



Standard Guide for Use of Joint Sealants¹

This standard is issued under the fixed designation C 1193; 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 describes the use of a cold liquid-applied sealant for joint sealing applications. Including joints on buildings and related adjacent areas, such as plazas, decks, and pavements for vehicular or pedestrian use, and types of construction other than highways and airfield pavements and bridges. Information in this guide is primarily applicable to a single and multi-component, cold liquid-applied joint sealant and secondarily to a pre-cured sealant when used with a properly prepared joint opening and substrate surfaces.

1.2 An elastomeric or non-elastomeric sealant described by this guide should meet the requirements of Specification C 834, C 920, or C 1311.

1.3 This guide does not provide information or guidelines for the use of a sealant in a structural sealant glazing application. Guide C 1401 should be consulted for this information. Additionally, it also does not provide information or guidelines for the use of a sealant in an insulating glass unit edge seal used in a structural sealant glazing application. Guide C 1249 should be consulted for this information.

1.4 Practice C 919 should be consulted for information and guidelines for the use of a sealant in an application where an acoustic joint seal is required.

1.5 This guide also does not provide information relative to the numerous types of sealant that are available nor specific generic sealant properties, such as hardness, tack-free time, or curing process, among others. Guide C 1299 should be consulted for information on generally accepted comparative values for the characteristics and properties of the more common generic types of liquid-applied sealant.

1.6 The values stated in SI units are to be regarded as the standard. The values given in parenthesis are provided for information only.

1.7 The Committee with jurisdiction for this standard is not aware of any comparable standards published by other organizations.

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 Standards:

- C 510 Test Method for Staining and Color Change of Single- or Multicomponent Joint Sealants
- C 717 Terminology of Building Seals and Sealants
- C 719 Test Method for Adhesion and Cohesion of Elastomeric Joint Sealants Under Cyclic Movement (Hockman Cycle)
- C 792 Test Method for Effects of Heat Aging on Weight Loss, Cracking and Chalking of Elastomeric Sealants
- C 794 Test Method for Adhesion-in-Peel of Elastomeric Joint Sealants
- C 834 Specification for Latex Sealants
- C 919 Practice for Use of Sealants in Acoustical Applications
- C 920 Specification for Elastomeric Joint Sealants
- C 1083 Test Method for Water Absorption of Cellular Elastomeric Gaskets and Sealing Materials
- C 1087 Test Method for Determining Compatibility of Liquid-Applied Sealants with Accessories Used in Structural Glazing Systems
- C 1135 Test Method for Determining Adhesion Properties of Structural sealants
- C 1247 Test Method for Durability of Sealants Exposed to Continuous Immersion in Liquids
- C 1248 Test Method for Staining of Porous Substrate by Joint Sealants
- C 1249 Guide for Secondary Seal for Sealed Insulating Glass Units for Structural Sealant Glazing applications
- C 1253 Test Method for Determining the Outgassing Potential of Sealant backing
- C 1299 Guide for Use in Selection of Liquid-Applied Sealants
- C 1311 Specification for Solvent Release Sealants
- C 1330 Specification for Cylindrical Sealant Backing for Use with Cold Liquid-Applied Sealants

¹ This standard 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 June 10, 2000. Published July 2000. Originally published as C 1193-91. Last previous edition C 1193-91 (1999).

- C 1375 Guide for Substrates Used in Testing Building Seals and Sealants
- C 1382 Guide for Determining Tensile Adhesion Properties of Sealants When Used in Exterior Insulation and Finish Systems (EIFS) Systems
- C 1401 Guide for Structural Sealant Glazing
- C 1442 Practice for Conducting Tests on Sealants Using Artificial Weathering Apparatus
- C 1472 Guide for Calculating Movement and Other Effects When Establishing Sealant Joint Width
- D 2203 Test Method for Staining from Sealants

3. Terminology

3.1 *Definitions*—Refer to Terminology C 717 for definitions of the following terms used in this guide: adhesive failure, bicellular sealant backing, blooming, bond-breaker, bridge sealant joint, butt sealant joint, cell, cellular material, chalk, chalking, chemically curing sealant, closed cell, closed cell material, closed cell sealant backing, cohesive failure, compatibility, compatible materials, compound, control joint, creep, cure, cured, dirt pick-up, elastomeric, elongation, expansion joint, fillet sealant joint, gasket, hydrostatic pressure, isolation joint, fluid migration, joint filler, laitance, latex sealant, modulus, non-sag sealant, open cell, open cell material, open cell outgassing, sealant backing, primer, reversion, rundown, seal, sealant, sealant backing, self-leveling sealant, shelf-life, solvent release sealant, shrinkage, silicone sealant, skin, structural sealant, substrate, tooling, tooling time, weathertight, working life (pot life).

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *durability, n*—ability of a sealant joint and its parts to perform its required function over a period of time under the influence of the environment.

3.2.2 *durability limit, n*—point at which loss of performance leads to the end of service life.

3.2.3 *pre-cured sealant, n*—a preformed, factory cured, elastomeric material.

3.2.4 *premature deterioration, n*—failure to achieve predicted service life.

3.2.5 *service life, n*—actual period of time during which no excessive expenditure is required for maintenance or repair of a sealant joint.

4. Significance and Use

4.1 This guide provides information and guidelines for consideration by the designer or applicator of a joint seal. It explains the properties and functions of various materials, such as sealant, sealant backing, and primer, among others; and, procedures such as, substrate cleaning and priming, and installation of the components of a sealed joint. It presents guidelines for the use and application of the various materials, design of a sealant joint for a specific application, and environmental conditions and effects that are known to detrimentally affect a sealant joint. The information and guidelines are also useful for those that supply accessories to the sealant industry and for those that install sealants and accessory materials associated with sealant use.

4.2 In addition to the design and installation data in this guide, consult the sealant manufacturer about applications for

its products and their proper use and installation. Considering the range of properties of commercially available sealants, the variety of joint designs possible, and the many conditions of use, the information contained herein is general in nature.

4.3 To assist the user of the guide in locating specific information, a detailed listing of guide numbered sections and their descriptors are included in Appendix X2.

5. General Considerations

5.1 *General*—Proper selection and use of a sealant is fundamental to its ultimate performance, service life, and durability. A sealant joint subjected to movement and other similar performance factors should be designed for the particular application to avoid compromising its performance capability and causing failure (See 15). If not designed for the particular application, failure is a distinct probability. Equally important is the proper selection and use of other materials and products associated with sealant use. These include substrate cleaner, surface conditioner or primer, type of sealant backing material, bond-breaker, and joint filler, among others. The ability of a sealant installation to remain weather tight is critically dependent on proper preparation, continuity, and durability of the substrates to which the sealant will adhere, and compatibility of the sealant with the materials it will contact, including the substrates. The proper application and installation of the various materials and products, following the established joint design criteria, avoids premature deterioration of the sealant joint. For a sealant joint that is difficult or expensive to access (for example, tall buildings and certain roofs) a sealant should be selected that will have excellent environmental weathering characteristics to minimize maintenance. The following sections describe joint design guidelines and the properties and use of a sealant and its associated materials.

5.2 *Durability*—The durability of a sealant and a sealant joint is related to many factors. For example, environmental exposure to solar radiation, ozone, heat-aging, and atmospheric contaminants can lessen sealant durability. Inadequate construction tolerances and improper sealant joint design for movement and other effects can contribute to sealant joint failure, which is usually expressed as adhesive or cohesive failure of the sealant. Inadequate installation (for example, where the sealant profile is inappropriate for movement, where substrates have not been properly cleaned and, if required, primed, and the sealant inadequately tooled, among others) are common causes of failure. Conditions of exposure and design (where, for example, a sealant joint is exposed to constant wetting or to pedestrian or other traffic) can lessen sealant and sealant joint durability. The type of sealant, its primary polymer backbone, and the particular sealant formulation can also contribute to lessened durability, especially if a sealant is misused for an application or for conditions of use not appropriate for it. Frequently, various combinations of environmental exposure and conditions of use occur which can result in lessened durability. For example, depending on sealant type, joint movement combined with heat aging and cold weather exposure or joint movement combined with heat aging and moisture can result in failure. To enhance durability, it is important that the sealant type is matched to the conditions of

use and exposure and that the sealant joint is of proper design for those conditions of use and exposure. In any event, eventual replacement of a sealant that has reached its durability limit must be planned for in the initial design and installation to facilitate future remedial work.

5.2.1 Durability Testing—Presently, testing for sealant durability consists of exposing small-scale sealant samples to artificial weathering, without cycling movement, in a laboratory accelerated weathering device to actinic radiation, moisture, and heat according to Practice C 1442. Additionally, environmental exposure at various locations (for example Florida, Arizona, Texas, and certain northern latitudes) is also conducted. Correlation of artificial weathering to environmental exposure is important to assess the relevance of laboratory test results to predicting sealant performance during environmental use (1, 2). Laboratory tests to date indicate that at least several thousand hours of artificial weathering exposure is necessary to adequately predict a minimum level of environmental performance. For example, if changes occur five times faster in a laboratory device than under environmental conditions (a typical average acceleration factor for a number of materials), and the desired lifetime of a material is about five years, as much as one year of artificial weathering may be necessary to qualify a material for the application. The latest ASTM weathering standards recommend as a minimum exposure time that necessary to produce a substantial change in the property of interest for the least stable material being evaluated. However, this may not be long enough to qualify a material for the desired application. Environmental performance will vary with latitude. For example, a sealant used in Chicago will perform differently than the same sealant used in Florida for a similar application. Compass orientation also has an effect, with a northerly exposure sealant tending to last longer than a southerly. The incident solar radiation is a primary contributing factor, among others, to lessened durability. Other conditions being equal, the sealant in Chicago will in general perform for a longer time period than the same sealant used in Florida.

5.2.1.1 The latest durability testing programs indicate that artificial weathering performed concurrently with movement of a sealant joint sample seems to more realistically predict sealant and sealant joint environmental performance (3, 4, 5, 6). Current ASTM laboratory test methods, that include a durability component, such as C 719, do not provide an adequate prediction of sealant long-term environmental performance and therefore potential sealant and joint durability.

5.2.1.2 Test method C 719 evaluates the movement of a new sealant without the benefit of any aging or weathering and thereby provides data only for an unaged sealant.

5.2.1.3 The user of a sealant should realize that most manufacturer's data sheets report laboratory testing data conducted in an idealized, as-cured state and not as a weathered condition that represents how the sealant will actually appear and perform on a building. Additionally, the performance and other properties reported on many data sheets does not include movement during the curing process.

5.2.1.4 Almost all building sealant applications have movement-during-cure. These natural movements during cure

almost always decrease the performance capability of a sealant. Therefore, data sheet performance properties, if correct, generally overstate the expected environmental and cyclic movement performance of a sealant. With this in mind, a sealant joint design should always be performed with mitigating design factors included in the design to account for movement-during-cure (See 12.5).

5.3 Adhesion—Obtaining and then maintaining long-term adhesion of a sealant is the primary variable in a successful installation. A sealant manufacturer will determine what is necessary to achieve adequate adhesion to a particular substrate, and if a primer or surface conditioner is necessary, by using laboratory test methods. In some applications, glass, metal or other substrates may have coatings, surface treatments or difficult-to-remove contaminants requiring special cleaning techniques or primers. Due to this surface variability, the substrates should be sampled and tested by the sealant manufacturer from actual production runs of the materials. Specification C 920 requires a sealant to be rated as Use M, A, G, or O. When listed by a sealant manufacturer it indicates that, in general, the sealant has been found to adhere to and is suitable for use with that substrate type. This is not necessarily a guarantee of adhesion. Samples of the actual substrate should always be tested for adhesion before use, since materials and finishes can be variable or products can change with time and formulation from that as previously tested. Consideration should also be given to identifying a sealant which, without the use of primers if possible, will provide adequate adhesion.

5.3.1 Adhesion Testing—Adhesion of a sealant to a substrate surface or another material or component is determined using laboratory Test Methods C 794 and C 719. Adhesion testing by a sealant manufacturer typically will be performed after one day or 7 days of water immersion. For many applications this is not an adequate test exposure to predict long term sealant joint performance. It is the user's responsibility to evaluate the water immersion condition of an adhesion test conducted by the sealant manufacturer and determine if it is applicable to a particular use. If not, the user should obtain appropriate data consistent with the intended application. In general, for most materials, sealant manufacturers have extensive previous adhesion testing experience and can usually indicate if their sealant will or will not adhere to a generic material's surface. Therefore, pre-qualification testing, prior to specifying, is usually not necessary unless the manufacturer does not have relevant data for a particular material or if the adhesion to a generic substrate varies significantly. Careful review of a sealant manufacturer's data sheet is important, since some only report extension or simple cyclic movement performance not including all the Test Method C 719 parameters and conditions. To monitor for any subsequent surface changes, consideration should be given to evaluating substrate adhesion on the installed substrates at the project site prior to beginning the installation of the sealant and periodically during the installation. Appendix X1 describes project site adhesion testing methods.

5.4 Compatibility—A sealant must be compatible with the materials and surfaces with which it will be in contact. Occasionally, materials that are in close proximity, but not in

contact with the sealant, can have an effect on the installed sealant. Incompatibility can cause, as a minimum, a discoloration of the sealant or, at its extreme, sealant deterioration or adhesion loss. Compatibility must never be assumed but always established by a formal program of testing by the sealant manufacturer, since there are no “always compatible” combinations of a sealant with other materials. A sealant should be tested for compatibility with other sealants which it may contact and with materials and finishes it contacts or is in close proximity. Materials and finishes, with time and exposure to the ultraviolet component of sunlight, can exude or release plasticizers or other materials into a sealant, which can cause a sealant to change color or lose adhesion. Also, these accessories can have surface residues or contaminants from manufacturing that can migrate into the sealant. A change of sealant color is evidence of a potentially detrimental chemical reaction, and although adhesion may not be initially lost, the color change could be predictive of a future loss of adhesion. Other sealant characteristics that could also be affected by incompatibility include the ability of a sealant to cure fully, its ultimate strength development, and its aesthetic qualities.

