Standard Guide for Secondary Seal for Sealed Insulating Glass Units for Structural Sealant Glazing Applications[1]

This standard is issued under the fixed designation C 1249; 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 guide covers design and fabrication considerations for the edge seal of conventionally sealed insulating glass units, herein referred to as IG units. The IG units described are used in structural silicone sealant glazing systems, herein referred to as SSG systems. SSG systems typically are either two or four sided, glazed with a structural sealant. Other conditions such as one, three, five, six sided may be used.

1.2 This guides does not cover the IG units of other than conventional edge seal design (Fig. 1); however, the information contained herein may be of benefit to the designers of such IG units.

1.3 In an SSG system, IG units are retained to a metal framing system by a structural seal (Fig. 2). The size and shape of that seal, as well as numerous other SSG system design considerations, are not addressed in this guide.

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 problems, 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:*

C 639 Test Method for Rheological (Flow) Properties of Elastomeric Sealants[2]

C 679 Test Method for Tack-Free Time of Elastomeric Sealants[2]

C 717 Terminology of Building Seals and Sealants[2]

C 794 Test Method for Adhesion-in-Peel of Elastomeric Joint Sealants[2]

C 1087 Test Method for Determining Compatibility of Liquid-Applied Sealants with Accessories Used in Structural Glazing Systems[2]

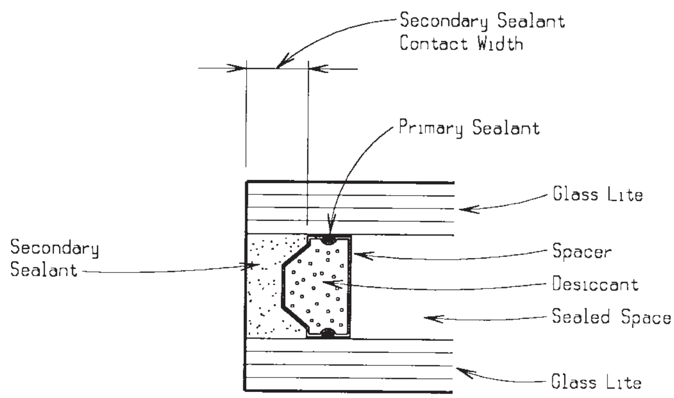

FIG. 1 Sealed IG Edge Seal: Basic Components

C 1135 Test Method for Determining Tensile Adhesion Properties of Structural Sealants[2]

C 1184 Specification for Structural Silicone Sealants[2]

E 631 Terminology of Building Constructions[2]

E 773 Test Method for Seal Durability of Sealed Insulating Glass Units[2]

E 774 Specification for Sealed Insulating Glass Units[2]

2.2 *Other Standards:*

Sigma 73-8-2B Test Methods for Chemical Effects of Glazing Compounds on Elastomeric Edge Seals[3]

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminology C 717 for definitions of the following terms used in this guide: adhesive failure, bead, cohesive failure, compatibility, cure, elongation, gasket, glazing, joint, lite, modulus, non-sag sealant, seal, sealant, sealant backing, setting block, shelf-life, silicone sealant, spacer, structural sealant, substrate, tooling, and working life. Refer to Terminology E 631 for the definition of sealed insulating glass as used in this guide.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *desiccant*—a hygroscopic material that adsorbs water or may adsorb solvent vapors, or both (see Fig. 1).

3.2.1.1 *Discussion*—The desiccant maintains a low relative humidity in sealed insulating glass.

[1] This guide is under the jurisdiction of ASTM Committee C24 on Building Seals and Sealants and is the direct responsibility of Subcommittee C24.10 on Specifications, Guides and Practices.

Current edition approved Sept. 15, 1993. Published November 1993.

[2] *Annual Book of ASTM Standards*, Vol 04.07.

[3] Available from SIGMA, 111 E. Wacker Dr., Ste. 600, Chicago, IL 60601.

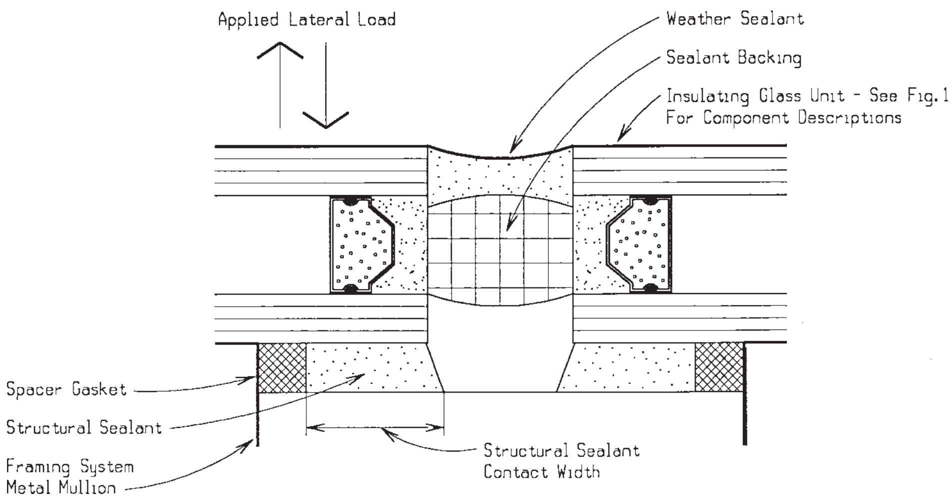

FIG. 2 Typical A-Side SSG System Mullion: Horizontal Section (Vertical Joint)

3.2.2 *primary seal*—A joint seal of which the sealant resists moisture vapor permeation into the desiccated space of sealed insulating glass (see Fig. 1).

3.2.2.1 *Discussion*—It also resists inert gas permeation (for example, argon) from the IG unit sealed space if the intent is to use an inert gas.

3.2.3 *secondary seal*—a joint seal of which the sealant structurally unites the two glass lites and spacer of sealed insulating glass (see Fig. 1).

3.2.4 *spacer*—a fabricated shape that creates an appropriate distance between two lites of glass in sealed insulating glass (see Fig. 1).

3.2.4.1 *Discussion*—As a component of the edge seal system, the spacer also resists vapor migration into sealed insulating glass and provides a container for a desiccant.

3.2.5 *structural seal*—a joint seal of which the sealant structurally adheres an IG unit to a metal framing system (see Fig. 2).

3.2.5.1 *Discussion*—The structural seal transfers applied loads to the framing system as well as accommodates differential movements between the IG unit and the framing system.

3.3 *Symbols:Symbols:*

3.3.1 A = area, m^2 ($in.^2$).

3.3.2 C_s = sealant contact width, shear, mm (in.).

3.3.3 C_t = sealant contact width, tension, mm (in.).

3.3.4 D = design factor, dimensionless.

3.3.5 F_s = allowable shear stress, Pa (psi).

3.3.6 F_t = allowable tensile stress, Pa (psi).

3.3.7 F_y = yield stress, Pa (psi).

3.3.8 H = height, m (ft).

3.3.9 L = perimeter length, m (ft).

3.3.10 M = mass per unit area, N/m^2 (lb/ft^2).

3.3.11 P = applied load, Pa (lbf/ft^2).

3.3.12 W = width, m (ft).

4. Significance and Use

4.1 It should be realized that the design of an IG unit edge seal for use in SSG systems is a collaborative effort of at least the IG unit fabricator, sealant manufacturer, and design professional, among others.

