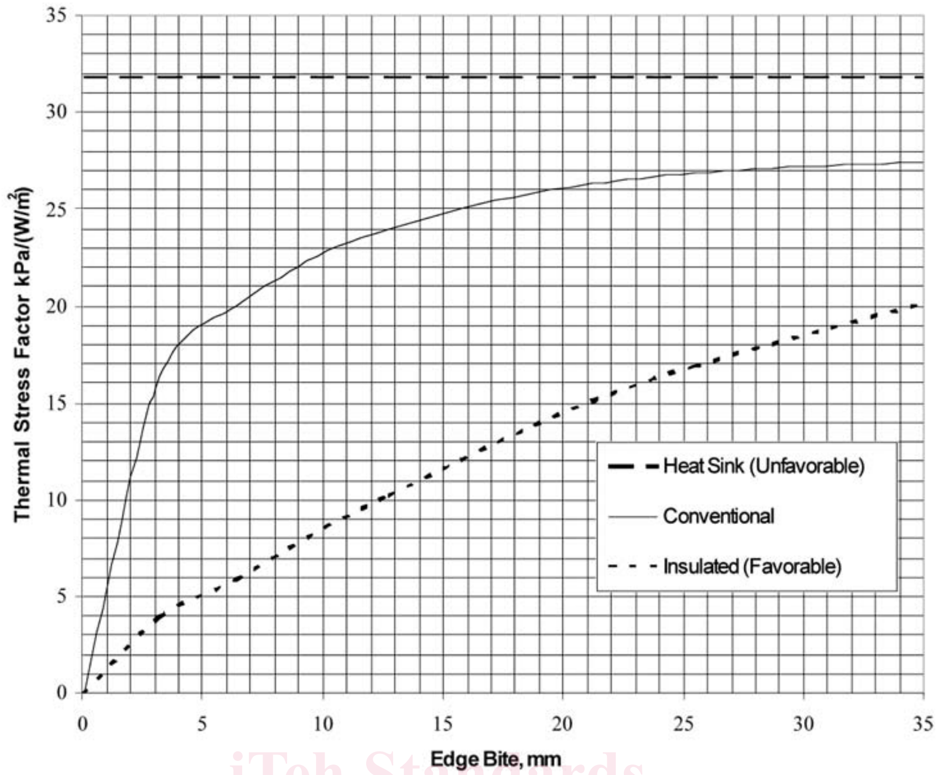

FIG. 1 Edge Thermal Stress Factor Chart

6.8 Determine the perimeter of the glass lite by adding twice the width to twice the height.

6.9 Determine the allowable thermal stress, $\sigma_{allowable}$, from Fig. 4 using the glass perimeter and the specified acceptable P_b.

6.10 If $\sigma_{calculated} > \sigma_{allowable}$, P_b for the glass exceeds the specified probability of breakage for the thermal design conditions. If P_b for the glass exceeds the specified probability of breakage, the user shall consider using strengthened glass, modifying the controllable design conditions, or having a more comprehensive thermal stress analysis performed.

7. Report

7.1 The report shall consist of the design example worksheet presented in Fig. 5 or, as a minimum, shall include:

7.1.1 Project name,

7.1.2 Date,

7.1.3 Project location,

7.1.4 Glass type,

7.1.5 Glass dimensions,

7.1.6 Edge bite,

7.1.7 Frame type,

7.1.8 Solar absorptance (A_s),

7.1.9 Solar transmittance (T_s),

7.1.10 Total Solar Reflectance of Shade Device (RSD),

7.1.11 Incident solar irradiance (I_s),

7.1.12 Acceptable probability of breakage (P_b),

7.1.13 Allowable thermal stress ($\sigma_{allowable}$),

7.1.14 Calculated thermal stress ($\sigma_{calculated}$), and

7.1.15 Conclusion.

8. Keywords

8.1 annealed glass; flat glass; glass; thermal breakage; thermal load; thermal stress; soda-lime silica glass