5.4.1 Compatibility Testing—Materials or components that are nearby or touch the sealant should be tested for compatibility using Test Method C 1087. This test is performed in the laboratory with prepared samples of substrate finishes, gaskets, and various accessory materials, among others. Any color change of the sealant after testing, is sufficient evidence to cause additional evaluation for use of the candidate material or finish. This test is usually performed to prequalify a material or component for use. In general, for most materials, sealant manufacturers have extensive previous compatibility testing experience and can usually indicate if their sealant is compatible with a particular material. Therefore, pre-qualification testing, prior to specifying, is usually not necessary unless the manufacturer does not have relevant data for a particular material. An important aspect concerning compatibility is that often a sealant or joint accessory is substituted at the last minute as an “or equal” product. Products are not equal in compatibility unless they are equally tested for compatibility. Therefore, if a sealant or an accessory material is substituted, the new combination should also be tested for compatibility.

5.5 Substrate Staining—A sealant, depending on formulation and the quality of its components, can cause staining of adjacent substrate surfaces. Staining by a sealant is usually due to fluid migration or rundown (7-11). Both porous and non-porous substrates are susceptible to this staining mechanism. Fluid from a sealant can migrate into the pores of a porous substrate and then migrate to its exposed surface adjacent to the sealant. The fluid can then discolor the substrate surface or become an attractant for environmental pollution or dirt pick-up. This staining has been colloquially referred to as “clouding” due to its visual appearance. Fluid can also migrate through the exposed surface of the sealant and then run down onto adjacent porous or non-porous surfaces and become an attractant for environmental pollution or dirt pick-up. Staining of porous substrates has proven to be difficult if not impossible to completely remove. Removal has usually been most successfully achieved using an appropriate poultice; however,

complete and lasting removal of the stain is rarely achieved. Staining of non-porous surfaces can also be difficult to remove. Depending on the material, the type of fluid, and the type of environmental pollution or dirt pick-up, the staining may be easily removed or can not be removed resulting in a permanent stain to the surface. Development of cleaning materials and methods must be a collaborative effort of the sealant manufacturer and the stained material manufacturer.

5.5.1 Stain Testing—Laboratory testing for potential staining of a porous substrate by a sealant can be performed using either Test Method D 2203, C 510, or C 1248. These test methods are typically used prior to sealant installation to test a specific substrate material with a particular sealant. It should be realized that the tests are meant to be predictive based on accelerated laboratory procedures that attempt to duplicate the natural environment. They are not always successful in duplicating the natural environment and in identifying a potential staining combination of sealant and substrate. Environmental testing for staining can also be performed using a mock-up of the particular sealant and substrate exposed to the same conditions as the end use. This procedure is usually lengthy, sometimes taking years before a judgement can be made as to staining potential. The sealant manufacturer should be consulted for advice since they have a history of their products and staining potential with particular substrate materials. Test data from a method such as C 1248 should be evaluated along with the sealant manufacturer’s recommendation and exposure data from older installations.

5.6 Sealant Color Change—A sealant, in use, can change color. A joint designer should be aware that developing a special color for a particular application might be inappropriate and additionally become a “throw away” cost. The surface color of some sealants can change in as little as a few years depending on local environmental conditions. Color change can be caused by blooming, ultraviolet and visible radiation absorption, chalking, pollutants in the atmosphere, dirt pick-up, cleaning solutions, and adjacent materials, among others (7-9). Blooming is the movement of components in a sealant to its surface where they attract dirt and atmospheric contaminants to the surface of the sealant, changing its apparent color. Ultraviolet and visible radiation absorption from the sun can permanently alter a sealant, depending on the type and quality of pigment and stabilizer ingredients. Colors that seem to be most affected by ultraviolet and visible radiation absorption are generally those created using organic coloring agents. Better color stability is achieved using inorganic colorants. The degree of color change due to this effect is variable depending on the exposure of the sealant (e.g. northerly versus southerly facing) and the environment (southern versus northern latitudes in the same hemisphere). The formation of chalk (a powder) on a sealant surface due to chalking can impart an apparent color change to the sealant’s surface by hiding the color of the sealant. Most powders tend to be whitish in color, although a color other than white can develop. Organic polymer based sealants, as they weather, can be self-cleaning as rain-water can wash away the surface chalk. A sealant can discolor due to the accumulation of atmospheric contaminants or dirt pick-up as the period of environmental exposure increases. Color change

caused by blooming, chalking, and the accumulation of atmospheric contaminants or dirt pick-up, can usually be cleaned from the surface of the sealant using cleaning solutions and procedures recommended by the sealant manufacturer. Building facades are normally cleaned on a periodic basis. Cleaning solutions used for other facade materials may have a deleterious effect on the color and other properties of a sealant and should be verified as having no effect by a mock-up test program prior to application. Occasionally, a substrate material that a sealant is adhered to, or another material that it is in incidental contact with, can cause a color change in the sealant through migration of substrate or material components into the body of the sealant.

5.6.1 Color Change Testing—Test Method C 1087 can be used to determine if sealant contact with a material will cause the sealant to discolor or lose adhesion. Test Method C 510 can also be used; however, its value is limited due to the relatively short time period for the test. Further, it would primarily be useful for porous substrates that may be discolored by components of the sealant that migrate into it. Test Method C 792 can be used to assess the chalking potential of a sealant; however, this test also has a relatively short time period for the test. It should be realized that the tests are meant to be predictive based on accelerated laboratory procedures that attempt to duplicate the natural environment. They are not always successful in duplicating the natural environment and in identifying a potential color change combination of sealant and substrate. Accelerated laboratory tests that use a full spectrum of radiation, such as a xenon lamp, are most useful in predicting color change. Environmental testing for color change can also be performed using a mock-up of the particular sealant and substrate exposed to the same conditions as the end use. This procedure is usually lengthy, sometimes taking years before a judgement can be made as to a color change potential. The sealant manufacturer should be consulted for advice since they have a history of their products and color change potential with particular substrate and incidental contact materials. The specifier or user can also confirm performance by observing older installations.

5.7 Liquid Immersion—Some sealant applications, for instance a water retention structure or a waste water treatment facility, require a sealant that can tolerate extended periods of continuous immersion in water or other liquids (12, 13). Also, certain building joint applications, such as for plazas and other horizontal surfaces, can subject a sealant to intermittent short or long term immersion in rain water or snow melt. Water immersion of a sealant is often associated with an accelerating influence on loss of adhesion of the sealant to a substrate and degradation of properties including sealant reversion. For other than continuous water immersion situations, it is prudent to design joints that are not exposed to prolonged water immersion. These joints typically are under some stress from movement or other effects that, in combination with immersion, can result in a premature loss of adhesion. An important consideration in immersion situations is the development of a constant dead load due to hydrostatic pressure on the sealant and its adhesion to a substrate. For such applications, an adhesion test should include the effect of hydrostatic pressure on the sealant

and its adhesion to a substrate, as well as prolonged water exposure described in 5.7.1. An appropriate practice for a sealant joint subject to immersion is to design the joint profile as a continuous “bath tub plug.” This is a joint with tapered sides or similar design to cause hydrostatic pressure to assist in forming a compression seal, by pushing a sealant against the substrate.

5.7.1 Liquid Immersion Resistance Testing—Test Method C 1247 can be used to assess adhesion of a submerged sealant to a substrate. Water or other liquids can be used with this method to determine sealant performance. However, this method does not test the added influences of a constant stress from hydrostatic pressure or an induced sealant stress from joint movement. For a particular application, this test may not be an accelerated test depending on the temperature of the test liquid used in the application. The C 1247 test temperature is 50 °C (122 °F) and if that is also the application liquid temperature, then the method may not be an accelerated test. Also, most available immersion test data is based on clean water as the liquid. If a particular application has other than clean water as the liquid, the user should have the test performed with the liquid in which the sealant will be immersed.

5.8 Environmental Influences:

5.8.1 Low Temperature—A low substrate temperature during installation generally decreases adhesion since the sealant surface wetting characteristic is reduced. Also, a low ambient air temperature, depending on the sealant formulation and polymer backbone, can reduce the extrudability of a sealant and restrict its ability to flow into joint openings, thereby forming voids in the sealant. Frost, both visible and non-visible, or ice may be present on a cold substrate surface inhibiting adhesion. For these reasons, a sealant is more appropriately applied at an ambient air temperature above 4°C (40°F). If application is necessary when there is visible frost or ice on a substrate surface, the frost or ice must be removed by solvent wiping, evaporation of the solvent, and finally a dry wipe. There is a risk of non-visible frost forming when evaporative cooling of a solvent, used to remove visible frost, causes the substrate temperature to fall below the dew point. A simple test, to determine the presence of non-visible frost on a metal surface is to place a hand on the surface. Heat from one hand will melt the frost, if it exists, and wet the surface. Also, for adhesion, the manufacturer of the sealant should be consulted regarding the extrudability and surface-wetting characteristics of the sealant as applicable to a particular substrate material. A low temperature can be quite detrimental to a cured sealant’s performance. A low temperature can retard cure of the sealant. Some sealants become stiff at a low temperature. If there is joint movement at a low temperature, a failure can result due to the reduced movement capability of the sealant and the increased stress generated at the sealant adhesion surface. If a low temperature will be a factor, then knowledge of sealant performance at low temperature is fundamental as well as knowledge of its brittle point (glass transition temperature). It should be realized that the low temperature used in Test Method C 719 is –26°C (–15°F) and may need to be lowered depending on the particular low temperature application.

5.8.2 High Temperature—The sealant applicator should be aware that a sealant that is marginal with respect to hot weather sag resistance may present a problem when working on an application that has a solar exposure. A substrate surface, depending on color and thermal mass, can develop a high surface temperature, which can exceed a sealant's high temperature stability level. Such high temperatures can occur on some dark colored surfaces in the summer. Knowledge of a sealant's sustained high temperature stability and the expected in-use substrate surface temperature is fundamental to developing a durable sealant joint. Many organic sealants will start to deteriorate at 70 to 80 °C (158 to 176 °F). A sealant that meets Specification C 920 is tested by method C 639 for its flow (rheological or sag) properties at a temperature of 50 ± 2 °C (122 ± 3.6 °F). Depending on a particular sealant and application this may not be adequate. Hot weather may also accelerate sealant cure time, resulting in a shortened working life and tooling time, while tack-free time will be reduced and rain resistance accelerated. This is particularly helpful for a water-based sealant, which is usually more susceptible to rain damage within the first few hours after application. A high substrate temperature can increase bubble formation in a sealant from outgassing of a sealant backing and thus must be avoided (See 9.3).

5.8.3 Moisture—Sealant installation, in unprotected exterior locations, cannot be performed during or immediately after a rain and should not be performed when there is a threat or knowledge of imminent rainfall. However, rainfall after application usually has no serious effect on most sealants if the sealant has clearly formed a surface skin. Even a sealant with a skin can be affected if there is forceful impingement of water, prolonged flowing of water, or prolonged immersion of a sealant joint. The sealant manufacturer should be consulted for a specific recommendation when confronted with these or similar situations. The moisture level in a porous substrate can also affect sealant adhesion, especially for joints that occur in horizontal surfaces such as plazas.

6. Substrate

6.1 General—Sealants have been developed to seal joints between numerous substrate materials, the more common of which are brick and concrete masonry, concrete, various metals, stone, and glass. Substrates are generally classified as either porous or non-porous. Some substrates are generally more difficult to adhere sealant to than others. Surface characteristics vary considerably, and some substrates may not be suitable for achieving a joint seal unless treated either mechanically or chemically, or both. The substrate must be properly prepared in all cases of use. The substrate must be clean, dry, sound, and free of loose particles, contaminants, foreign matter, water-soluble material and frost and ice.

6.2 Types:

6.2.1 Porous—Materials representative of this type are brick and concrete masonry, concrete, unpainted wood, some building stones, and most cement-based materials. The classification of a material as porous is generally related to its having a pore structure in the body of the material. A water-repellent treatment or coating on a porous substrate may inhibit sealant adhesion. Since these coatings are not always visually appar-

ent, their existence is sometimes unknown until an adhesion failure occurs or testing is performed before installation. These conditions require special consideration and consultation with both the substrate and sealant manufacturers to determine suitable substrate preparation methods and which primer(s), if required, should be used before a sealant is applied. Often, reliability of a selected cleaning and priming method can be predicted only by adhesion testing of a trial application at the project site on project materials. Other problematic conditions are sealant incompatibility with other chemical products on a porous material, such as concrete surface laitance, which provides a weak substrate, and an adhesion-inhibiting form-release agent on a concrete surface. It is therefore essential that these materials be removed from a porous substrate surface. Substrate porosity can also accelerate sealant adhesion loss when the substrate is wetted or immersed. A primer or surface conditioner (See 8) may improve sealant adhesion durability, even if not required for adequate initial adhesion.

6.2.2 Non-Porous—Stainless steel, lead-coated copper, and anodized aluminum, factory-applied organic coatings, paints, and glass are examples of materials that are considered non-porous. These materials are non-absorptive. A proprietary treatment or protective coating on a metal surface may inhibit sealant adhesion and should be removed completely. Where a painted or coated metal is the substrate, the adhesion of the paint or coating to the substrate as well as the compatibility and bond of the sealant to the paint or coating is a matter of concern. Also, non-porous materials are often of the type that can't be cut and reshaped at a project site. This becomes a concern when a joint opening, due to workmanship or other considerations, has become smaller than the minimum acceptable width for the joint design. Typically, the joint opening cannot be modified to make a wider joint to permit application of the planned sealant. When this occurs, either a different sealant with greater movement capability should be installed or the joint design should be changed to a fillet or bridge type sealant joint if aesthetically acceptable (See 14.1.4.5 and 14.2).

6.2.3 EIFS—An Exterior Insulation and Finish System (EIFS) presents a porous substrate that may be acceptable for sealant adhesion provided certain procedures are followed (14-16). Most manufacturers recommend adhering sealant directly to the base coat and avoiding adhesion to the finish coat which can soften on exposure to moisture and lose adhesion as the sealant extends and exerts a stress on the finish coat. Typically, a sealant that has a low modulus should be used. A low modulus sealant will have a lower stress at the sealant and substrate interface when the joint is in extension. Due to the difficulty that can be encountered in performing remedial work for an EIFS sealant joint, the selected sealant should have very good environmental weathering characteristics so that it will last for the useful lifetime of an EIFS installation. Since an EIFS system is water-based, if it becomes saturated with rainwater or snow melt, the adhesion of a sealant to an EIFS base coat can be lessened. Information on sealant tensile adhesion properties when used with EIFS can be found in Guide C 1382. EIFS can not tolerate grinding or cutting during sealant removal so it is a good candidate for use of a bridge type sealant joint or precured sealant, in a remedial

sealant application. This may be helpful since it does not require the removal of all the old or failed sealant but does change the appearance of the joint seal.