4.2 This guide provides information on silicone sealants that are used for the secondary seal of IG units that are glazed into SSG systems.

4.3 Information is also provided on the other major components of the IG unit edge seal, compatibility of components, durability, and quality assurance (QA).

5. Insulating Glass Unit

5.1 *Insulating Glass Unit Components*—The edge seal of an SSG system IG unit consists of the two lites of glass, spacer, desiccant, primary sealant, and secondary sealant (Fig. 1) **(1)**.[4] This type of IG unit is referred to commonly as a dual-seal unit in that it has separate primary and secondary seals. A single-seal IG unit is inappropriate at this time for SSG systems and should not be used. The following sections describe the components of a dual-seal IG unit briefly.

5.2 *Glass and Architectural Coatings*:

5.2.1 *Glass*—All types of glass have been used in the fabrication of IG units, including monolithic, laminated, tempered, heat-strengthened, tinted, heat-absorbing, light reducing, patterned, and wired. Almost all glass is produced by the float manufacturing process, in which the glass ribbon that emerges from the furnace is floated on a bath of molten tin, allowing gravity to produce essentially flat parallel surfaces.

5.2.2 *Architectural Coatings*—These coatings, which are applied to the surface of the glass prior to IG unit fabrication, are generally grouped into one of two categories: low-emissivity or reflective. They are both metallic or metallic oxide materials and in some cases are in multi-layers, deposited onto or into a glass surface. The coatings are deposited primarily by two methods: magnetic sputtering onto the glass surface and pyrolitic deposition into the glass surface. Low-emissivity coatings are visually transparent and reflect long-wave infrared radiation, thereby improving the thermal transmittance of the glass. In general, they also decrease but to a lesser extent than reflective coatings, visible light transmission,

[4] The boldface numbers in parentheses refer to the list of references at the end of this guide.

and transmitted solar radiant energy. Depending on lighting conditions, reflective coatings are generally considerably less transparent than low-emissivity coatings. These coatings provide a reduction in transmitted solar radiant energy, conductive heat energy, and visible light into the building interior. Ceramic enamel, silicone, and pressure-sensitive vinyl and polyester film are applied to the surface of glass to make spandrel glass.

5.3 *Spacer*—Spacers are fabricated primarily from roll-formed hollow metal shapes and are available in numerous profiles, depending on the application. Metals typically used are aluminum, both mill finish and anodized, galvanized steel, and stainless steel, with aluminum used predominately. The spacer establishes the size of the sealed space, provides surfaces for installation of the primary sealant, is hollow for desiccant installation, and forms the third surface of the cavity created at the edge of the glass lites for installation of the secondary sealant.

5.4 *Desiccant*—These substances are hydrophilic crystalline materials that are installed into the hollow of the spacer, usually on at least two sides of the IG unit. Commonly used desiccants are molecular sieves or a blend of silica gel with molecular sieves. Their purpose is to adsorb residual water and solvent vapor in the sealed space immediately after fabrication of the IG units. They also maintain a low relative humidity in the sealed space for the life of the IG unit by absorbing infiltrating moisture vapor.

5.5 *Primary Sealant*—This sealant provides a high level of moisture vapor migration resistance and controls and minimizes gas and solvent migration into the IG unit sealed space. The sealant also acts as a barrier to the permeation of inert gases (for example, argon) when these gases are used in the sealed space of the IG unit. The sealant is designed to fill the space between the sides of the spacer and the faces of the two glass lites and to develop adequate adhesion to the surfaces of both materials. The primary sealant must also have sufficient movement capability to not fail due to limited differential movement that may occur between the spacer and the glass lites. Polyisobutylene-based materials have been found to be very suitable for this purpose. The primary sealant contributes little to the structural function of transferring lateral loads and holding the IG unit edge assembly together. These functions are fulfilled by the secondary sealant.

5.6 *Secondary Sealant*:

5.6.1 This sealant transfers negative lateral loads, occurring on the exterior lite of glass, to the interior lite of glass, which then transfers the load to the structural sealant that adheres the IG unit to the metal framing system. It also functions as the adhesive that unites the two glass lites and spacer together as a unit and prevents excessive movement from occurring in the primary seal **(2)**. The secondary sealant must maintain adequate adhesion to the glass lites and spacer and also maintain other performance properties, such as strength and flexibility after prolonged environmental exposure. Failure of the secondary seal to do so could result in excessive movement in the primary seal and fogging of the IG unit or adhesive or cohesive failure of the secondary seal and catastrophic failure of the IG unit.

5.6.2 Four generic classes of sealants are used presently for a conventional IG unit edge seal system (non-structural sealant). These sealants are polysulfides, polyurethanes, hot-melt butyls, and silicones. For SSG systems, only IG units with a dual-seal (polyisobutylene primary seal and silicone secondary seal) have the required durability for the application and are the only sealants permitted for SSG systems.

5.7 *Enclosed Gas*—The IG unit sealed space encloses a gas such as air, argon, krypton, or sulfur hexafloride. Air is normally used if conventional thermal resistance properties are required. Argon and krypton are used to increase the IG unit thermal resistance. Sulfur hexafloride is used in applications in which increased resistance to sound transmission is necessary. When using gases other than air, the IG unit edge seal system must be capable of retaining a substantial percent of the gas for the life of the IG unit; otherwise, thermal or sound transmission performance will decrease to an unacceptable level.

5.8 *Breather and Capillary Tubes*:

5.8.1 *Breather Tube*—A breather tube is a small tube or hole that is factory-placed through the spacer of the IG unit to accommodate an increase in sealed air space pressure when an IG unit is shipped to a higher elevation than where fabricated. The breather tube allows the sealed air space pressure to equalize to the atmospheric pressure at the installation site. The breather tube is sealed prior to the IG unit installation. Special sealed space gases (see 5.7) cannot be used in IG units that have breather tubes.

5.8.2 *Capillary Tube*—A capillary tube is a very thin bore tube of specific length and inside diameter that is factory-placed through the spacer of the IG unit. A capillary tube fulfills the same function as a breather tube and, in addition, is left open after installation to permit the sealed space of the IG unit to continue to pressure equalize with fluctuating ambient air pressure. Special sealed space gases (see 5.7) cannot be used in IG units that have capillary tubes.

SECONDARY SEALANT DESIGN CONSIDERATIONS

6. Structural Properties

6.1 *General*:

6.1.1 The design of an IG unit edge seal parallels the methodology used for the design of the SSG system structural joint that adheres an IG unit to a framing system. SSG system structural sealants must meet the requirements of Specification C 1184. Presently, there is no comparable specification for sealants used for the secondary sealant of IG units; however, sealants should meet the requirements of Specification C 1184 (as a minimum) in the absence of another applicable specification.

6.1.2 The following sections provide the design professional with information on the design of the IG unit edge seal secondary sealant regarding the following: allowable tensile strength; modulus properties; appropriate design factors; and design of the secondary sealant for the effects of shear stress, tensile stress, and combined stresses.