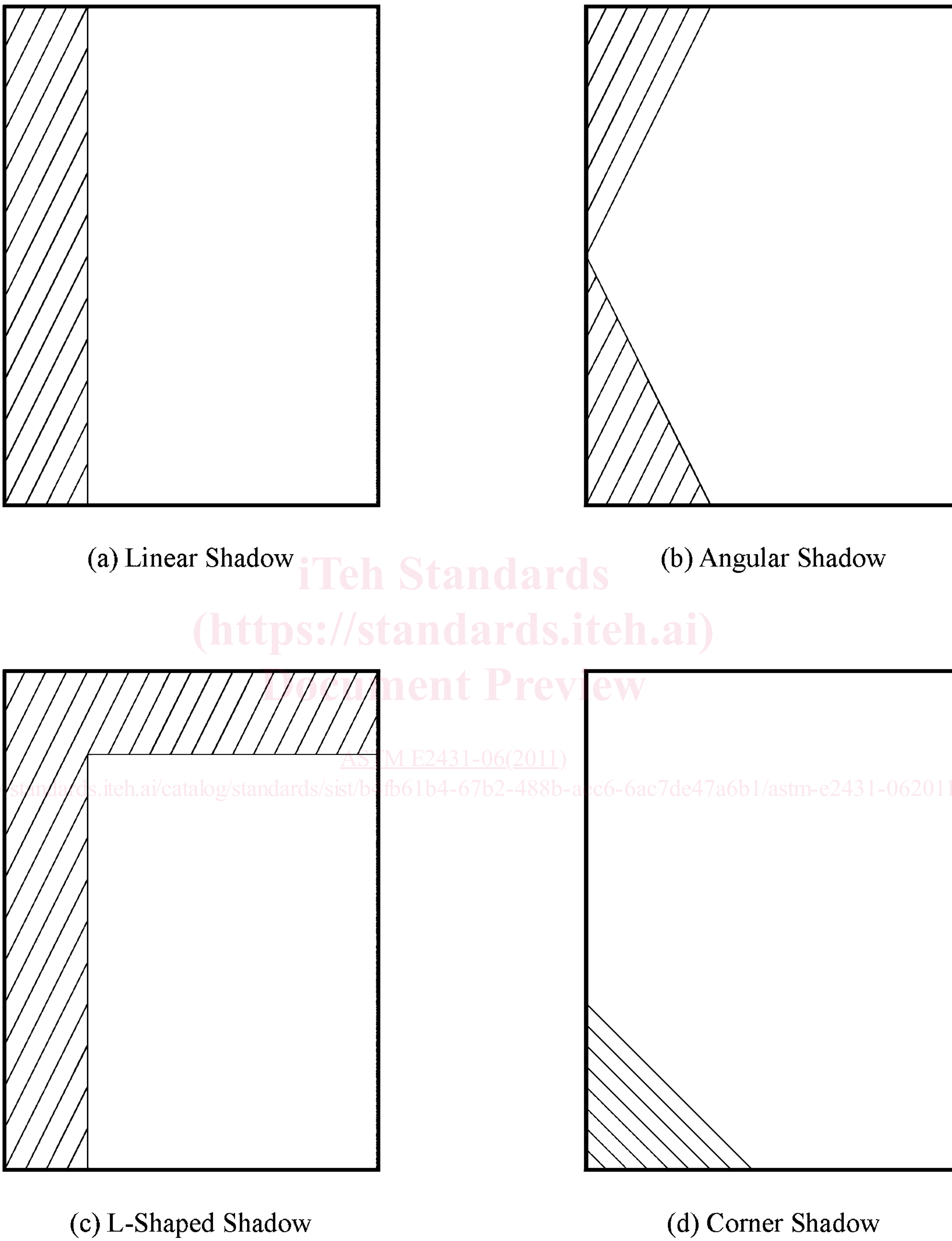

FIG. 2 Shadow Conditions

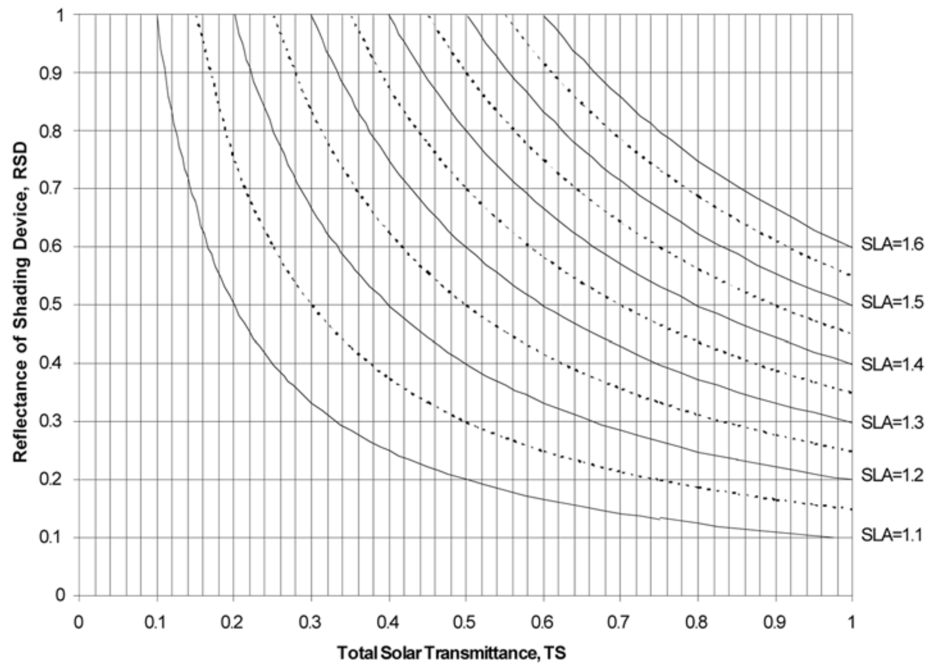