7. Cleaner

7.1 General—The quality of a cleaning method, cleaning solution, and cleaning cloths, among others, is as important as the quality of a sealant. The surfaces to which a sealant will be applied must be properly cleaned. Any deleterious substances, such as oil, grease, or powdery deposits that may interfere with adhesion, must be removed completely.

7.2 Procedure:

7.2.1 Porous Substrate—Grinding, brushing, blowing off with oil-free compressed air, and wiping with cloths are typical procedures that are used to clean a porous substrate. Solvents are not generally used since they tend to dissolve contaminants and then re-deposit them in the pores of the material where they become very difficult to remove. A porous substrate should be free of dust, dirt and any other contaminant that would interfere with sealant adhesion. Concrete-based substrates should have any laitance removed. Laitance is an unsound surface for sealant adhesion. Grinding or brushing should be performed with materials and tools that will not leave deleterious substances (e.g. metal or fibrous particles) detrimental to sealant adhesion.

7.2.2 Non-Porous Substrate—Degreasing solvents, such as methyl ethyl ketone (MEK), toluene, xylene, acetone and mineral spirits have been used as cleaners. Many of these solvents are regulated due to their potentially hazardous nature and volatile organic compound (VOC) content. It is necessary to know the environment and safety provisions for a specific application before a particular solvent is selected for evaluation as a cleaner. Some solvents that may be considered appropriate are effective degreasers but can leave a residue film on the cleaned surface, which should be removed. A residue film can be removed using a solution of fifty percent isopropyl alcohol (IPA) and fifty percent water. However, this solution is not an effective degreaser. A two step cleaning method can be used. The first step is a solvent, which is a degreaser followed by the second step, which is a solution of IPA and water to remove any residue film. The sealant applicator should work closely with the sealant manufacturer to develop a suitable cleaning procedure as determined by testing (See 16.4.4). When received at a shop or construction-site, and prior to use, a cleaning agent should have its quality verified. Small quantities of organic and other contaminants, in the shipped cleaning agent, can adversely affect adhesion of the sealant to a cleaned surface. Additionally, containers for storage and use of a cleaning agent must be clean. Cleaning cloths, rags, or paper wipes must also be free of contaminants and be lint free. Some commercially available disposable cloths or wipes contain additives, such as lanolin to improve softness. These additives will contaminate a surface and affect sealant adhesion.

8. Primer

8.1 General—The purpose of a primer is to improve the adhesion of a sealant to a substrate. A primer functions in three ways. First, it changes the chemical characteristics of the substrate surface to render it more suitable for the sealant.

Secondly, it stabilizes the substrate surface by filling pores and strengthening weak areas. Lastly, it reduces capillary pressure of moisture through a substrate surface. Some sealants require the use of a primer on all substrates, while some require them on only certain substrates or on none at all. The need for a primer and the adhesion results achieved can vary, not only with the substrate type, but also with the quality of the substrate. No consistent recommendation can be made regarding which substrate surfaces will require priming. Priming is dependent on the sealant manufacturer, sealant type and formulation, substrate, and, in some instances, use and exposure. With some sealants different primers are required for different substrates. This poses a difficult application problem when two different substrates require two different primers on opposite sides of a joint opening. This should be considered when selecting a sealant. Many sealants require a primer for maximum adhesion to concrete and masonry surfaces. To determine if a primer is required for a specific application, perform adhesion testing as described in 5.3.1.

8.2 Materials—A primer or surface conditioner is a specially formulated liquid developed and recommended by the manufacturer of the sealant. A primer, if required, is normally furnished by the sealant manufacturer and is typically formulated for use only with the same manufacturer's sealant. A primer from one sealant manufacturer should never be used with a sealant from another manufacturer unless it has been tested and approved by the manufacturer of the sealant with which it will be used. Some sealant manufacturers have several primers that are used with their different sealants and with different substrates. Selection of a primer for use with a particular sealant and substrate or substrate finish should be the responsibility of the sealant manufacturer based on data obtained from testing performed on submitted substrate finish samples. As for a sealant, a primer must be stored and applied in accordance with the manufacturer's recommendations and used within its stated shelf-life.

8.2.1 Color—It is not uncommon for a primer to be clear as well as various shades of pink, red or yellow. The sealant manufacturer should establish an acceptable primer color, and its range. A primer that does not conform should be discarded and replaced. A primer of questionable color or one that is different from the manufacturer's description should never be used.

8.2.2 Clarity—Clarity is often confused with color. A clear primer is free of particulate matter or settling and is not cloudy. A primer may be water-white or various colors, such as, pink, red, yellow or some other color, and also clear. The sealant manufacturer should establish the need for and degree of clarity, and the acceptability of solid material in a primer. A primer of questionable clarity or one that is different from the manufacturer's description should never be used.

8.3 Application:

8.3.1 General—Dipping a cloth or brush in a container of primer may result in inadvertent contamination of the primer. Frequently, an applicator will use a squeeze bottle to pour primer on a cloth or brush (See 16.4.6.1). The length of time a primer must cure before the sealant can be applied should be as recommended by the sealant manufacturer. With some primers,

a sealant can be applied almost immediately, while with others a lengthy cure time is required. The latter, when complied with, can cause construction scheduling difficulties for the sealant installer for some applications and should be taken into consideration.

8.3.2 Porous Substrate—Often a sealant will require a primer for adequate adhesion to porous substrate surfaces, especially concrete and masonry. A primer is applied to a properly cleaned and prepared porous substrate usually using a brush.

8.3.3 Non-Porous Substrate—Depending on the surface, a sealant may require a primer for adequate adhesion to non-porous substrates, especially some metals and organic factory-applied coatings or paint films. A primer on a non-porous surface will generally function by changing the chemical characteristics of the substrate surface to render it more suitable for adhesion of a sealant. A primer is typically applied to a properly cleaned and prepared non-porous substrate using a clean, lint-free, uncolored cloth.

9. Sealant Backing

9.1 General—A proper joint design will require the selection and use of sealant backing to ensure anticipated performance and a weather tight joint. Sealant backing should meet the requirements of Specification C 1330. Some non-absorptive sealant backings may act as a secondary barrier in the event of sealant failure (See 9.5.3). It is not expected that the secondary barrier can accomplish this intent completely, or the sealant would not be required. For an application where the degree of water absorbency of a sealant backing is a concern, the backing can be evaluated using Test Method C 1083. Sealant backing and sealant compatibility can be verified by using Test Method C 1087 (See 5.4.1). If the sealant backing is to be used in a joint that will experience movement, then the sealant backing should not cause or contribute to a three-side adhesion condition that would restrict movement of the back of the sealant joint between substrates. Materials that are commonly used for sealant backing include polyurethane, polyethylene, and polyolefin foams. These materials are fabricated or extruded into sealant backing that can have an internal cellular structure that is composed of open-cell material, closed-cell material, or a combination of both. The use of sealant backing to which the sealant will not adhere, or that is so soft as to not restrict sealant movement, may preclude the need for a bond breaker. Some sealant backing may be incompatible with the substrate and sealant and cause stains on either or both. Materials impregnated with oil, bitumen, non-curing polymers, and similar materials should not be used as sealant backing. Some sealant backing may be factory-coated with a suitable material that will provide a barrier to staining. To confirm suitability, the barrier coating should be acceptable to both the sealant and sealant backing manufacturers. When required, a bond breaker may also be capable of performing the function of a barrier against staining of the sealant.

9.2 Function:

9.2.1 Normal—A sealant backing for a building joint application can have three primary purposes. First, it is used to control the depth and shape of the sealant in the joint opening. Secondly, it assists in attaining full wetting of the substrate

when the sealant is tooled. Lastly, depending on type, it allows movement of the backside of the sealant between substrates. A sealant backing should be capable of resisting permanent deformation before and during sealant application. A sealant backing for this application is a flexible closed-cell or open-cell plastic foam, closed-cell or sponge rubber rod or other appropriate shape that is compatible with the sealant. The sealant should be applied immediately after sealant backing placement to prevent water absorption from rain or condensation. Due to the ease of compressibility of open-cell foam sealant backing, this type of sealant backing can be used in varying joint widths provided that adequate compression of the backing is maintained.

9.2.2 Temporary Joint Seal—Sealant backing can serve as a temporary joint seal for weather protection or as a secondary barrier behind the prime sealant barrier, or both. As a temporary seal, an elastomeric gasket with low compression set, such as closed-cell foam or rubber, should be selected for building joint applications (walls). A sealant backing for this application may be compatible elastomeric tubing or rod of such materials as neoprene, butyl, or EPDM. These may be applied immediately as a temporary seal until the sealant is applied, after which they serve to a limited degree as a secondary water barrier. As with closed-cell sealant backing, these materials should be non-absorbent to water and gas and not blow or emit gas upon mild heating or rupturing, since this can cause bubbling of the sealant. In addition, this sealant backing should have the ability to remain resilient at temperatures as low as -26°C (-15°F) and have low compression set.

9.3 Material:

9.3.1 Open Cell Foam—An open-cell, sponge-type material such as urethane foam can be used. This material may be satisfactory for an application, provided its water absorption characteristics are recognized. It should not be used where water absorption by the sealant backing may be detrimental to sealant performance, such as for a horizontal joint or where condensation or infiltration of water can occur behind the backing in a vertical joint. An open-cell sealant backing is normally made from a polyurethane material, which is fabricated into various size cylindrical, rectangular, or other shapes that do not have a surface skin. By not having a surface skin the risk of outgassing is avoided. Due to its open cell structure this sealant backing has a low density and is easily compressible into place. However, the open cell structure can wick and retain water that may infiltrate behind the sealant joint or through other system deficiencies. The use of an open cell sealant backing should be carefully evaluated so that the possibility of a water-saturated sealant backing in direct contact with a sealant is precluded, or where condensation or infiltration can occur behind the sealant backing in a vertical joint, particularly before the sealant cures. Open cell sealant backing that is uncompressed should have a width approximately 40 to 50 percent greater than the joint width. This will ensure adequate compression when in place, so that it will not fall out of the joint before sealant application or be displaced deeper into the joint opening when the sealant is tooled against it. An open cell sealant backing material will allow a sealant that cures by exposure to atmospheric moisture or air to cure from the

interior or unexposed sealant face as well as its exposed face, thereby accelerating sealant cure. For some applications, where movement during cure is expected, an open cell sealant backing material can be beneficial to accelerating sealant cure and minimizing sealant exposure to movement-during cure.

9.3.2 Closed Cell Foam—A closed-cell foam sealant backing is non-absorbent to liquid water and gas and should not emit gas upon mild heating as this can cause bubbling of the sealant. Generally, this sealant backing material is used where the joint opening width is constant with little variation. A closed cell sealant backing is usually made from a polyethylene material, but also from neoprene, butyl or EPDM and combinations thereof. It is extruded usually into various size cylindrical or sheet shapes that have a surface skin. Due to its closed cell structure this sealant backing has a low density and is less easily compressible into place than an open cell sealant backing. However, the closed cell structure tends to not wick and retain water that may infiltrate behind the sealant joint or through other system deficiencies. However, if proper workmanship is not employed during installation, the surface skin of the backing can be punctured and the backing can out-gas into an uncured sealant producing voids and other defects in the cured sealant. This condition can result in water infiltration and compromise the ability of the sealant to accommodate movement. Test Method C 1253 can test sealant backing for outgassing potential; however, it tests the outgassing potential of a purposely punctured sealant backing. A condition that this method will not identify is a closed cell sealant backing that has a thin skin that following installation subsequently ruptures due to environmental conditions. Caution should be exercised when installing this sealant backing to avoid puncturing it or causing excessive compression. Closed cell sealant backing that is uncompressed should have a width approximately 25 to 33 percent greater than the joint width. This will ensure adequate compression when in place, so that it will not fall out of the joint before sealant application or be displaced deeper into the joint opening when the sealant is tooled against it.

9.3.3 Bicellular Foam—This sealant backing is normally made from a polyolefin or polyethylene material which is extruded typically into various size cylindrical shapes that have a surface skin. It has an open cell structure with a surface skin. Due to its surface skin, it has the water absorption characteristics primarily of a closed cell sealant backing; however, the cut ends can wick and retain water. Due to its combination of open and closed cell core, if the surface skin is punctured this backing will not out-gas into an uncured sealant. However, the skin can wrinkle or fold over when installing the sealant backing into a joint opening if it is over sized for the opening or installed by pressing inward on one side of the sealant backing. Folding over of the bicellular sealant backing will result in a sealant profile that may not be conducive for optimum movement performance. It is useful for textured or rough substrate surfaces like some exposed aggregate precast concrete, where skin puncturing is likely.

9.3.4 Others—Some joint applications may require use of an elastomeric material, such as butyl, EPDM, neoprene, or other polymers fabricated into an appropriate shape. These materials can be formulated as a closed-cell, sponge or dense

rubber gasket. The gasket may then function as sealant backing. The performance properties of these other materials are usually matched to a specific application. For example, in pedestrian walkways, the sealant backing may have to be a high-density material to assist in resisting the impact of a high heel shoe on the sealant surface. Use of these materials is dependent upon appropriate compatibility testing of a particular gasket with the proposed sealant (See 5.4.1). Additionally, a bond breaker tape may be required to separate the gasket from the sealant and prevent three-side adhesion from developing.

9.4 Shape and Form:

9.4.1 Round—This shape is the most commonly used for butt type sealant joints. It creates a concave inboard face on the sealant. The various types of sealant backing materials are produced in several diameters for application in a variety of joint opening widths.

9.4.2 Rectilinear—Some sealant applications may require a square or rectangular shape sealant backing. As an example, a horizontal expansion joint in a masonry wall may require this shape to appropriately accommodate wall flashing and sealant (17). A sealant joint that is wide and shallow will often use this shape. To accommodate installation, a pressure sensitive adhesive and release paper can be applied to one face.