6.2 *Sealant Yield Stress*—The minimum sealant yield stress (F_u) (or tensile adhesion value) is determined by Test Method C 1135 by pulling to failure small laboratory specimens of sealant having a cross-section similar (but not necessarily identical) to that used in a structural seal. Sealant manufacturers usually report this value in a table of performance criteria for a particular sealant. An example of a sealant manufacturer's reported value for F_u would be 896 kPa (130 psi) for a two-part high-modulus sealant.

6.3 *Sealant Tensile Stress*:

6.3.1 The allowable sealant tensile stress (F_t) for SSG system structural seals is determined by dividing the ultimate stress (F_u) by an appropriate design factor (D) ((Eq 1)).

$$F_t = F_u/D \tag{1}$$

6.3.2 For example, using a manufacturer's published ultimate stress (F_y) for a sealant of 559 kPa (80 psi), with a design factor (D) of 4.0, and substituting these values into (Eq 1), results in the following:

$$F_t = 559/4.0 = 138 \text{ kPa} \tag{2}$$

or

$$F_t = 80/4.0 = 20 \text{ psi} \tag{3}$$

6.3.3 Current industry practice for the structural seal of an SSG system, which was determined empirically, is to limit the value of F_t to 138 kPa (20 psi). The SSG system structural seal contact width (Fig. 2) is usually established using the applied lateral load, acting in tension, in conjunction with the 138 kPa (20 psi) tensile stress. Additional contributory stresses from, for example, thermal movement, dead load (see 6.6), sealant cross-section dimension, non-linear glass deflection under load, internal sealant stress due to cure shrinkage, prestress in sealant due to differential building component movement, and variation in sealant physical properties can also influence this value. If these additional factors are a significant concern, an allowable tensile stress (F_t) of below 138 kPa (20 psi) may be appropriate for the SSG system structural seal sealant.

6.3.4 Regarding the secondary sealant for IG units, some IG unit fabricators recommend using values for F_t such as 207 kPa (30 psi) in lieu of the more conservative 138 kPa (20 psi) value used for the SSG system structural seal. The rationale for using higher values for F_t is the already high quality of the fabricator's QA program for fabricating the IG unit edge seal. Better QA results in more consistent adhesion of the secondary sealant, and higher values for F_t can therefore be maintained reliably. In addition, the cladding design load is usually chosen as the maximum to occur in a 50 or sometimes 100-year return period. Because of this, the actual tensile stress on the secondary sealant is typically a lower value and in some areas a relatively small percentage of the F_u value. If a value of F_t in excess of 138 kPa (20 psi) is proposed, it must be evaluated carefully. This careful evaluation is especially significant since F_t does not give significance to the additional stress factors discussed in 6.3.3.

6.3.5 Presently, for the IG unit secondary sealant, the stress in the secondary sealant is usually limited to 138 kPa (20 psi). The applied lateral load, which is shared between the two lites of glass of the IG unit, in conjunction with the 138 kPa (20 psi) limit, is used to calculate the secondary sealant contact width required to resist the applied lateral load (see 6.7). This equal load sharing is applied only when the two lites are of equal thickness.

6.3.6 It is not within the scope of this guide to specify a particular tensile stress (F_t) for the IG unit secondary sealant. This should be an informed decision made by the design professional, in conjunction with the structural sealant manufacturer and IG unit fabricator, considering, among other factors: building code requirements, degree of risk, and the particular SSG system and IG unit requirements.

6.4 *Design Factor*:

6.4.1 For SSG system structural seals, a factor ranging from 4 to 12 was originally selected for the structural sealant during the beginnings of SSG technology. This range recognized the many variables and unknowns, such as determining applied loads and load distribution accurately, the relatively poor tear strength if three-sided adhesion occurred, and the difficulty of determining the actual sealant stress. This approach is consistent with traditional engineering practice, in which uncertainty and unknowns are mitigated to a certain extent by using a design factor, sometimes referred to as a safety factor. The design factor can be determined by using (Eq 1) and solving for D. It should be noted, however, that higher-strength sealants do not improve the probability of attaining and maintaining long-term sealant adhesion. Adhesion concerns are decreased by lower design stress (f_t). Since adhesion is one of the primary concerns in every aspect of structural glazing, a higher design factor is best achieved by using smaller design stresses (F_t).

6.4.2 For example, for a sealant in which F_u = 896 kPa (130 psi), with a value of F_t = 138 kPa (20 psi), the value of D will be 6.5. If a different sealant, in which F_u is 345 kPa (50 psi), is used with a value of 2.5 for D, F_t will be 138 kPa (20 psi). Presently, a lower-limit design factor (D) of 2.5 is being used for SSG system structural sealants. This lower limit is based on the following: the successful performance of SSG system structural sealants since approximately 1972, advances that have occurred in adhesion technology, and the implementation of QA programs. Higher design factors are not to be construed as rationale to change the design stress (f_t) to values above 138 kPa (20 psi).

6.4.3 It is not within the scope of this guide to specify a particular design factor for the IG unit secondary sealant. This should be an informed decision made by the design professional, in conjunction with the structural sealant manufacturer and IG unit fabricator, considering, among other factors: building code requirements, degree of risk, and the particular SSG system and IG unit requirements.

6.5 *Sealant Modulus and Joint Stiffness*:

6.5.1 The design of the structural seal in SSG systems should consider the relationships of joint shape, joint stiffness, and sealant modulus so that the outward movement of the peripheral edge of the IG unit, by an applied lateral load, is no more than 1.6 mm (1⁄16 in.) for a glass lite nominal thickness of 6 mm (1⁄4 in.). Test Method C 1135 can be used to determine that the elongation of the structural sealant at 138 kPa (20 psi) is less than 1.6 mm (1⁄16 in.). The 1.6-mm (1⁄16-in.) movement or sealant elongation is related to the position and support provided to the outer lite of the IG unit by setting blocks that are recessed from its outer face, usually by one-half the nominal glass thickness. If outward movement is excessive and the IG unit outer lite drops off the setting blocks, it could cause a failure of the IG unit edge seal.

6.5.2 From the above discussion, it should also be apparent that the outward, and in some cases downward (see 6.6), movement of the outer glass lite of an IG unit relative to the inner lite, under the influence of the applied lateral load, must also be limited. Detrimental movement or change in the secondary seal shape **(3)** could cause a seal failure in the primary sealant, resulting in fogging of the enclosed space. The modulus of the secondary sealant, as well as the shape and size of the secondary seal, should be evaluated.

6.6 *Sealant Contact Width for Shear Stress*:

6.6.1 Good glazing practices require that glass, including IG units, be supported by two setting blocks located at approximately the ¼ points of the glass width. Although not generally recommended, installations are occasionally designed in which the glass or IG unit is not supported by setting blocks (Fig. 3). Contact the sealant and IG manufacturer for specific recommendations. The dead load of the IG unit is supported by the SSG system structural seal with such installations. This will result in a constant dead load shear (Fig. 3) stress (F_s) on the sealant and the potential of a downward movement of the IG unit under the influence of gravity **(4)**. Because of special considerations, in some unusual situations some sealant and IG manufacturers have approved specific installations with no setting blocks. If this is ever done, the sealant and glass manufacturer and design professional must review the design and details, and the dead load shear stress (F_s) on the SSG system structural sealant is limited to no more than 6895 Pa (1 psi) and often considerably less (for example, 3400 Pa or 0.5 psi).