FIG. 3 Solar Load Adjustment Factor, SLA

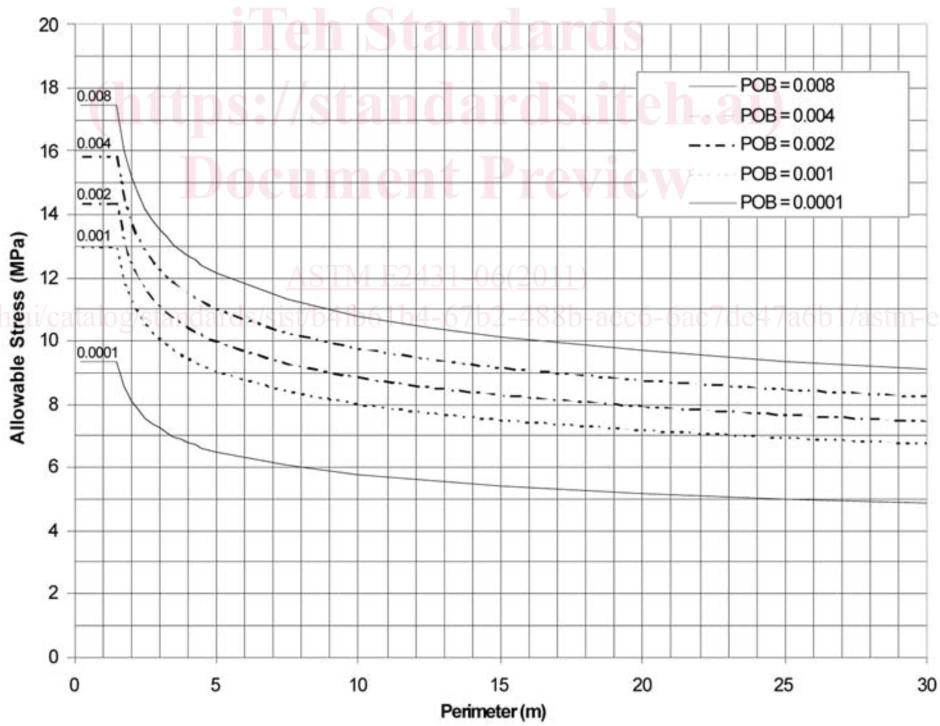

FIG. 4 Probability of Breakage (POB) Chart