9.4.3 Triangular—A fillet type sealant joint is most effective if a triangular shaped sealant backing is used at the root of the joint (18). To accommodate installation, a pressure sensitive adhesive and release paper can be applied to one face. Triangular sealant backing can be fabricated from open cell polyurethane or closed cell polyethylene foam. Some manufacturers provide quarter-round sealant backing in lieu of triangular.

9.5 Application:

9.5.1 Vertically Oriented Surface—A surface that is sloped from vertical no more than 15 degrees is generally considered as vertical. One that is sloped more than 15 degrees should be considered as a horizontal surface relative to choice and use of sealant backing (See 9.5.2). Open cell, closed cell, and bicellular sealant backing can be used for a joint in a vertical surface. Choice of material, and its cellular structure, is dependent on a particular application. Water absorption characteristics of a sealant backing may be a deciding factor. Water saturated sealant backing has been identified as a cause of sealant adhesion loss and, in some cases deterioration of a sealant, when in prolonged contact with it.

9.5.2 Horizontal Surface—Sealant backing for joints in floors, pavements, sidewalks, plazas, patios, and other light traffic areas is generally made from extruded closed cell, high density foam, resin impregnated fiberboard, or elastomeric tubing or rods. The sealant backing material should have at least the following properties. It should remain resilient to temperatures as low as -26°C (-15°F); should exhibit good compression recovery; should not out-gas, caused by heating or rupturing, resulting in the formation of voids in the sealant; and should not absorb water. In addition, it should be capable of providing support for the sealant in traffic areas. A sealant backing can support the sealant in a narrow horizontal joint seal subject to pedestrian or vehicular traffic. For a joint more

than 50 mm (2 in) wide, a metal plate with a bond breaker is normally used under the sealant to support it, especially when the sealant is used for vehicular traffic (See Fig. 1). Sealant backing and joint filler should not exude liquids under compression, as this could exert sufficient hydraulic pressure to cause sealant failure by forcing the sealant from the joint opening. Various combinations of sealant backing and joint filler are often used to satisfy the several requirements of a horizontal joint seal. For example, premolded joint filler may be used to form a joint opening in concrete. At sealant installation time, the recess above the joint filler may be wet and contaminated or the joint filler may not be compressed against the substrates, due to shrinkage of concrete or thermal movement of the joint opening, permitting loss of sealant if a self-leveling type is used. The problem may be resolved by allowing a greater recess above the premolded joint filler, or by using a joint filler with a removable strip. The strip is removed, replacing it with an additional sealant backing under compression, across the joint opening width, and to the proper depth, just prior to application of the sealant (See 14.1.5.3 and Fig. 1).

9.5.3 *Temporary Joint Seal*—Sealant backing can function as a temporary joint seal for weather protection when conditions are unsuitable for immediate sealant application. As a temporary joint seal, it is subject to weathering, and normally should be replaced prior to sealant application with a new permanent sealant backing. In some cases, the temporary sealant backing may be suitable for use as a permanent sealant backing. The following conditions, however, would render it unsuitable and necessitate replacement with new material; if it becomes wet; if it becomes dirty or otherwise contaminated; if it takes a compression set and will not remain in place under tooling pressure; if its surface has been damaged or ruptured or punctured during the cleaning operation prior to sealant application. If the intent is to use the temporary sealant backing as a permanent sealant backing, and there is a question as to its suitability, the sealant manufacturer should be consulted for a recommendation.

10. Joint Filler

10.1 *General*—Use of a joint filler is frequently encountered in concrete and masonry construction to form, for example, an expansion, control, or isolation joint. Frequently, the joint is deeper than the thickness that results from the sum of the sealant depth and its (usually round) sealant backing. The remaining joint depth is occupied with a permanent joint filler. Materials typically used for the joint filler include closed-cell polyethylene for masonry joints and compressible asphalt impregnated cane fiber for concrete joints subject to traffic. These materials are fabricated into the desired shape, usually rectilinear.

10.2 *Function*—The joint filler can provide additional support for the sealant and its sealant backing when a joint occurs in a horizontal surface subject to traffic. Additionally, in masonry wall construction, it can be installed as the masonry is constructed to preclude mortar droppings from occupying the joint opening. Mortar droppings in a joint opening are incompressible and will prevent a moving joint from properly closing due to thermal or other movements. The joint filler also needs to be compressible enough to avoid restricting joint movement.

11. Bond Breaker

11.1 *General*—A bond breaker should be used to prevent adhesion of a sealant to any surface or material on which adhesion would be detrimental to the performance of the sealant (See Fig. 2). A bond breaker is normally a self-adhesive, pressure sensitive tape, usually made from a TFE-fluorocarbon or polyethylene material, to which a sealant will generally not adhere. The use of duct tape as a bond breaker material is unacceptable. A material impregnated with oil, bitumen, a non-curing polymer, or similar deleterious material should also not be used as a bond breaker. A bond breaker has very low or no adhesion to a sealant thereby avoiding a three-side adhesion condition. Liquid-applied bond breaker is not recommended due to the difficulty of installing it on the intended surface without contaminating the sealant adhesion surface. A bond breaker should be applied to the bottom of a

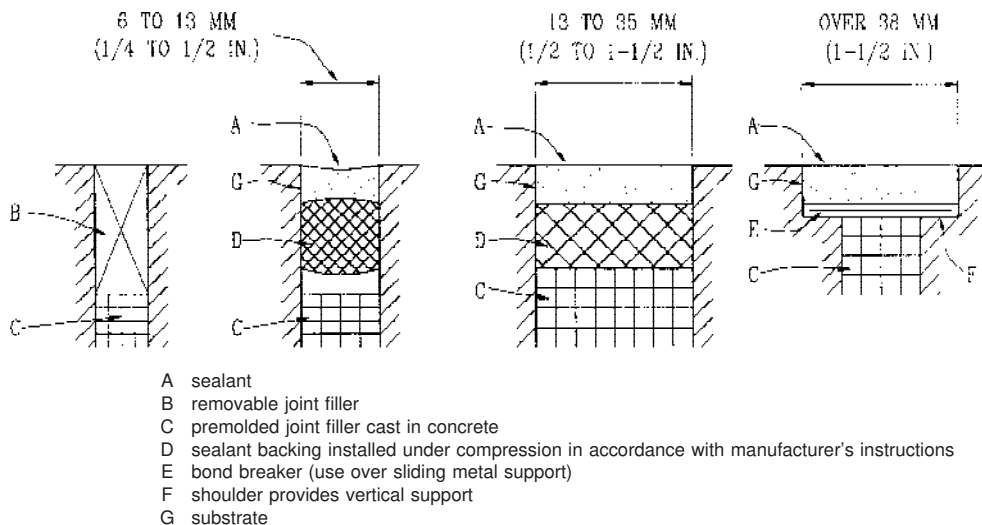


FIG. 1 Use of Sealant Backing and Joint-Fillers in Horizontal Applications

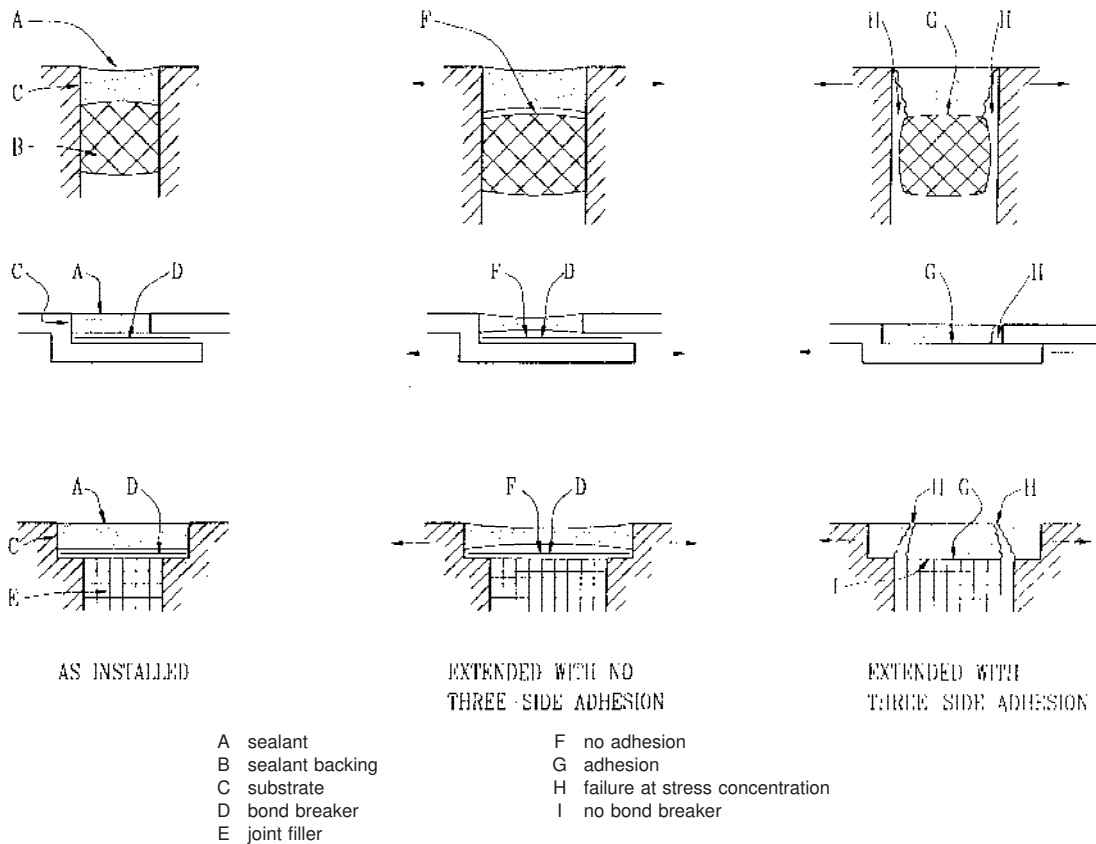


FIG. 2 Sealant Joint Configurations Experiencing Movement and Illustrating Effect of Three-Side Adhesion

joint containing a rigid, non-flexible sealant backing material or to a raked mortar joint to preclude the possibility of the sealant adhering to these materials and forming detrimental three-side adhesion where movement will occur. A bond breaker is not required to prevent a sealant from adhering to a soft, flexible, open cell sealant backing material that would not significantly restrict the freedom of movement of a sealant. Typically, they are also used where dimensional constraints preclude the use of a conventional sealant backing. Frequently, in remedial sealant work a bridge type sealant joint is required, wherein a bond breaker tape is used to separate an old sealant from the new and to permit the designed movement capability of the new sealant (19).

11.2 *Compatibility and Adhesion Testing*—When bond breaker tape is required for an application, its compatibility (See 5.4.1) and lack of adhesion with a sealant should be confirmed by testing. Instances have occurred, wherein a newly developed sealant formulation has had detrimental adhesion to a previously acceptable bond breaker material. Sealant manufacturers are continually improving the adhesion characteristics of their products which, in some cases, may result in a sealant adhering to a bond breaker tape of a particular material or formulation. Bond breaker tape and sealant manufacturers can provide information on the use of particular products from each manufacturer and compatibility and lack of adhesion characteristics when used in combination. If reliable and current information is unavailable, a simple adhesion test can be performed either in a laboratory or at a project site.

11.2.1 *Adhesion Test Method*—A sample of the substrate for the project or any suitable size substrate that the sealant will adhere to is acceptable. A 100 mm (4 in) length of bond breaker tape is applied to a properly prepared and cleaned substrate surface. On the bond breaker tape and substrate, a thin rectangular layer of sealant about 3 mm (1/8 in) thick, a minimum of 50 mm (2 in) long, and wider than the tape by at least 25 mm (1 in) on each side of the tape, is applied and tooled crosswise to the tape. The sealant is allowed to cure as recommended by the sealant manufacturer. Using a finger, the sealant is lifted from the surface of the tape. If there is no adhesion of the sealant to the bond breaker, the sealant will readily lift from the tape surface while remaining adhered to the substrate surface. If there is resistance to separation of the sealant from the tape surface it may not be appropriate for a particular application. If the sealant adheres to the tape it is unacceptable for use as a bond breaker material.

12. Liquid-Applied Sealant

12.1 *General*—A liquid-applied sealant is classified as a single-component or multi-component material and of a non-sag or a self-leveling formulation. The tack-free time and cure time of a sealant may be important sealant selection criteria. It may be necessary, depending on the application, to use a sealant with a relatively quick tack-free time to preclude surface damage to the sealant or to limit dirt pick-up at a construction site.

12.2 Cure Time—The cure time of a sealant should always be considered. Depending on the application, a fast cure single-component, a multi-component, or a precured sealant can be recommended depending on the curing circumstances required. A sealant with a relatively slow cure time when placed in a joint that is affected by relatively rapid dimensional change, that is usually thermally induced, may be exposed to movement-during-cure (See 12.5). Typically, rapid dimensional change occurs with a material that has low thermal mass and dark coloration such as a dark anodized aluminum curtain wall. A sealant joint in a material that has high thermal mass, such as a concrete or masonry wall, will have a dimensional change that is slower and cure time can be less critical. Some sealants are especially sensitive to the level of ambient humidity. In climates with a low relative humidity, the selection of a sealant requiring atmospheric moisture for curing may result in an extended cure time which is a known cause for early failure due to sealant movement-during-cure. If cure time is an important consideration, a particular sealant and joint design should be evaluated for suitability to the application.

12.3 Type:

12.3.1 Single-Component—A single-component sealant requires no mixing and is furnished typically ready for application in a tube or sausage-shaped package and occasionally in a bulk container. Typically, the cure time of a single-component sealant is longer than that of a multi-component sealant, since atmospheric moisture is usually required for curing of the sealant. The quantity of available atmospheric moisture is highly variable depending on the time of year and geographic location of an application. A single-component sealant is purposely formulated for a slower cure time for packaging reasons (to increase shelf life). Generally, use of a single-component sealant, in an arid or desert region, is discouraged by sealant manufacturers, since complete cure may not be attained in a reasonable period of time.