6.6.2 With such installations, the secondary seal of the IG unit must also be designed to resist shearing stress and potential movement induced by the dead load of the outer lite of glass. Unacceptable differential movement of the two lites could cause a seal failure in the primary sealant, resulting in fogging of the enclosed space. The minimum sealant contact width required due to dead load shear stress, assuming no contribution from the primary seal, can be determined using (Eq 4).

$$C_s = (M*A)/(F_s*L) \tag{4}$$

6.6.3 For example (Fig. 4), for an IG unit with W = 1.219 m (4 ft), H = 1.829 m (6 ft), M = 311.22 N/m^2 (6.5 lb/ft^2), L = 6.096 m (20 ft), and F_s = 6895 Pa (1 psi), the contact width for the secondary sealant would be determined as follows. Only the weight of the exterior lite of glass will cause a shearing stress in the secondary sealant, so one-half of the weight of the IG unit is used in the calculation. Substituting into (Eq 4) results in the following:

$$C_s = (155.61*2.2296)/(6895*6.096) = 8.25 \text{ mm} \tag{5}$$

or

$$C_s = (3.25*24)/(1*20*12) = 0.325 \text{ in.} \tag{6}$$

6.7 *Sealant Contact Width for Tensile Stress*:

6.7.1 The minimum secondary sealant contact width (C_t) required to resist the applied lateral tensile load can be determined using (Eq 7), which is based on trapezoidal load distribution theory. Other load distribution theories may be applicable, depending on, among other factors, IG unit shape and size **(5)**. Any influence from the primary seal is not considered.

$$C_t = (P*W/2)/F_t \tag{7}$$

6.7.2 For example (Fig. 4), for an IG unit with W = 1.219 m (4 ft), H = 1.829 m (6 ft), P = 1436 Pa (30 lbf/ft^2), and F_t = 138 kPa (20 psi), the contact width for the secondary sealant would be determined as follows. With a sealed IG unit, there is load sharing between the two lites of glass. If both lites are of the same thickness, the lateral load (P) is shared almost equally; and, if of unequal thickness, the load shared by each lite will vary, depending on the difference in thicknesses **(6)**.

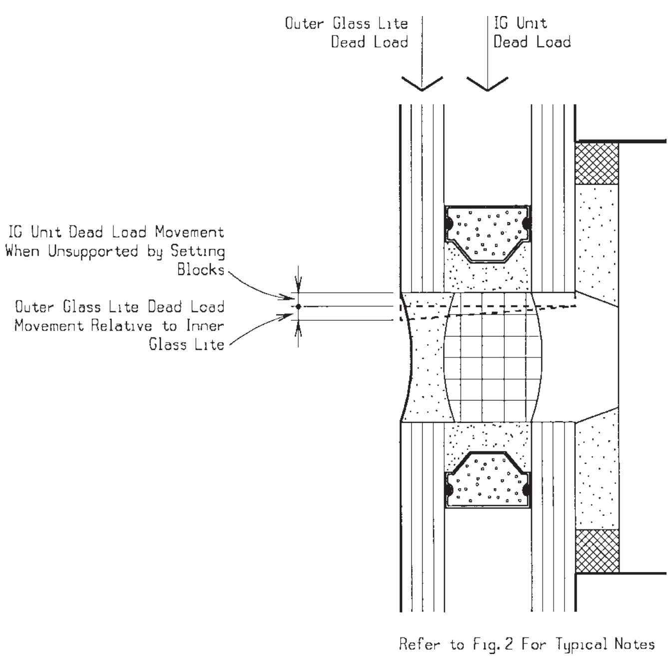

FIG. 3 Dead Load Movement of IG Unit: Vertical Section (Horizontal Joint)

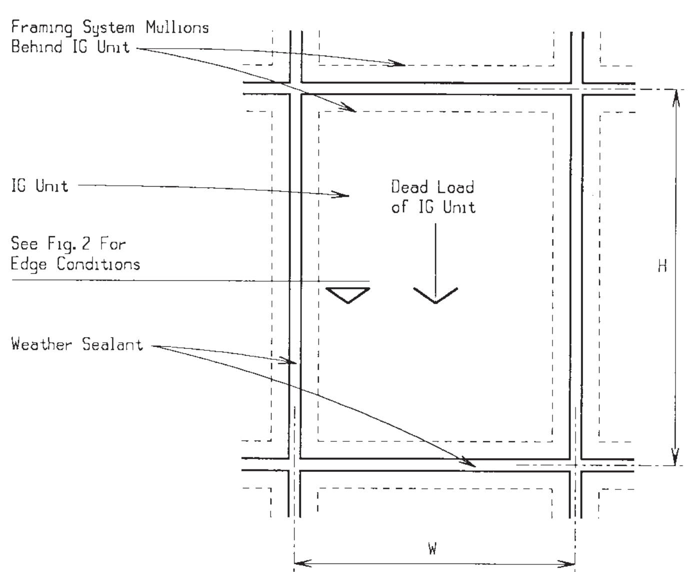

FIG. 4 Elevation of a Four-Sided Structural Sealant Glazed IG Unit

For the following example, both lites are the same thickness, and the secondary seal therefore experiences approximately one-half the applied load. Substituting into (Eq 7), using the least dimension, which is the width (*W*) of the IG unit, results in the following:

$$C_t = (718*0.6096)/138 = 3.2 \text{ mm} \quad (8)$$

or

$$C_t = (15*2)/(20*12) = 0.125 \text{ in.} \quad (9)$$

If the lites are of unequal thickness, equal load sharing cannot be employed, and appropriately higher values are to be used.

6.7.3 If it has been determined that an unsupported IG unit is allowable in a given situation and both the deal load and wind load calculations are performed, the largest of the calculated contact widths must be used.

6.8 *Combined Stresses*:

6.8.1 Depending on, among other factors, loading conditions (that is, tensile and shear loads), IG unit shape and size, secondary sealant, and secondary seal shape and size, the effects of combined stresses on the secondary sealant may require consideration **(7)**.

6.8.2 It should also be realized that the final secondary sealant contact width may have to be greater than as determined by calculation. Other factors, such as spacer geometry **(8)**, fabrication procedures, and fabrication tolerances, may have to be considered to determine a minimum acceptable secondary sealant contact width.

7. Adhesion

7.1 *General*:

7.1.1 Adhesion of the secondary seal to the IG unit edge seal components is one of the most critical functions of the sealant. The secondary sealant adheres the glass, with or without a glass coating, and spacer into a rigid yet flexible system, and, in addition, transfers applied lateral loads from the outer lite to the inner lite of the IG unit. Poor sealant adhesion to any of the IG unit edge seal components can have adverse effects on IG unit performance.

7.1.2 Time, temperature, water and water vapor, ultra-violet radiation, and foreign chemicals can affect the adhesion and performance of the secondary seal. The following sections address adhesion issues related to glass, glass coatings, and spacers, among other factors, that commonly occur with IG units.

7.2 *Glass and Architectural Coatings*:

7.2.1 *Glass*—Adhesion of a silicone secondary sealant to a properly prepared, uncoated glass surface has proven to be tenacious. To develop adequate adhesion, the glass surface must be properly cleaned (see 7.4) immediately prior to sealant application.

7.2.2 *Architectural Coatings*—A wide variety of glass coatings are currently available for architectural glass. Adhesion of the sealant to these coatings depends on the type of architectural coating and its particular type of top coat, such as titanium dioxide or silicon dioxide, among other types, and the coating application technique, such as a pyrolitic or magnetic sputtering process. No generalized statement can be made regarding sealant adhesion to the many available architectural coatings, since variations may occur even for a given type of coating and application process due to process conditions. The adhesion of the sealant to an architectural coating on glass must be verified on samples of actual manufactured specimens for each job by the sealant manufacturer. The adhesion of some architectural coatings to glass may degrade with time, and coating deletion (removal) may be required.

7.2.3 *Coating Deletion*—This is usually performed by abrasion, with an abrasive wheel, or by burning the coating off with a high-temperature flame. Any coating deletion technique will result in a glass surface that is chemically and physically different from a normal glass surface. Adequate adhesion of the sealant to this glass surface should be verified. A representative sample should be submitted to the sealant manufacturer. Statements regarding the durability and adhesion of the architectural coating to a glass surface can be made only by the glass manufacturer or coating applicator.

7.3 *Spacer*—Adhesion of the secondary sealant to the spacer is required to prevent "walking" or displacement of the spacer into the vision area of the IG unit and potential edge seal failure and fogging. Different secondary seal sealants will develop various levels of adhesion to the vast array of available spacer materials. For example, some sealants may develop excellent long-term adhesion to an anodized spacer, whereas others may not. Long-term adhesion can be verified by many different standard test methods. The sealant manufacturer can suggest and perform various tests, such as those found in Test Methods C 794, E 773, and C 1135, to predict the long-term adhesion of the secondary seal to the spacer under various physical and environmental conditions.

7.4 *Cleaning*—As with all sealants, adequate substrate cleaning can be critical to developing long-term adhesion of the secondary sealant to the various IG unit edge seal components. Cleaning techniques and solutions must not be harmful to the substrates, should remove surface contaminants completely, and should not leave a surface residue that is harmful to sealant adhesion. The glass (including the coating), spacer, and sealant manufacturer can provide information on acceptable procedures and materials for adequate cleaning and preparation of the various adhesion surfaces.

7.5 *Environmental and Service Conditions*—The installed IG unit and its edge seal are exposed to varying service conditions. Adhesion of the IG unit secondary sealant may degrade with time, given adverse or unacceptable service conditions. Water, as both a vapor and liquid, combined with elevated temperatures and ultraviolet radiation from sunlight, has proven to have the most potential detrimental effect on sealant adhesion. Water (infiltrated or condensed) that can accumulate within an SSG system glazing channel has proven to contribute to premature IG unit edge seal failure and is therefore undesirable. Glazing channels should be drained to the exterior to preclude the accumulation of water. The effect of various service conditions is also dependent on the type of glass (architecturally coated, tinted, or clear) and glazing orientation (vertical or sloped). Test methods such as Test Method C 1135 can be used to evaluate the tensile adhesion values (and thus adhesion) of secondary sealants when exposed to various combinations of service or accelerated aging conditions. If internal condensation is seen in an IG unit, the unit should be replaced in a timely fashion because secondary sealant degradation or adhesion loss may have occurred.

8. Compatibility

8.1 *General*—The incompatibility of materials in contact with or close proximity to the secondary sealant of the IG unit will usually result in a lessening of the adhesive strength or a complete loss of adhesion of the secondary sealant. Time, elevated temperature, and other environmental factors such as ultra-violet radiation can influence compatibility. Incompatibility is not desirable since sealant adhesive failure can result in fogging of the IG unit or detachment of the exterior lite of glass from the building. Test Method C 1087 can be used to determine whether a secondary sealant and another material are compatible. Metal components, sealants, or any combination of materials used in the construction of the IG unit, as well as components of the SSG system that can influence the edge seal, must have their compatibility with the secondary sealant verified by appropriate testing. This compatibility testing may vary in degree, depending on system configuration, that is, two or four sided structurally glazed. The degree of compatibility testing, depending on system configuration, has not been agreed to by the SSG industry and varies from manufacturer to manufacturer.

8.2 *Structural Sealants*:

8.2.1 There is presently no consensus standard test method for determining the compatibility of other system sealants, including the SSG system structural sealant, with the secondary seal of an IG unit; however, sealant suppliers and IG unit manufacturers have developed their own standard test methods to determine compatibility, such as Sigma No. 73-8-2B.

8.2.2 The first SSG system structural glazing silicone sealants were one-part acetoxy curing formulations. These acetoxy curing sealants were generally found not acceptable when IG units were introduced to structural sealant glazing. The IG unit secondary seal was typically a two-part silicone sealant. The acetic acid released during cure of the acetoxy structural glazing or weather seal sealant, in combination with water, could cause softening of the IG unit secondary seal, eventually resulting in adhesive failure and premature IG unit edge seal failure. Neutral curing one- and two-part structural silicone sealants have substantially replaced the acetoxy curing sealants and are the type used predominantly today for SSG system structural sealant joints.

8.2.3 Acetoxy curing silicones may be used in some SSG system designs that utilize IG unit two-part silicone secondary seals, provided that the sealant manufacturer's predetermined procedures are followed. In general, there should be no accidental or other physical contact between the acetoxy sealant and secondary seal of the IG unit. Also, there should be sufficient space and ventilation or time lapse between application of the acetoxy structural or weather seals to allow the acetic acid byproducts of curing to dissipate from the secondary seal. However, in the absence of more positive safeguards, it would be prudent to avoid their use in order to eliminate any possibility of premature IG unit edge seal failure due to the potential incompatibility of sealants. Also, if the IG secondary seal is an acetoxy curing type, no concerns about compatibility exist when an acetoxy cure structural glazing sealant is used.

8.3 *Setting Blocks, Spacers, and Accessories*—The compatibility of the IG unit secondary seal with setting blocks, spacers, or other rubber or plastic accessories can be evaluated with Test Method C 1087. When an edge of the IG unit is captured mechanically, all materials that contact the secondary sealant on this edge must be tested and approved for non-structural or incidental contact applications. When an edge of the IG unit is attached structurally to a framing member by means of a structural seal, all materials that contact the secondary seal on this edge must be tested and approved for contact in structural or full contact applications. Experience has shown that materials such as neoprene (chloroprene) and some EPDM polymer rubbers can be chemically incompatible with IG unit secondary sealants. Ultra-violet radiation heat tends to accelerate any incompatibility. If the setting block or accessory and the IG unit secondary seal are protected from direct ultra-violet radiation heat by a cover or such, heat will still be there, and indirect ultra-violet radiation can still reach the components through internal reflection in the IG unit glass lites. It is critical that the setting blocks and accessories be of a material that is compatible with the IG unit silicone secondary seal.

8.4 *Other Materials*—Other materials that are used in SSG systems may have to be evaluated for compatibility. These materials can include the SSG system exterior weather sealant, sealant backing, glazing gaskets in two-sided SSG systems, and metal framing and mullion joinery sealants. These materials may also be evaluated using Test Method C 1087 and various sealant manufacturers' standard test methods.