12.3.2 Multi-Component—A multi-component sealant is mixed at the project site just prior to application. Typically, the components in two, or in some cases three, containers are combined. A principal advantage of a multi-component sealant is a relatively rapid cure time after mixing, since all the ingredients for curing of the sealant are contained within the combined components. Disadvantages include the inconvenience of mixing by an applicator and a concern that the components will not be thoroughly and properly mixed. A frequently encountered mixing problem is the introduction of air into the mixture by improper use of the mixing equipment. Failure to mix the components in accordance with the manufacturer's instructions will result in the sealant not attaining its intended performance properties. Improper mixing can also trap air bubbles in the sealant. Proper mixing usually requires a slow-speed mixing device, mixing for a designated period of time, and periodic scraping of components from the side and bottom of the container. To guard against inadvertent spills of sealant components, mixing should occur on a disposable surface such as a tarp.

12.4 Formulation:

12.4.1 Modulus—The term modulus, when used for a liquid-applied sealant, is defined as stress at a corresponding

strain (elongation). The strain is expressed as a percent of the original at-rest dimension. For example, a sealant having a stress of 689 kPa (100 psi) at 50 % strain would be called a 689 kPa (100 psi) modulus sealant. This usage is not in accordance with standard engineering terminology where modulus is the ratio of stress divided by strain. For practical purposes, it is a qualitative measure of the relative stiffness of a cured sealant; and indirectly, the level of stress created at the adhesion surface when the sealant is in extension. When a sealant is in extension for an extended period of time, tension modulus becomes an important consideration. For example, when a sealant is adhered to a concrete substrate, and the sealant joint is in extension, the tensile strength of the concrete must be greater than the tensile strength of the sealant otherwise failure of the substrate, by cracking or spalling, is a distinct possibility. The modulus of a sealant should be matched to the characteristics of the substrate to which it is adhered. The sealant industry has generally categorized a sealant as having a low, medium, or high modulus. One must be cautious when reading a manufacturer's literature since these designations have no standardized meaning. What one manufacturer may describe as a low modulus sealant another might describe as a high modulus. The best assurance the user has is to be aware of the level of stress created at the adhesion surface by joint movement when comparing different sealant products. There is also a compression modulus, which is related to the force that is produced when a joint is in compression. A sealant that is very hard or stiff can exert an unacceptable force on the adhesion surface when a joint experiences compression and, in some instances, causing failure of a friable substrate by spalling.

12.4.1.1 Low—A sealant in this category usually has a relatively high movement capability. However, modulus is independent of movement capability and a low modulus sealant implies that when extended it creates a relatively low stress at the sealant and substrate interface. There are applications where this is desirable. For instance, a substrate that is relatively low in tensile strength or with an EIFS substrate.

12.4.1.2 Medium—A sealant in this category is used for general purpose joint sealing applications. A medium modulus sealant represents the majority of elastomeric products that are used in the sealant industry. They are used for joints that experience movement and for other general sealing applications.

12.4.1.3 High—A sealant in this category is typically not used for joints that experience movement, since, when in extension, a relatively high level of stress can occur at the sealant and substrate interface. It is often used as a glazing sealant wherein glass or other panels are sealed into a framing system and expected movement is low. There can be a high modulus sealant with a high elongation characteristic; however, in extension it will exert a very high force on the sealant adhesion surface, thus requiring a good quality and strong substrate and very strong and durable sealant adhesion to the substrate. When using a high modulus sealant, care should be taken to develop an adhesion surface depth sufficient to not exceed the sealant adhesive strength or the strength of the substrate surface when the sealant is experiencing joint extension.

12.4.2 Movement Capability—A liquid-applied sealant meeting Specification C 920 is rated for cyclic movement capability using Test Method C 719. Typical sealant movement ratings, as described by Specification C 920, are class 12 ½ and 25. The class designation indicates that a sealant has the capability of $\pm 12\frac{1}{2}$ and ± 25 percent movement (\pm means plus and minus). For example, using a class 25 sealant, a joint that is 13 mm ($\frac{1}{2}$ in) wide when installed is capable of compression to 10 mm ($\frac{3}{8}$ in) and extension to 16 mm ($\frac{5}{8}$ in) without experiencing adhesive or cohesive failure. This class designation convention differs from that used by many other countries. A liquid-applied sealant meeting Specification C 1311 is rated as having a $\pm 7\frac{1}{2}$ percent movement capability, and for those meeting Specification C 834 no movement rating is assigned. These ratings are determined in a controlled laboratory under ideal circumstances. The ability of a sealant to exhibit its full movement capability, in a typical application, is also a function of proper sealant joint design, appropriate substrate cleaning and, if required, priming, correct installation of the joint components, and satisfactory sealant installation and tooling. A sealant can rarely develop its full movement capability in a typical application. The natural phenomena of continuation of sealant cure, long-term weathering, and movement during sealant curing will result in lesser capability than its manufacturer-documented movement capability. Therefore, the informed joint designer will use a sealant at less than its rated movement capability as determined by C 719.

12.4.3 Non-Sag—A non-sag sealant is a gunnable type for building joint application and is furnished as either a single- or multi-component compound. Although referred to as non-sag, the sealant may exhibit sag characteristics under certain conditions of temperature and joint width (See 5.8.2). Sag or slump limitations are established by Specification: C 834, C 920, or C 1311. Generally, a non-sag sealant is designed to not sag in a vertical application at ambient temperature up to 50°C (122°F).

12.4.4 Self-Leveling—A self-leveling sealant also may be a single- or multi-component compound. It is used for joints in horizontal applications and is formulated to self-level at an ambient temperature of 4°C (40°F) or higher. Although a non-sag sealant may be used for horizontal applications such as deck joints, the self-leveling type is easier to install since it is poured into the joint opening and normally does not require tooling. If the slope of the horizontal surface is too great, a non-sag sealant may be required to avoid having the self-leveling sealant flow downhill under the influence of gravity. A self-leveling sealant is, by necessity, held to a level slightly below the horizontal surface to avoid overflow when pouring and to accommodate a cured sealant bulge when a joint is in compression. This may be objectionable and should be considered in the design of the joint. A non-sag sealant that can be tooled flush, but concave, with the horizontal surface may be preferable aesthetically and to help avoid surface abrasion when compressed (See 14.1.8).

12.4.5 Extrudability—A sealant, whether single- or multi-component, is formulated to have certain extrusion characteristics at a specified application temperature established by Specification: C 834, C 920, or C 1311. A sealant not extruding

properly should not be used since this may indicate poor quality, lack of package stability, or insufficient working life.

12.4.6 Conditioning—A sealant has an optimum temperature range for handling, which can vary considerably depending on the type of sealant. The sealant should be stored at a temperature within this range for at least 16 hours before use. When the ambient temperature at the joint opening is below the sealant storage temperature, the sealant should be used as quickly as possible since a low sealant temperature can result in a very long working life for a multi-component sealant. Conversely, when the ambient temperature at the joint opening is above the sealant storage temperature, the sealant should be used as quickly as possible since a high sealant temperature can result in a very short working life for both a single- and multi-component sealant.

12.4.7 Painting—Most sealants can be painted with water or oil-based paint after the sealant has cured. However, some cannot (See C 1299). Most silicone-based sealants are not paintable. Consult both the sealant and paint manufacturers before painting. Other types of sealants are generally paintable, but the manufacturer's recommendations should be followed. The best practice is to allow the sealant to cure several days (the longer the better) before painting. This will allow the sealant to properly develop a surface skin and attain a portion of its performance properties before painting and will reduce paint cracking. Painting a sealant surface too soon after application may retard the sealant rate of cure. However, it should be recognized that most paints would not accommodate as much movement as a sealant can and thus a painted sealant surface cracks and distorts and sometimes delaminates from the surface of a high movement sealant. For those situations, an appropriate solution is to use a sealant of a color suitable to the application and not paint the sealant surface. Sometimes a painted sealant surface can be beneficial. The paint coating becomes a barrier to ultraviolet radiation preventing it from reaching a sealant susceptible to its degrading affects and lessening its durability as time progresses.

12.5 Movement-During-Cure:

12.5.1 Damage Potential—The potential for damage is real and the resultant damage can be severe. Movement-during-cure can create numerous forms of damage to a sealant joint. Depending on conditions, movement-during-cure can cause adhesive or cohesive failure shortly after installation (catastrophic damage); or, with less severe conditions, can reduce the movement capability of the cured sealant, sometimes without obvious change to its surface appearance. Research has described various types of damage that a sealant can experience when there is movement-during-cure (20-24). Wrinkles, cracks, and bulges can form in the sealant surface. Early joint extension tends to crack the thin film of sealant (skin) that can form on some sealant formulations. Joint compression and cycling tends to create bulges, wrinkles and permanent sealant profile deformation from that intended. Unfortunately, damage can occur within the sealant that is not always visible on its surface. Voids can be created within the sealant. On the interior facing surface of the sealant (sealant backing face), cracks can develop. Sometimes they form near the sealant's adhesion to the substrate, since the uncured sealant may adhere (albeit at a

low level) to the sealant backing or bond breaker tape, concentrating stress and strain in the uncured sealant at the edge of the backing.

12.5.2 Potential Causes—Damage from movement-during-cure is a complex condition that depends upon a large number of potential causes. These include, among others, time of day of sealant installation, direction of initial joint movement (i.e. compression or extension), magnitude of the movement, and number of movement cycles. Additional potential causes include rate of sealant cure, nature of sealant cure, solar exposure, climatic conditions, humidity level, an inadequately designed or installed joint, and orientation of a joint. The joint designer should consider these conditions, when determining a particular joint design. Generally, the magnitude of joint movement and the sealant cure rate are the two most important factors to evaluate for the development of a movement-during-cure condition. A sealant joint that is inadequately designed or installed undersized is especially prone to a movement-during-cure condition. The movement capability of an inadequately designed or installed joint is usually smaller than planned. Therefore, movement-during-cure represents a larger percentage of planned movement capability of the cured sealant joint resulting in an even greater risk of detrimental movement-during-cure.

12.5.3 Test Method Limitations—A sealant joint experiences movement on a facade due to thermal, moisture, or other effects (See 12.5.2). This movement occurs when sealant is applied in a joint, while the sealant is curing in the joint, and after the sealant has cured. Unfortunately, current ASTM test methods use cured sealant test specimens and do not yet evaluate the impact of joint movement that may occur while the sealant is curing.

12.5.4 Sealant Type and Cure Rate—A sealant that requires a relatively long time to cure to an elastomeric rubber, will have an increased chance of more and larger movements during cure. A low environmental temperature typically prolongs sealant cure time. A low environmental humidity also tends to prolong the cure time of a single component sealant that requires atmospheric moisture for the curing reaction. Also, a sealant that forms a skin during cure is more prone to splitting (cohesive failure) during joint extension, since stress and strain from the movement are concentrated in the skin while the sealant is curing. These factors typically increase the risk of encountering a movement-during-cure condition during a cool season and in a dry climate.

12.5.5 Damage Assessment:

12.5.5.1 General—Damage from movement-during-cure can arise in a newly sealed joint or during mock-up evaluation of a sealant joint. It may be necessary to evaluate the level of damage by physical observation or laboratory test.

12.5.5.2 Physical Observation—A qualitative assessment of sealant damage and a quantitative assessment of the extent of such damage can be made by evaluating the exterior surface of the sealant for defects, such as cohesive or adhesive failure or bulging. Additionally, samples of the sealant can be removed from the joint to evaluate for the presence of internal voids or concealed adhesive or cohesive failure. Unfortunately, other than by experience, there are no industry guidelines for

correlating observed damage to a percentage reduction in cured sealant movement capability without performing laboratory tests.

12.5.5.3 Laboratory Tests—The preferred method of assessing the impact of sealant damage is to remove samples of the sealant and substrate from the construction. The samples can then be tested using Test Method C 719. Sealant cycling by this method will assist in determining a new joint movement capability rating. If the substrate cannot be removed, then it may be possible to carefully and neatly cut a full width sealant sample from the substrate and re-adhere it to another substrate in the laboratory, using a thin layer of sealant. A C 719 cycling test can then be performed. This approach would not be viable if a sealant defect(s) occurs near the sealant adhesion surface, which would be disturbed during the sealant removal process.

12.5.6 Joint Movement:

12.5.6.1 General—An important variable is the amount of joint movement that is likely to occur while the sealant cures. As an order-of-magnitude guide, there is significant risk of catastrophic failure if the joint movement-during-cure is 35 percent or more of the cured sealant movement capability. As an example, a 13 mm (1/2-in) wide joint with a sealant that has a C 719 established movement rating of ± 25 percent has a cured movement capability of ± 3 mm (1/8 in). If a sealant experiences movement-during-cure of 1.5 mm (1/16 in) this could represent a serious risk to the sealant depending on its formulation and polymer backbone. Laboratory studies have found that severe movement-during-cure can reduce the cyclic movement capacity of a cured sealant joint by as much as 50 percent.

12.5.6.2 Use of a Mock-up—At a lower level of movement-during-cure, it is prudent to evaluate the risk of a problem using an in situ or laboratory mock-up, or both, to evaluate the sealant before its installation at the project site. A movement indicator (sometimes referred to as a scratch plate) can be installed prior to installation to record actual joint movement. A field mock-up is preferable to a laboratory mock-up, since it is more likely to be representative of the actual environmental and movement conditions, unless installed too far in advance of the actual installation of the sealant. If that occurs, a laboratory mock-up may be able to simulate the actual environmental conditions. However, it should be realized that there are no standard test methods yet for movement cycling of a sealant joint during cure to simulate actual environmental conditions.

12.5.6.3 Thermal Movement—Typically, the largest source of movement-during-cure is due to thermal movement. A substrate material's surface temperature is a result of the interaction of two general components, ambient air temperature and solar radiation heat gain. The annual difference in air temperature (winter to summer) in much of the United States ranges from about 90°C (50°F) in warmer regions to 100°C (180°F) in colder regions. Solar radiation heat gain of a substrate material ranges from about 90°C (50°F) for a light-color, high heat capacity material to about 180°C (100°F) for a dark-color, low heat capacity material. Thus, depending upon the characteristics of a wall or other system in which the sealant is installed, and its geographic location, the solar

radiation heat gain component can be generally 33 to 66 percent of the total thermal movement. If all of the movement at a joint, after cure, is due only to thermal movement, then there is frequently a significant risk of major sealant damage due to movement-during-cure. As an example, a sunny day, in these situations, can create 35 percent or more of the cured joint movement capability by warming the substrate material. The most commonly encountered severe condition occurs with a dark-color, low heat capacity material, such as a wall system of bronze color, aluminum wall panels.