9. Durability

9.1 *General*:

9.1.1 The durability and performance of an IG unit is largely dependent on the quality of the edge seal and especially on the secondary seal durability and performance. The Sealed Insulating Glass Manufacturers Association (SIGMA) and Insulating Glass Certification Council (IGCC) currently recommend Test Method E 773 and Specification E 774 as instruments to use to quantify performance and determine the suitability of IG unit edge seal systems.

9.1.2 The SSG industry has required the use of dual-seal IG units containing a silicone secondary sealant to obtain the desired performance and to develop the necessary durability and longevity. It is believed that this edge seal configuration will provide the best IG unit performance of any edge seal configuration available.

9.1.3 A general rule-of-thumb in curtain wall system design is that the curtain wall life expectancy should be the life of the building or approximately 50 years. IG unit fabricators typically provide a 10-year warranty for dual-seal units. IG units manufactured with the proper components and workmanship, as described in this guide and as recommended by the particular edge seal component suppliers, should, in theory, perform acceptably for a period in excess of the typical manufacturer's warranty if glazed properly on the building.

9.1.4 The following sections describe briefly the various environmental conditions that are known to affect IG unit durability.

9.2 *Environmental Conditions*:

9.2.1 *General*—Several environmental conditions, either separately or in various combinations, in conjunction with exposure time, can influence IG unit edge seal performance after installation. These conditions include temperature, water, ultra-violet radiation, and applied stresses.

9.2.2 *Temperature*:

9.2.2.1 Typical IG unit secondary sealants are flexible at moderate temperatures, with sufficient movement capability to withstand applied stresses and other conditions. IG units are exposed to environmentally induced temperature extremes and change after installation. The surface temperature of an IG unit edge seal can range from as high as 71°C (160°F) to as low as − 40°C (−40°F) in some situations. In addition to environmental influences, the range of temperature will also be related to IG unit glass type (clear, tinted, or coated) and glazing method (exposed IG unit edge or pocket glazed).

9.2.2.2 The edge seal must retain sufficient flexibility and maintain adequate adhesion to the glass and spacer during temperature change and at temperature extremes. If the secondary seal changes detrimentally in modulus with temperature extremes, failure of the sealant from cracking or adhesive failure can occur. This, of course, can potentially result in catastrophic IG unit failure.

9.2.3 *Water*:

9.2.3.1 IG units are exposed frequently to high humidity or, in some instances, water exposure (in which the IG unit edge seal is immersed) for short time periods. This can occur due to, among other factors: wet or humid environmental conditions, slow draining or overloaded glazing channel drainage systems, or as a result of deficient curtain wall or window design wherein drainage systems are deficient or become nonfunctional with exposure. If the IG unit edge seal is exposed for extended periods of time to water or water immersion, edge seal failure and possible catastrophic failure of the IG unit can result.

9.2.3.2 The design of the SSG system should permit water to drain freely and rapidly and not remain in the glazing system. However, the potential for water exposure exists even in the best of designs; therefore, the IG unit secondary seal should not be able to be affected by high humidity or intermittent water immersion.

9.2.4 *Ultra-Violet Radiation*:

9.2.4.1 During the life of the IG unit, a secondary seal will be exposed to a certain amount of ultra-violet radiation from sunlight. Reflectively coated and laminated glasses used in IG units will not protect the IG unit secondary seal completely.

9.2.4.2 For some sealants, ultra-violet radiation can function as a catalyst to cause either an increase in sealant modulus (stiffness) or a degradation of sealant adhesion to a glass surface. These effects can cause the secondary sealant to become brittle, with reduced movement capability.

9.2.4.3 Since the secondary seal of an IG unit is the structural component for the exterior glass lite, the secondary seal must be relatively unaffected by ultra-violet radiation.

9.2.5 *Applied Stresses*:

9.2.5.1 An SSG system IG unit can be exposed to a variety of applied stresses during its lifetime. Applied stresses include wind load, differential thermal movement, building frame movement or settlement, seismic load, snow load, and dead load, among other factors. The IG unit secondary seal must retain sufficient elastomeric properties during its lifetime in order to accommodate properly any applied stresses placed on the IG unit.

9.2.5.2 Applied stresses on IG units containing lesser-quality sealants than those available for the secondary seal can contribute to premature edge seal failure from either failure of the sealant due to cracking, modulus increase, or brittleness; sealant selection is therefore important. This can further result in decreased flexibility and increased sealant stress and failure of the secondary seal in adhesion due to high bondline stress.

9.2.5.3 Currently, only silicone sealants have been used for the secondary seal of IG units used in SSG systems. Compared to conventional IG units, which use organic sealants such as polysulfides, polyurethanes, or hot-melt butyls, silicone sealants have the required greater durability when exposed to temperature change and extremes, water exposure, ultra-violet radiation, applied stresses, and various combinations of these factors.

9.3 *Insulating Glass Unit Reglazing*:

9.3.1 Perfection is difficult to attain, and usually some IG units will inevitably fail prematurely for one of many reasons, such as improper edge seal component selection, poor edge seal fabrication, glass breakage during transportation and installation, material incompatibility with the edge seal components, continuous water immersion of the IG unit edge seal, and deficient curtainwall system design, among other factors. Reglazing is required when IG unit failure occurs.

9.3.2 Reglazing is costly with respect to material, labor, and equipment requirements. Furthermore, the reglazing of structurally glazed IG units can be difficult to perform in the field. The potential for reglazing should be minimized and the ease of reglazing maximized.

9.3.3 To preclude IG unit failures related to fabrication as much as possible, highest quality materials and workmanship should be used in IG unit edge seal fabrication. Quality materials, sealants, and installation procedures are required that also incorporate ongoing QA procedures as a condition for their use. The IG unit fabricator should also coordinate with the curtainwall designer to simplify reglazing procedures.

QUALITY ASSURANCE CONSIDERATIONS

10. General

10.1 The quality of an IG unit and the unit's performance after long-term exposure to environmental conditions will depend greatly on the quality of the IG unit edge seal components and workmanship. This section provides information on IG unit QA procedures, as well as generally describing IG unit fabricator-performed testing of secondary sealants. It should be realized that QA procedures are also required for the other components of the edge seal system (primary seal and spacer). Their QA procedures need not be different from those used for conventional dual-seal IG units.

10.2 Good general record keeping procedures are required for any QA program. Permanent records should be kept of secondary sealant delivery dates, lot number(s), and testing results, among other items.

11. Secondary Sealant

11.1 *General*—IG unit performance in SSG systems will depend greatly on the choice of secondary sealant and its long-term performance. The IG unit fabricator should work closely with the secondary sealant supplier to develop and ensure that necessary fabricator and industry certification testing is performed. It is essential that the sealant manufacturer's recommendations for application equipment and application procedures for the sealant be followed. The IG unit secondary sealant should have fabricator-performed QA testing conducted for each new lot number of sealant material(s) and also conducted periodically during production.

11.2 *Lot Number*—The IG unit fabricator should check the sealant lot number(s) to ensure that the sealant is within its stated shelf-life. Sealant lot numbers used during IG unit production, as well as test results for each sealant lot number, should be recorded in quality control (QC) document.

11.3 *Mixing Test, Multi-Component Sealant*—A multi-component sealant requires an initial start-up procedure, at least daily, every time a production line is started. When beginning work, the various sealant component lines (usually base and curing agent) should be opened. Material should be purged through the lines until the sealant emerging from the dispensing gun ceases to be white or off-white or streaky, or both, in color and becomes uniform in color. A uniform color indicates adequate mixing of the sealant components. A mixing test, commonly referred to as a" butterfly test" (see Appendix X1), is recommended to confirm adequate mixing of the sealant components. The results of the tests, conducted for each lot number, should be retained and recorded in a QC document.

11.4 *Tack-Free Time Test, One-Part Sealant*—A tack-free time test should be performed on one-part sealants at the beginning of each working day. The purpose of the test is to verify sealant working life, or tack-free time. Any unacceptable variation in tack-free time (too short or too long) from the sealant manufacturer's recommendation for the sealant may indicate that the sealant is out of shelf-life. Test Method C 679 can be used to verify a sealant's tack-free time. The results of the tack-free time test should be recorded in the QC document, along with the corresponding sealant lot number.

11.5 *Snap-Time Test, Multi-Component Sealant*—A snap-time test should be performed on multi-component sealants once full mixing, as described by 11.3, has occurred. See Appendix X2 for a description of the test method. This test verifies the sealant working life and deep section cure times, as well as the mix ratio of the components. Any unacceptable variation in the snap-time (too long or too short), from the sealant manufacturer's recommendation for the sealant, may indicate that the sealant component mix ratio is incorrect or that one or more components may be out of shelf-life. The snap-time test results should be recorded in the QC document for the corresponding sealant lot number.

11.6 *Rheological (Flow) Property Test*—A flow or sag test can be performed using either Test Method C 639 or by simply inspecting the IG units after fabrication. Obviously, a non-sag sealant is desired. Any sealant sag or flow will not only result in excess labor and time to retool and clean the sagged sealant, but they can also indicate an out-of-shelf-life sealant, which could result in a poorly cured secondary seal and deficient IG unit performance. Results or comments on sealant rheology can also be recorded in the QC document for the corresponding sealant lot number.

11.7 *Adhesion Test*:

11.7.1 A peel adhesion test, such as Test Method C 794 (suitably modified for actual glass cleaning procedures), should be performed on a regular basis to verify that the secondary sealant has attained acceptable adhesion to a specific glass or coated glass surface. If the sealant fails primarily in adhesion, it may not be acceptable. The sealant supplier should be contacted to help in determining the cause if this occurs. Adhesion results should be recorded in the QC document for the corresponding sealant lot number.

11.7.2 Test Method C 794 cannot be used to determine whether the secondary sealant attains acceptable adhesion to the spacer. See Appendix X3 for a suggested test procedure. If the sealant fails primarily in adhesion, it may not be acceptable. The sealant supplier should be contacted to help in determining the cause if this occurs. Adhesion results should be recorded in the QC document for the corresponding sealant lot number.

12. Insulating Glass Unit Edge Seal

12.1 *General*—It should be realized that IG units must be assembled properly and that each component of the edge seal system must be used properly such that the intended performance and durability is attained. Individual edge seal components must be compatible with each other and within the IG unit fabricator's design and performance specifications for the individual component. Edge seal component suppliers and IG unit fabricators should have resolved these factors before production. Regarding individual edge seal components, the following information is provided.

12.2 *Secondary Sealant*:

12.2.1 The secondary sealant must be applied continuously, forming a uniformly dimensioned bead, filling the cavity with sealant completely. A multi-component sealant must be mixed fully and used at the desired component mix ratio (see 11.3 and 11.5).

12.2.2 Bubbles, skips, and bond voids are discontinuities in the seal and should be avoided, as they may lead to areas of stress concentration under applied loads, resulting in premature IG unit failure. The IG unit fabricator will establish the maximum size and number of discontinuities that are acceptable for an IG unit.

12.3 *Primary Sealant*—The primary seal sealant must be applied in a continuous, uninterrupted, properly sized bead with no skips or voids. Skips and voids could result in lessened IG unit durability by providing a vapor migration path into the sealed space of the IG unit.

12.4 *Spacer*—The spacer must be prepared properly and cleaned and free of dirt, grease, and other materials detrimental to secondary sealant adhesion. The spacer must be aligned properly on the glass surfaces, creating the required pocket size, to receive the secondary sealant.

12.5 *Spacer Corner Construction*:

12.5.1 *Corner Key*—Low moisture and gas permeation properties must be exhibited by the corner key. A corner key must be clean and dry and fit tightly into the hollow of the spacer. Injecting or plugging the corner key with a butyl sealant is recommended in order to reduce the potential of gaps or imperfections occurring at the corners, which can become a vapor migration path into the sealed space of the IG unit.

12.5.2 *Welded, Soldered, or Bent Spacer*—This corner construction would exhibit the lowest potential for the formation of a vapor migration path into the sealed space of the IG unit due to the excellent vapor resisting characteristics of an all-metal corner. This type of corner construction is recommended for an IG unit glazed in an SSG system to increase the potential durability of the IG unit edge seal to preclude expensive future replacement.

12.6 *Desiccant*—The desiccant must be stored and handled properly and then used in the proper amount when installed into the spacer. The desiccant must be dry at the time of installation into the spacer. Desiccant suppliers furnish test kits that can be used to ensure that the desiccant has not been preloaded with moisture vapor before it is installed in the spacer.

13. Industry Standards

13.1 *General*—The IG industry has developed standards to determine the performance of an IG unit. The IGCC currently uses ASTM test methods and specifications for determining the performance and suitability of IG units. The following describes these test methods briefly.

13.2 *Test Method E 773*—The purpose of Test Method E 773 is to provide a means of evaluating the relative durability of the edge seal system for an IG unit. The test method involves placing IG units in a high-humidity chamber at 60°C (140°F) and 95 % relative humidity; at the end of the prescribed time period, the units are removed, frost point determined, and chemical dewpoint observed. The IG units are then placed in an accelerated weathering machine that exposes the IG units to a prescribed cycle of temperature change between − 30 and 57°C (−20 and 135°F), water spray, and ultra-violet radiation. Again, the IG units are observed for frost point and chemical dew point. Finally, the IG units are tested for fogging after being exposed to ultra-violet radiation and elevated temperature conditions for a prescribed time period.

13.3 *Specification E 774*—Specification E 774 classifies sealed IG units into three categories, C, B, or A, depending on the durability achieved in accelerated testing according to Test Method E 773. The intent of Specification E 774 is to provide a quantification and basis for judgement of the suitability of sealed IG units for SSG systems. Sealed IG units for SSG systems should be rated CBA for maximum potential edge seal durability.

13.4 *SIGMA*—Proper IG unit fabrication is important to the ultimate performance and durability of the unit. Adequate production monitoring and certification is necessary. SIGMA requires that their fabricating members be certified. SIGMA has approved the IGCC, Associated Laboratories Incorporated (ALI), and National Certified Testing Laboratories (NCTL) certification programs. All three certification programs use Test Method E 773 and Specification E 774 as a basis for certification. The certification programs also require two unannounced inspections each year of the fabricators' facilities and procedures. IG units for SSG systems should be fabricated and certified as described by the appropriate SIGMA-approved programs.