12.5.6.4 Movement Combinations—For a sealant joint that experiences combined movement from thermal and moisture change or structural movement, the relative percentage of cured joint movement due to thermal change is reduced. Thus, a movement-during-cure condition is less likely, since it generally is caused by only thermal movement.

12.5.7 Reducing Movement-During-Cure:

12.5.7.1 General—When significant substrate movement is expected during sealant cure, the following approaches can help reduce the risk of a movement-during-cure condition from occurring. They generally fall into three categories: accelerate sealant cure rate, reduce joint movement, or use a precured sealant.

12.5.7.2 Sealant Cure—Use a sealant that has a fast rate of cure. In general, a multi-component sealant tends to cure at a faster rate than a single-component sealant. Verify sealant cure rates with individual manufacturers for specific products. Some manufacturers allow the addition of small amounts of water when mixing a multi-component sealant to accelerate its cure rate. This should only be done on the written advice of the sealant manufacturer. Some sealant manufacturers produce a fast cure single-component sealant and some have test data on the effects of movement-during-cure for their various products. The sealant manufacturer can make a sealant recommendation, based on the test data, for a particular application that involves movement-during-cure.

12.5.7.3 Sealant Backing—Use open-cell sealant backing to allow air (and its water vapor) to reach both surfaces of the joint to promote cure from both surfaces. Open-cell sealant backing may be inappropriate if there is a risk of future liquid water retention in the sealant backing, resulting in possible premature deterioration of the sealant, the joint seal, or adhesion of the sealant to the substrate.

12.5.7.4 Joint Movement—If appropriate to the joint design, alternate joint openings can be blocked to temporarily prevent compressive movement. Doing so results in that movement being shifted temporarily between alternate joints. Sealant can then be installed in the blocked joints, and following appropriate cure of the sealant, removal of the blocks. This procedure is then repeated for the previously unblocked joints. Another approach is to delay sealant application until after the structure is in the shade and has cooled or during cloudy or more temperate days. Shade can be created using tarps and other shading devices, if feasible. Lastly, if consistent with a particular building's aesthetic intent, a joint design can be made larger than that determined by calculation using Guide C 1472 if significant movement-during-cure is expected.

12.5.7.5 Precured Sealant—A precured sealant generally is available as a gasket or compression seal, rectilinear sheet, and a molded three-dimensional shape. There are several manufacturers that make precured, preformed gasket and compression seal shapes that can be used in lieu of a liquid-applied sealant. In general, they can be installed in the joint opening under compression or can be adhered to the joint substrates with an epoxy adhesive. Liquid-applied sealant manufacturers have developed precured, rubber sheet extrusions and molded forms that can be adhered with a thin layer of an adhesive-sealant to a substrate surface (25-28). The adhesive-sealant used for a precured sealant will typically cure rapidly. A precured sealant has been used successfully, when other techniques are not possible, to seal joints that would experience detrimental movement-during-cure for a liquid-applied sealant.

13. Precured Sealant

13.1 General—Presently, there is no specification that describes preformed silicone sealant extrusion minimum required performance properties. These products are increasingly being used in remedial sealant applications for the repair or replacement of failed liquid-applied sealant joints (See Fig. 3) (29). They are especially useful when repair or replacement is not possible with a liquid-applied sealant or the joint opening is deficient for movement capacity and can not be economically enlarged. They have also proved very beneficial in sealing of window, curtain wall, and skylight systems that have exhibited premature deterioration and developed water leakage. Additionally, they are useful for joints that experience large movement during cure. A precured sealant is formulated and extruded by the manufacturer to provide a product with a low modulus. The low modulus of the precured sealant, when in extension, creates a low state of stress at the interface of the precured sealant with the thin layer of adhesive-sealant adhering the assembly to a substrate. This characteristic makes these products most appropriate for use on a weak substrate such as EIFS and some stones for example, sandstone. Use of these products in such situations is generally referred to as “face sealing.” A precured sealant is generally not recommended for use on a horizontal surface subject to traffic (unless protected) or for a below grade application.

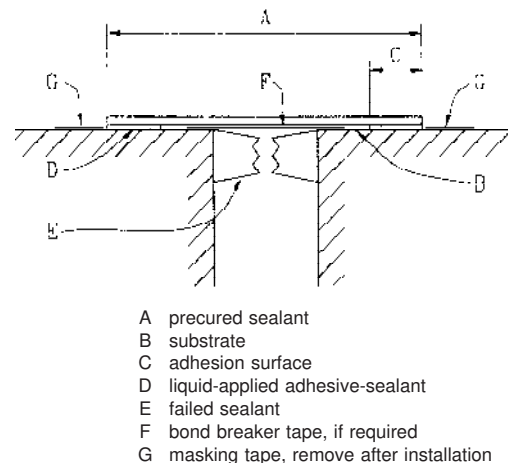


FIG. 3 Cross-Section of a Typical Precured Sealant Extrusion Application

13.2 *Type*—Generally, a precured sealant is extruded as a rectangular profile in a ribbon like shape. A precured extruded sealant is generally available in several manufacturer stocked widths such as, 25, 38, 50, 75, and 102 mm (1, 1-½, 2, 3, and 4 inches). The precured sealant is generally packaged as a roll typically about 30 m (100 ft) long. Thickness is determined by the sealant manufacturer; however, they are generally available in at least a 2 mm (1/16 in) thickness. Depending on manufacturer and application they can be extruded with a series of ribs to assist in obtaining adhesion of the adhesive-sealant to the precured sealant. Other shapes (e.g. accordion) are also available as well as molded corners and intersections. Depending on the application, a manufacturer will extrude or mold a custom shape, provided there is sufficient quantity. To obtain continuity of seal, a molded shape is typically adhered to a ribbon-like shape using a compatible liquid-applied adhesive-sealant. A preformed sealant extrusion or shape is adhered to a substrate surface also using a compatible liquid-applied adhesive-sealant. The same concerns indicated in 7, relative to substrate cleaning, and 5.3 relative to adhesion, also applies to these products, in particular, for adhesion of the liquid-applied adhesive-sealant to a substrate.

13.3 *Movement Capability*—Sealant manufacturers indicate that precured sealant movement capability is determined primarily by using a modified Test Method such as C 719 or C 1135. Sealant manufacturers rate the movement capability of a precured sealant extrusion, generally, as a plus and minus value. Presently, movement capabilities of up to +200 % and -75 % are currently available. For example, a +200, -50 product, for a joint application requiring an unadhered width of 25 mm (1 in), could be expected to flex to 13 mm (0.5 in) and extend to a dimension of 50 mm (2 in) without experiencing adhesive or cohesive failure of the adhesive-sealant. The ability of a precured sealant to exhibit its full movement capability, in a typical application, is also a function of proper joint design, appropriate substrate cleaning and, if required, priming for the adhesive-sealant, and satisfactory adhesive-sealant and precured sealant installation and tooling.

13.4 *Environmental Conditions*—A precured sealant has few environmental restrictions relative to its use; however, an adhesive-sealant that adheres a precured sealant to a substrate has the same environmental concerns as a liquid-applied

sealant. Wet or damp substrates and the possibility of rain are conditions that must be recognized (See 5.8).

13.5 *Color*—A precured sealant, depending on manufacturer, is available in several standard colors. Custom colors are usually available, however only by a minimum quantity order.

13.6 *Painting*—If a precured sealant is formulated with a silicone polymer, painting or coating it with conventional paints or coatings is not recommended. Doing so generally results in paint or coating delamination from the precured sealant surface. As a result, it is not capable of being reliably painted with anything but a silicone-based paint or coating.

14. Sealant Joints

14.1 *Liquid-Applied:*

14.1.1 *General*—A liquid-applied sealant is usually installed in one of three general configurations; butt joint, fillet joint, and bridge joint. The design geometry of these joint seals is related to numerous factors, including desired appearance, spacing of joints, anticipated joint movement, sealant movement capability, substrate layout, and tooling method, among others. Figs. 4-6 indicate some typical joint seal applications and terminology. The two-stage rain-screen joint in Fig. 7 is designed to vent to the exterior and pressure equalize the chamber between the exterior rain screen seal and the interior air seal (30). For a butt sealant joint, the shape of the sealant (i.e. hourglass, shallow hourglass, shallow rectangular, deep rectangular, and square) can result in differing performance for the same conditions of exposure. An evaluation of butt sealant joint shapes is available in Reference (31)

14.1.2 *Width*—There are several factors to be evaluated when establishing the required width of a liquid-applied sealant joint. Paramount among them is designing the sealant joint for the anticipated movement, construction tolerances, and other effects known to influence the movement capability of a particular application (See 15). Not designing a joint for at least anticipated movement and tolerances often results in failure of the joint as a weather-seal. Other influences affecting the establishment of joint width include desired appearance, spacing of joints, and tooling method. Under no circumstances should a liquid-applied sealant be applied in a joint opening that is less than 6 mm (0.25 in) wide. It is very difficult and impracticable to install sealant effectively in such a small width

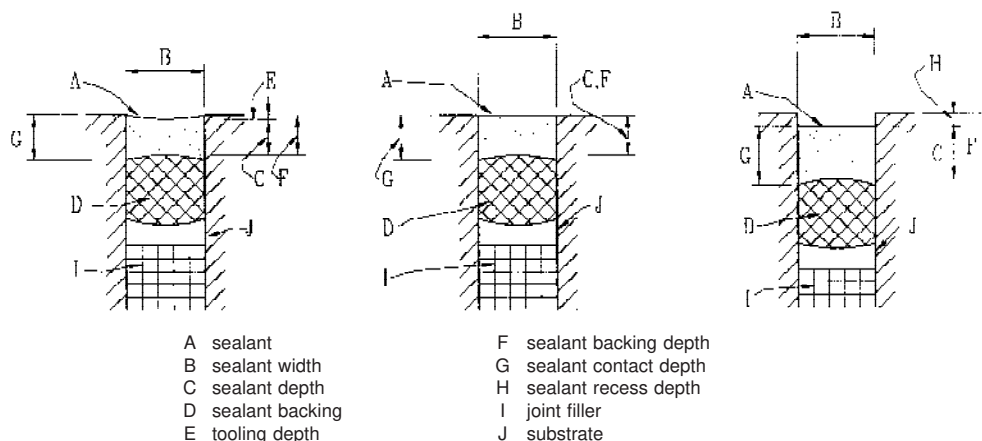
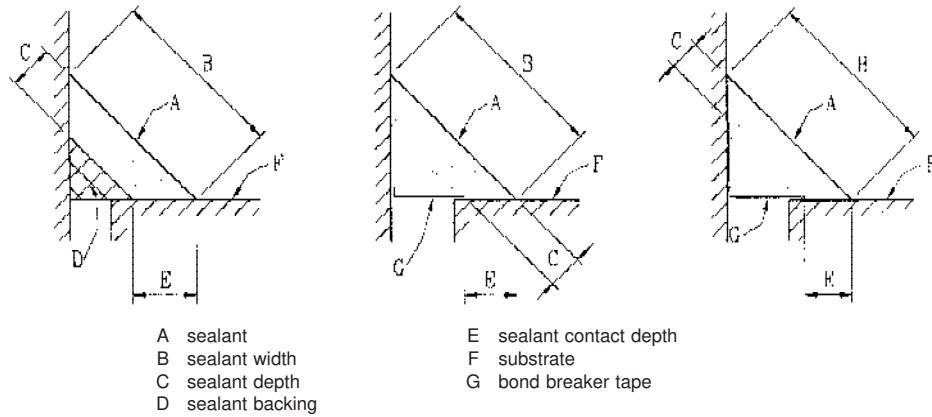


FIG. 4 Typical Butt Type Sealant Joint Cross-Sections



NOTE 1—The sealant surface can be tooled flat as indicated or concave or convex depending on an application's requirements.

FIG. 5 Typical Fillet Sealant Joint Cross-Sections

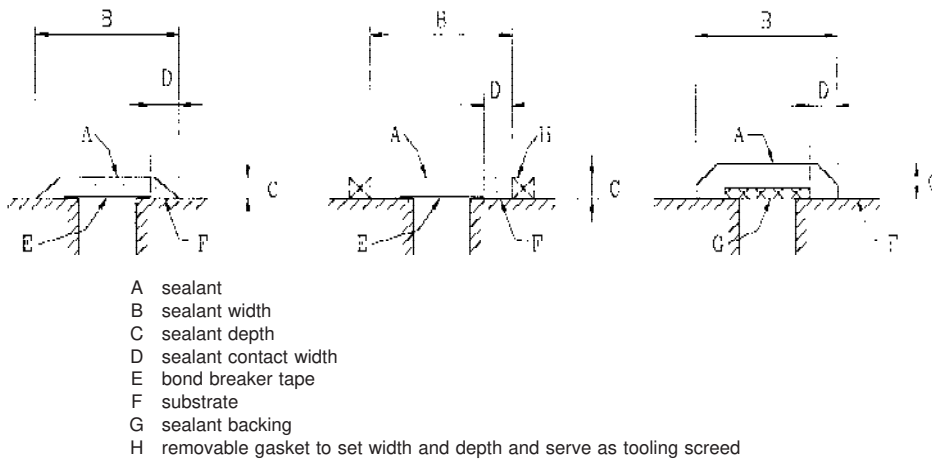
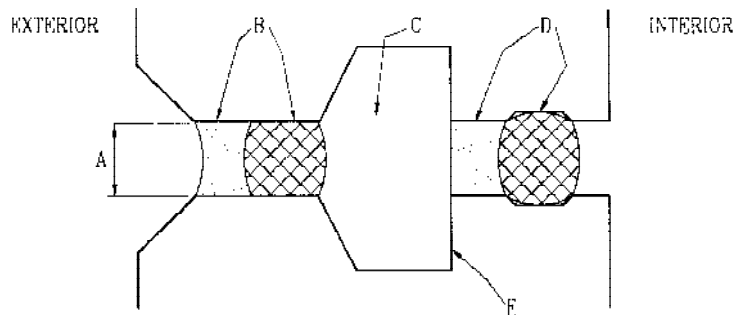


FIG. 6 Typical Liquid-Applied Bridge Sealant Joint Cross-Sections



- A 25 mm (1 in.) minimum for access to interior air seal
- B sealant and sealant backing preferred for rain screen, preformed compression seal also used
- C pressure equalization chamber; vent to outside, with chamber baffles appropriately spaced vertically and horizontally
- D sealant and sealant backing installed from outside to facilitate continuity of air seal; building framework hinders application of continuous air seal from interior
- E shoulders required for tooling screed

FIG. 7 Two-Stage Pressure Equalized Joint Seal

and is generally not recommended by most sealant manufacturers. Generally, for a joint width over 50 mm (2 in) a liquid-applied sealant in a vertical joint may sag before curing.

14.1.3 *Depth*—Sealant depth is dependent on the sealant width determined by calculation, the generic sealant polymer,

and the general sealant joint shape (i.e. butt, fillet or bridge shape). However, the depth of the sealant at the substrate should be no less than 6 mm (0.25 in). A depth less than this dimension, unless recommended by a sealant manufacturer, is difficult to create consistently and can result in less than

adequate sealant adhesion to a substrate. Substrate type, such as a rough and variable finish on a porous substrate, may require a sealant depth greater than the following general guidelines to result in the minimum recommended sealant depth. The manufacturer of the sealant, depending on the requirements of a particular application, can provide a recommended sealant depth. Sealant manufacturers do not agree on the required width-to-depth relationship for a butt type sealant joint; however, generally accepted guidelines are as follows:

14.1.3.1 *Porous Substrate*—For a butt sealant joint in concrete, masonry, stone or similar porous materials, the depth of the sealant may be equal to the width of the joint for a width from 6 to 13 mm (0.25 to 0.5 in). For a width from 13 to 25 mm (0.5 to 1 in) the sealant depth should be one-half the width or 6 to 13 mm (0.25 to 0.5 in). For a greater width, from 25 to 50 mm (1 to 2 in), the sealant depth should not be greater than 13 mm (0.5 in). For a joint width exceeding 50 mm (2 in), the depth should be determined by consulting with the sealant manufacturer.

14.1.3.2 *Non-Porous Substrate*—For a butt sealant joint in metal, glass, or other similar non-porous materials, the depth of the sealant should be 6 mm (0.25 in) for a joint width from 6 to 13 mm (0.25 to 0.5 in). For a width from 13 to 25 mm (0.5 to 1 in) the sealant depth should be no more than one-half the width up to a maximum of 9 mm (0.375 in). For a greater width, from 25 to 50 mm (1 to 2 in), the sealant depth should not be greater 9 mm (0.375 in). For a joint width exceeding 50 mm (2 in), the depth should be determined by consulting with the sealant manufacturer.

14.1.4 *Sealant Joint Type:*

14.1.4.1 *Concave Butt Joint*—In general, for a joint that will experience movement, this is the preferred sealant profile (See Fig. 8A). When sealant is tooled over a conventional round sealant backing, an “hourglass” sealant profile is established, which during joint movement, shifts the peak stresses away

from the adhesion surface and into the middle of the sealant joint. This is the most commonly encountered liquid-applied sealant joint profile.

14.1.4.2 *Flush Butt Joint*—For this joint, a sealant is tooled flat and flush with a substrate surface (See Fig. 8B).

14.1.4.3 *Recessed Butt Joint*—This joint design is similar to a flush joint except that the exposed sealant surface is recessed from the exposed substrate surface (See Fig. 8C). This profile can be difficult to tool with joint openings that vary in width. This profile is often used for a joint in a horizontal surface that is subject to pedestrian or vehicular traffic. Recessing the sealant allows the joint opening to close due to movement and the induced bulge in the sealant remains below the level of the substrate surface. When properly designed this does not present a tripping hazard to passersby.

14.1.4.4 *Fillet Joint*—A fillet sealant joint is often encountered in remedial sealing work (See Fig. 5). Frequently it is used because a conventional butt type sealant joint is not applicable (32). This can be a result of improper initial joint design or construction and the impracticability of enlarging an opening to install sealant in a butt type joint opening. Additionally, it is also used on uncapped ends of hollow extrusions where there is inadequate surface area for a conventional butt sealant joint.

14.1.4.5 *Bridge Joint*—When installed using a liquid-applied sealant, a layer of sealant, depending on generic polymer and applicator skill level, is placed over the joint opening from 3 to 6 mm (1/8 to 1/4 in) thick (See Fig. 6). As for a fillet joint, this profile is frequently used in a remedial sealing application to correct a failed joint when a butt type sealant joint is impractical. They also find frequent use, in combination with an appropriately sized bond-breaker, to correct failed lap joints in metal cap flashing and other similar applications.

14.1.5 *Sealant Joint Application:*

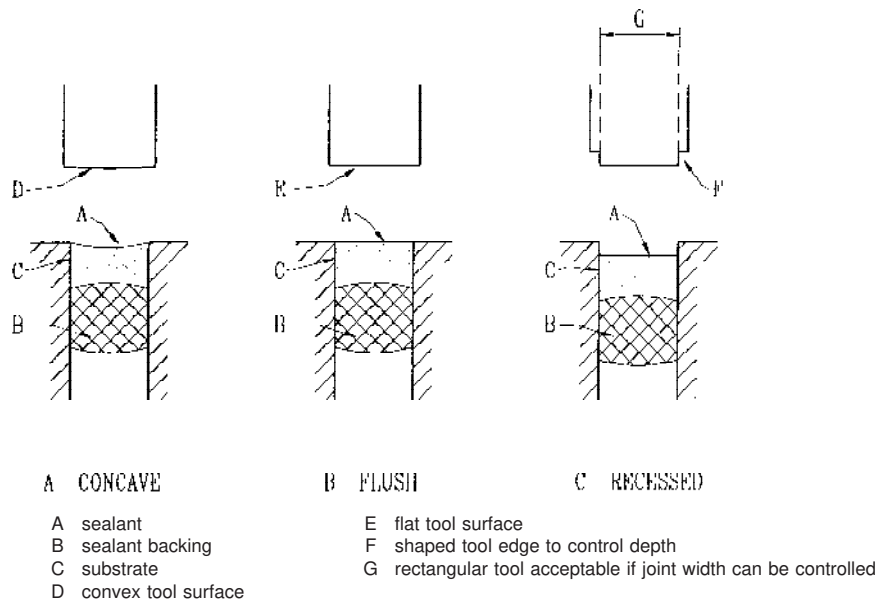


FIG. 8 Tooled Joint Configurations

14.1.5.1 *Vertical Surface*—A sealant joint on the face of a vertical surface can be oriented vertically, horizontally, or at any angle in between. Typically, the sealant is not formulated for a water immersion exposure. Characteristics of water flow on the surface of a wall should be evaluated, particularly for sloping and horizontal joints, where water can have a tendency to pool on or next to a sealant joint. Frequent or prolonged water contact or immersion can result in failure of the sealant in adhesion or a degradation of the sealant.

14.1.5.2 *Sloping Surface*—Water flow characteristics for a sloping surface, such as a skylight, should be considered. Frequently, sealant joint designs are encountered where water can pool on or collect and pool next to a sealant joint. Prolonged exposure to water can lessen sealant durability, usually resulting in loss of adhesion. Additionally, depending on a particular design, the sealant can become dirty due to the periodic collection and accumulation of water borne dirt and other contaminants. An adjacent surface, such as glass in a skylight, can become permanently disfigured due to the dirt and other contaminants that can collect next to the sealant joint. A sloping surface should be designed to adequately drain water from its surface, thereby precluding detrimental water and dirt accumulation.

14.1.5.3 *Horizontal Surface*—A sealant joint for a horizontal application with pedestrian access must be capable of resisting puncture (See Fig. 1). Typically, sealant and sealant backing are designed to be elastomeric, thereby allowing freedom of movement of the substrates. A relatively hard or rigid sealant or sealant backing would compromise movement. A sharp object such as a spike heel, small pebble, and environmental debris can puncture a sealant when backed by a soft, easily compressed material. This can cause permanent damage to the sealant joint and possibly present a tripping hazard to passersby. A pedestrian joint design that has had some success consists of semi-solid joint filler, such as fiberboard, with a bond-breaker applied to its surface in contact with the sealant. No universal durable solution to this problem has been developed; consequently, a periodic condition evaluation with appropriate maintenance of horizontal joints is a realistic consideration and should be a planned component of a facility maintenance program. Additionally, sealant joints in horizontal applications should be capable of freely draining water due to rain or snowmelt to prevent its accumulation on or near the sealant joint. Providing adequate slope to a horizontal surface for drainage is important. In general, a slope of no less than 3 mm (1/8 in.) per 300 mm (12 in.) is required to have adequate drainage characteristics. Most horizontal sealant joint applications with exposure to intermittent water will typically require the use of a substrate primer or surface conditioner, especially for a porous substrate.

14.1.5.4 *Liquid Immersion*—A sealant that is used for a liquid immersion application typically is a multi-component chemically curing formulation. A sealant should be verified, by Test Method C 1247 (See 5.7.1), that it is suitable for use with the intended liquid and for the anticipated service conditions and life. A sealant for a liquid immersion application must be applied to an appropriately cleaned, uncontaminated, and dry substrate surface. An open cell sealant backing should not be

used, since it can retain liquids, which can be detrimental to sealant durability. A sealant for liquid immersion will typically require a substrate primer. After application, a sealant must cure for at least 7 days, or the sealant manufacturer's written curing period for the application, before being submerged in a liquid. If the sealant joint will experience hydrostatic pressure then the sealant and sealant backing or bond breaker must be provided adequate support by an appropriately sized and installed and appropriately rigid joint filler or by use of an appropriate joint design (See 5.7). This is especially important for a sealant joint that is 25 mm (1 in) or more in width. For most applications a sealant joint is immersed in a relatively constant temperature liquid. If the liquid temperature will fluctuate significantly, then the sealant joint should be designed for the expected movement and tolerances (See 15). Typically, a sealant for liquid immersion can be used in a high temperature application, provided the liquid temperature does not exceed an upper limit of about 50°C (120°F). However, this is manufacturer and product dependent and should be verified prior to use.

14.2 *Precured Sealant:*

14.2.1 *Extruded Shape*—An extruded shape is typically installed over a failed sealant or a deficient joint opening width using a bridge type sealant joint design (See Fig. 3). An extruded shape could also be used in new construction applications provided the joint is properly designed. When used at an existing joint, usually the failed liquid-applied sealant does not have to be removed provided it does not project out of the opening and does not restrict any required joint movement. A bond breaker tape is usually installed over the failed sealant to separate it from the extruded shape if there is a concern for compatibility and to provide an unadhered width of the extruded shape to accommodate any expected movement. A liquid-applied adhesive-sealant adheres the extruded shape to the substrate surface. Typically, the width of the adhesion surface is recommended to be from a minimum of 6 mm (1/4 in) to 9 mm (3/8 in) depending on the width of the extruded shape. Cut and trimmed ends of two extruded shapes or when an extruded shape meets a molded shape are butted together tightly and sealed with a liquid-applied adhesive-sealant.

14.2.2 *Molded Shape*—A molded shape typically is used to seal failed metal-to-metal joints of window, skylight, and curtain wall systems. These joints can be sealed with a bridge type liquid-applied sealant; however, the use of a molded shape will usually result in a better performing and more aesthetically pleasing application. This application usually requires a three-dimensional molded shape since many of these joints will occur at corners and other framing system intersections. Additionally, to complete the sealing function, the molded shape will interface usually with other extruded or molded shapes and to a glass surface when required. A liquid-applied adhesive-sealant adheres the molded shape, usually along its perimeter, to the substrate and to the other extruded or molded shapes with which it interfaces.

15. Designing a Sealant Joint for Movement

15.1 *General*—Design professionals, for aesthetic reasons, have desired to limit the spacing and width of a sealant joint on an exterior wall and at other locations on a new building.

Frequently, a narrow width joint such as a 6 mm (1/4 in) wide joint is desired. Analysis of the performance factors and tolerances that affect a sealant joint is necessary to determine if a 6 mm (1/4 in) wide joint will have durability and be effective in maintaining a seal against the passage of air and water and not experience premature deterioration. If performance factors and tolerances are not understood, and included in the design of a sealant joint, then the sealant may reach its durability limit and failure is a distinct possibility (33). Sealant joint failure can result in increased building energy usage due to air infiltration or exfiltration, water infiltration, and deterioration of building systems and materials. Infiltrating water can cause spalling of porous and friable building materials such as concrete, brick, and stone; corrosion of ferrous metals; and decomposition of organic materials, among other effects. Deterioration is often difficult and very costly to repair with the cost of repair work usually greatly exceeding the original cost of the sealant joint work. Guide C 1472 can be used to calculate the width and depth required of a sealant joint to accommodate these affects. It is applicable to a sealant with an established movement capacity, in particular an elastomeric sealant that meets Specification C 920 with a minimum movement capacity range of $\pm 12\frac{1}{2}$ percent. It is also applicable to a precured, elastomeric joint seal with an established movement capacity. A joint for new construction can be designed by the recommendations in Guide C 1472 as well as a joint that has reached the end of its service life and needs routine maintenance or a joint that requires remedial work for a failure to perform. The following briefly summarizes the primary issues described by Guide C 1472.

15.2 Performance Factors—Proper sealant joint design can not be performed adequately without knowledge and understanding of factors that can affect sealant performance. Performance factors include material and system anchorage, thermal movement, moisture induced movement, live load movement, dead load movement, wind load movement, movement during sealant cure, elastic frame shortening, creep, shrinkage, and construction tolerances, among others. The following summarizes the most commonly encountered performance factors (that is, types of movement, thermal movement, and construction tolerances) that are known to influence sealant joint design. Performance factors can act individually or, as is mostly the case, in various combinations depending on the characteristics of a particular joint design.