13.5 *Other Standards*—Industry societies in other countries, such as the Insulating Glass Manufacturers of Canada (IGMAC), use the test methods and specifications of their respective countries to quantify the performance of IG units.

14. Keywords

14.1 adhesive failure; cohesive failure; edge seal; insulating glass; secondary seal; structural sealant; structural sealant glazing

APPENDIXES

(Nonmandatory Information)

X1. TEST METHOD FOR DETERMINING THE DEGREE OF MULTI-COMPONENT SEALANT MIXING (BUTTERFLY TEST)

X1.1 Scope

X1.1.1 This test method determines the thoroughness of mixing of a multi-component sealant.

X1.2 Apparatus

X1.2.1 *Paper*—Heavy, plain white, bond paper 216 by 280 mm (8½ by 11 in.).

X1.2.2 *Sealant*—Material to be tested as extruded from the dispensing apparatus.

X1.3 Procedure

X1.3.1 Fold the piece of paper in half across the lengthwise dimension. Dispense a bead of sealant approximately 76-mm (3-in.) long onto the crease in the paper. Fold the paper and, pressing on the surface, smear the sealant bead to a thin film roughly equivalent to a semi-circle in shape. Unfold the test specimen (paper) and inspect the formed sealant smear visually.

X1.4 Results

X1.4.1 If the sealant smear is a uniform dark color, the sealant is mixed properly and ready for production use. If the sealant is inconsistent in color or has streaks of different colors, the sealant is not mixed adequately and should not be used for the production of IG units.

X1.4.2 If the sealant was mixed inadequately, as described in X1.4.1, repeat X1.3.1 and X1.4.1 after additional sealant has been purged from the dispensing apparatus. If streaks or color inconsistencies continue to be present, equipment maintenance may be required (that is, cleaning of the static mixer, dispensing hoses, dispensing gun, or ratio system ball check valves). Consult the equipment manufacturer for maintenance requirements.

X1.5 Report

X1.5.1 Retain and mark the test specimens, in opened configuration, with the date, sealant lot numbers, and other pertinent information, and file the information in a QC document for future reference.

X2. TEST METHOD FOR SNAP-TIME OF MULTI-COMPONENT SEALANTS

X2.1 Scope

X2.1.1 This test method determines whether the rate of cure of a mixed sealant sample is within the sealant manufacturer's written specifications.

X2.2 Apparatus

X2.2.1 *Paper Cup*—Small paper cup of approximately 6 oz. capacity.

X2.2.2 *Spatula*—A wooden paint stirring stick, for example.

X2.2.3 *Sealant*—Material to be tested as extruded from the dispensing apparatus.

X2.3 Procedure

X2.3.1 Fill the cup approximately two-thirds to three-fourths full with sealant from the dispensing apparatus. Insert the spatula vertically into the center of the cup. Periodically, attempt to remove the spatula from the sealant.

X2.4 Results

X2.4.1 If the sealant strings and does not tear within itself (cohesively) when the stick is pulled from the sealant, the sealant has not snapped. Continue periodic testing. The time, in minutes after filling the cup, at which the sealant does tear within itself, and does not string, is termed the snap time.

X2.4.2 If the snap time is different from the sealant manufacturer's specified value for the particular sealant component mix ratio, contact the sealant manufacturer for guidance and inspect the dispensing equipment to determine the cause of the discrepancy (that is, sealant components out of shelf-life, equipment adjustment, or maintenance).

X2.5 Report

X2.5.1 File the snap time test number, snap time in minutes, date, sealant lot numbers, and other pertinent information in a QC document for future reference.

X3. TEST METHOD FOR SEALANT ADHESION TO AN INSULATING GLASS UNIT SPACER

X3.1 Scope

X3.1.1 This test method determines whether there is adequate adhesion of a sealant to the surface of a spacer.

X3.2 Apparatus

X3.2.1 *Spacer*—A length of spacer approximately 152-mm (6-in.) long.

X3.2.2 *Sealant*—Material to be tested as extruded from the dispensing apparatus.

X3.2.3 *Spatula*—Any suitable item to permit tooling of the sealant.

X3.3 Procedure

X3.3.1 Clean the spacer in a manner similar to that of the production cleaning process. Apply and tool a bead of sealant onto the spacer surface. After the sealant manufacturer's specified sealant cure time, pull on the sealant bead using one's hands, attempting to remove it from the surface of the spacer.

X3.4 Results

X3.4.1 If the sealant exhibits cohesive failure, it is considered to have acceptable adhesion to the spacer surface. If the sealant exhibits adhesive failure to the spacer, it may not be acceptable.

X3.5 Report

X3.5.1 File the adhesion test number, date, sealant lot number(s), spacer identification, test results (cohesive or adhesive failure), and other pertinent information in a QC document for future reference.

REFERENCES

(**1**) Spetz, J. L., "Design, Fabrication and Performance Considerations for Insulating Glass Edge Seals," *Science and Technology of Building Seals, Sealants, Glazing and Waterproofing, ASTM STP 1168*, C. J. Parise, ed., ASTM, Philadelphia, PA, 1992.

(**2**) Schoenherr, W. J., Haugsby, M. H., and Gladstone, M. E., "Silicone Sealants in Insulating Glass," *Science and Technology of Glazing Systems, ASTM STP 1054*, C. J. Parise, ed., ASTM, Philadelphia, PA, 1989, pp. 115–120.

(**3**) Bailey, J. R., Minor, J. E., and Tock, R. W., "Changes in Seal Shapes of Structurally Glazed Insulating Glass Units," *Building Sealants: Materials, Properties, and Performance, ASTM STP 1069*, T. F. O'Connor, ed., ASTM, Philadelphia, PA, 1990, pp. 42–52.

(**4**) Sandberg, L. B., and Rintala, A. E., "Resistance of Structural Silicones to Creep Rupture and Fatigue," *Building Sealants: Materials, Properties, and Performance, ASTM STP 1069*, T. F. O'Connor, ed., ASTM, Philadelphia, PA, 1990, pp. 7–21.

(**5**) Haugsby, M. H., Schoenherr, W. J., Carbary, L. D., and Schmidt, C. M., "Methods for Calculating Structural Silicone Sealant Joint Dimensions," *Science and Technology of Glazing Systems, ASTM STP 1054*, C. J. Parise, ed., ASTM, Philadelphia, PA, 1989, pp. 46–57.

(**6**) Vallabhan, C. V. G., and Chou, G. D., "Sealant Stresses in Structural Glazing: A Mathematical Model," *Building Sealants: Materials, Properties, and Performance, ASTM STP 1069*, T. F. O'Connor, ed., ASTM, Philadelphia, PA, 1990, pp. 22–41.

(**7**) Sandberg, L. B., and Ahlborn, T. M., "Combined Stress Behavior of Structural Glazing Joints," *Journal of Structural Engineering*, Vol 115, No. 5, May 1989, pp. 1212–1224.

(**8**) Sandberg, L. B., and Carbary, T. M., "Spacer Geometry Effects on Strength of Insulating Glass Joints for Structural Glazing Applications," *Science and Technology of Glazing Systems, ASTM STP 1054*, C. J. Parise, ed., ASTM, Philadelphia, PA, 1989, pp. 66–72.