15.3 Movements—There are four basic movements that sealant joints experience (See Fig. 9). These movements are compression (C), extension (E), longitudinal extension (E_L), and transverse extension (E_T). Longitudinal and transverse extension produce a shearing effect on a sealant joint. Frequently, sealant joints must accommodate more than one of the described movements and often somewhat simultaneously. Examples include the previously described extension and compression, as well as extension and/or compression combined with longitudinal or transverse extension. The effects of these movements can be combined to establish the joint width required for the expected combined movements. The design professional should evaluate the types of movement the joint will experience and design accordingly. Thermal movement is

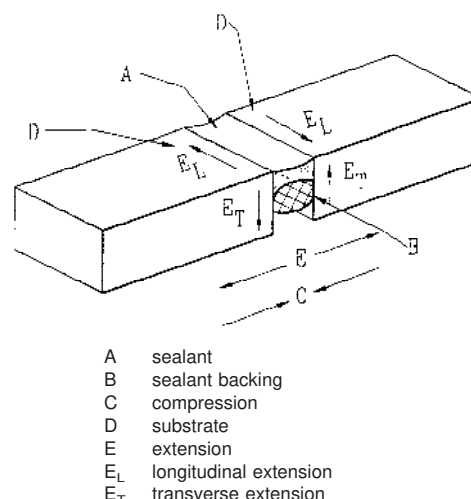


FIG. 9 Typical Sealant Joint Movement

usually the largest contributor to these movements; however, the other described performance factors can also contribute to movement. Guide C 1472 provides a methodology to take into account the accumulated anticipated movements of the joint (due to thermal and other performance factors) with the movement capability of the sealant.

15.3.1 Thermal Movement—Walls and other surfaces on or around buildings respond to ambient temperature change, solar radiation, wetting and drying effects from precipitation, and varying cloud cover by either increasing or decreasing in volume and therefore in linear dimension. The dimensional change of a material causes a change in the width of a sealant joint opening, producing movement in a sealant. Thermal movement is usually the predominate effect causing dimensional change. Thermal movement may need to be evaluated at different stages in a building's life; for example, expected temperature differentials may need to be considered for the building when it is: 1) under construction, 2) unoccupied and unconditioned, and 3) occupied and conditioned. Each of these stages will have different building interior environmental conditions, and depending on the building enclosure material or system being analyzed for movement, one of those stages may produce the maximum expected thermal movement. The required joint opening width, depending on construction procedures and material or wall system types, could be established during one of those stages. Determining realistic material or wall surface temperatures, to establish the expected degree of thermal movement, can be challenging. Guide C 1472 provides procedures to assist a joint designer in determining material or system minimum winter and maximum summer surface temperatures as well as information to assist in establishing joint opening installation temperature effects. This information is then used to determine the expected degree of thermal movement of a material or system.

15.4 Tolerances—A typical building is a combination of site-built and factory fabricated materials, components, and sub-systems. These materials and systems can be combined and constructed in complex arrangements. ASTM and industry trade associations, among others, establish industry recognized standards for construction tolerances (34). For some materials

or systems there are no industry recognized tolerances or the available tolerances are not directly applicable to sealant joint design. In these instances, a design professional should evaluate the conditions and establish tolerances for sealant joint work. A word of caution: ignoring the effects of construction tolerances when designing sealant joints will very often result in a failure of the joint as a seal, and frequently a failure of adjacent materials or systems, that due to joint opening narrowing, may come into detrimental contact with each other. Conversely, changing construction tolerances, by exceeding industry recommendations, needs to be carefully considered, since conditions can be created that can not be effectively achieved. Construction tolerances should be indicated for a sealant joint design, since they establish a level of quality and may affect the cost and performance of the work. Guide C 1472 provides information and a methodology to include construction tolerances (material, fabrication, or erection) in a calculation to determine a sealant joint width and its depth.

16. Sealant Installation

16.1 *General*—Analysis of many sealant joint failures indicates that the majority of failures can be attributed to improper joint preparation and deficient installation of the sealant and various joint components. The following briefly describes several aspects that must be considered when applying a liquid-applied or pre-cured sealant in unprotected environments to achieve a durable application. Also described are the various components and procedures that are required when installing a sealant and its associated accessories. A sealant manufacturer's written literature should always be consulted for the manufacturer recommended procedures and materials. A manufacturer will develop application specific recommendations if so requested.

16.2 *Environmental Conditions*—A sealant should not be installed during rain or when there is the threat of imminent rain fall. Wet or damp substrates from previous precipitation should be allowed to dry before application of primer or sealant. In general, sealant installation below 4°C (40°F) is discouraged, since ice or frost can form on a substrate which is detrimental to sealant adhesion. Frequently, ice or frost is not readily visible on a substrate (See 5.8.1).

16.3 *Remedial Sealant Work*—Remedial sealant work usually requires at least the same joint preparation requirements as for a joint in new construction. Obtaining adhesion to surfaces contaminated with a failed sealant can be challenging, often requiring greater than normal evaluation, in situ testing, and surface preparation (35, 36). In addition, it can require a considered and careful removal of an old sealant, since it can contain toxic or hazardous materials. Prior to removal, samples of the old sealant should be removed and tested to determine the presence of materials, such as polychlorinated biphenols (PCB) or asbestos. Removal and disposal of such a sealant must be consistent with applicable hazardous material safety requirements and locally applicable laws or regulations. Typically, the manufacturer of both the old and new sealant should be contacted for recommendations and guidelines for removal and disposal of the old sealant and application of the new sealant and accessory materials.

16.4 *Liquid-Applied Sealant:*

16.4.1 *General*—The following sections generally describe the various procedures associated with a typical liquid-applied sealant installation. Each installation should be evaluated for any changes or additions to these procedures required by that particular application.

16.4.2 *Joint Opening:*

16.4.2.1 *Inspection*—A joint, prior to having sealant installed, should be inspected to determine that it is in compliance with the joint design. For example, are the width and depth within the tolerances established for the joint design? If it is smaller, then sealant should not be installed until the joint designer has reviewed the deficient joint width or depth and developed an acceptable solution. If the width is greater, then sealant usually can be installed provided the larger joint is not aesthetically unacceptable. Any joint that is to experience movement must have a clear opening where the sealant and sealant backing and, if required, other accessories are installed. Incompressible materials in the joint opening, if left in-place, will restrict joint movement when the opening closes. Additionally, with cyclic movement, the incompressible materials can be dislodged, accumulate, and eventually cause a “ratcheting” action that will increase the joint opening width or detrimentally harm the substrate material(s) causing cracking, bulging, and other similar effects. This usually causes failure of the sealant or substrate materials. Such joints should have incompressible materials removed before accessories are installed or sealant application. The responsible parties should resolve any joint opening discrepancies prior to sealant installation.

16.4.2.2 *Substrate*—Inspection of a substrate is required to determine that it is sound and firm and acceptable for sealant application. A substrate that is unsound, cracked, or weak should be repaired prior to sealant application.

16.4.3 *Sealant Adhesion Tests*—It can not be stated enough that adequate sealant adhesion to a substrate must be verified by testing and then attained. These tests can be performed in the laboratory and in situ at the project site.

16.4.3.1 *Laboratory Test*—As described in 5.3, adhesion testing of a sealant with the actual substrate for the application is recommended well in advance of sealant installation at the project.

16.4.3.2 *In situ Test*—A substrate sample submitted for pre-installation laboratory adhesion testing can, depending on the material, experience subtle changes during production manufacturing of the material to cause sealant adhesion problems. For example, an anodized aluminum surface can develop variable sealant adhesion due to changes in or inadequate quality control of a sealing bath, which can vary from batch to batch. It is a good practice to perform a project site adhesion test prior to sealant installation, even when unusual conditions are not suspected. Additionally, it is also advisable to perform periodic adhesion testing during sealant installation to verify the quality of the work. The sealant manufacturer recommended cleaning and, if required, priming instructions for the application should be followed for an in situ test. Typically, the sealant is installed in the joint and following the recommended curing period is examined to determine if proper adhesion has been achieved. Determination of adequate adhesion in a joint is

currently a matter of judgement since there is no standard industry consensus for an in situ test method. In some cases in which an exposed surface of a substrate is also the same composition as the joint opening substrate, against which the sealant is to be applied, it may be possible to prepare an adhesion-in-peel sample following Test Method C 794. Appendix X1 includes three methods that can be used for in situ tests.

16.4.4 *Joint Preparation:*

16.4.4.1 *Surface Cleaning*—Joint opening substrate surfaces must be thoroughly cleaned removing all foreign matter such as dust, paint (unless a permanent protective coating), oil, grease, waterproofing or water-repellent treatments, water, surface dirt, and frost or ice. If remedial sealant work is performed the old and usually failed sealant must be satisfactorily removed to permit proper adhesion of the new sealant to the substrate.

16.4.4.2 *Porous Material*—Clean porous materials such as concrete, masonry, and unglazed surfaces of ceramic tile by brushing, grinding, blast cleaning, mechanical abrading, acid washing (if recommended by the sealant manufacturer), or combinations of these methods to provide a clean, sound substrate for optimum sealant adhesion. When acceptable a concrete substrate may be cut back to remove a contaminant and expose a clean surface. Remove laitance from concrete by acid washing, grinding, or mechanical abrading. Remove form oil from concrete by blast-cleaning. Remove loose particles that are present or that result from grinding, abrading or blast cleaning, by blowing out a joint opening with oil-free compressed air (or vacuuming) prior to application of a primer, if required, or a sealant.

16.4.4.3 *Non-Porous Material*—Chemically clean non-porous substrate surfaces, such as metal, glass, porcelain enamel, and glazed surfaces of ceramic tile with a sealant manufacturer recommended solvent. Other methods that are not harmful to the substrate and acceptable to the substrate and sealant manufacturer can be used. Remove temporary protective coatings on metallic substrates using a solvent that leaves no residue (See 7). Apply the solvent with clean oil-free, colorless cloths or lint-free paper towels using the two-cloth system. Do not dip cleaning cloths into a solvent, always pour the solvent on the cloth to eliminate the possibility of contaminating the solvent. A simple test to determine solvent cleanliness is to wipe some onto a clean mirror and look for any residue following evaporation of the solvent. Do not allow the solvent applied with the first cloth to air dry on the substrate without wiping with a second dry cloth. The intent of the two-cloth method is to wet the substrate with solvent that is on the first cloth by wiping the substrate to loosen and collect some of the contaminant. This is then followed immediately with the second cloth, before the solvent can evaporate from the substrate, to pick up any remaining solvent and loosened contaminant. Soiled cloths and wipes should be replaced frequently. Use of white wipes or cloths aids in determining replacement since a color change is readily apparent. A one-cloth method merely redeposits surface contaminants on the substrate as the solvent evaporates. This technique should not be used. A permanent substrate coating intended to remain must not be removed or damaged. Care should be taken in

using a cleaning agent to not deposit cleaning residue on other building surfaces, which may discolor or become permanently stained.

16.4.5 *Masking Tape*—Sealant droppings and smears on a non-porous substrate such as glass can be very difficult and time consuming to completely remove. On a porous substrate such as concrete, removal frequently involves mechanical alteration of the surface of the material resulting in objectionable aesthetic characteristics. To help avoid the possibility of sealant smears and the subsequent requirement to clean visible surfaces adjacent to the sealed joint, masking tape can be used continuously along the joint edges. Care should be taken to apply the tape at the joint edges and not in the joint opening. Tape should only be applied for the quantity of joint to be sealed the same day and should not be left in-place until the next day. Doing so may result in damage to the surface and may make removal difficult. When required, it must be a non-staining, non-absorbent, compatible tape and must be applied so as not to shift readily during sealant application. It must also be capable of being removed carefully, without disturbing the sealant, immediately after tooling of the sealant surface. Use of high-temperature masking tape, such as that used in an auto paint shop, helps on hot substrates. It permits removal without leaving an adhesive residue. Tooling a sealant to the edge of the masking tape, and preventing its accumulation under the tape when used on irregular surfaces, is an acquired skill and the applicator can not do this adequately without practice prior to the work being performed.

16.4.6 *Primer*—Prime a substrate surface when recommended by the sealant manufacturer (See 8). Primer should be installed prior to installation of the sealant backing to avoid inadvertent primer application on the backing. Prime only those surfaces that will be sealed with sealant the same day. If a previously primed surface that was performed the day before is encountered it will have to be reprimed. Use a primer or surface conditioner that is recommended by the sealant manufacturer. Follow a sealant manufacturer's published recommendation regarding the use of a primer or surface conditioner. However, it is important to recognize that an unanticipated condition may arise at a project site that may be detrimental to good sealant or primer performance if not corrected by special treatment. The sealant manufacturer should be consulted when such conditions exist or are suspected. In general, an in situ test should be performed to determine the proper treatment and sealant or primer recommendation, or both for an unanticipated condition. A word of caution: many primers can discolor a substrate surface or alter its appearance. Care should be taken so as to not splash or drip a primer onto an exposed substrate surface or other building surfaces.

16.4.6.1 *Application*—Most primers are applied as a relatively thin film that completely covers the sealant adhesion surface. An application that is dripping or running or one with skips and voids is not recommended and can result in deficient adhesion of the sealant. Proper dispensing of a primer is important to avoid primer contamination. The most commonly encountered technique of pouring a primer into an open cup or bowl is the least desired technique. Almost all sealant manufacturers indicate that the primer should be applied from a

closed container, for example a squeeze bottle, to a cloth or brush. The cloth or brush should not be dipped into a container of primer. Repeatedly doing so can contaminate the primer. Some primers, depending on the type of substrate, can be brush-applied, wiped on with a cloth, or wiped on with one cloth and wiped off with another. It is important that those who are applying a primer be supplied the proper equipment to contain, dispense, and apply a primer, and not just written instructions. A primer has a short application life once a container is opened. A small quantity of primer should be transferred to the application container for use that day. Any primer remaining in the application container at the end of the day should be discarded since it may have been affected by atmospheric moisture or its solvent may have substantially evaporated. The primed surface should be protected from becoming contaminated, for example, by being touched or handled by workman with dirty hands.

16.4.6.2 *Dry Time*—Different primers require different lengths of time between primer application and sealant installation. If a primer does not have adequate dry time, undesirable sealant adhesion quality may result or the solvent in the primer may adversely affect sealant cure. A primer normally requires a period of time to dry before sealant application. There usually is a maximum time interval between primer application and sealant application, which the sealant manufacturer can supply.

16.4.7 *Sealant Backing*—Installation of sealant backing should not be permitted with a sharp tool such as a putty knife or screwdriver. A sharp tool can puncture, crease, fold-over, or otherwise disfigure a sealant backing material resulting in potential damage to the sealant by outgassing or an unacceptable change in sealant profile that is detrimental to joint movement. A smooth face tool should be used to install it straight, uniformly, and at a constant depth. A depth controlled roller device works well. Sealant backing must be installed under adequate compression to hold it in-place in the joint opening and to resist the pressure applied when tooling a non-sag sealant into place (See 9). If not held in-place adequately it can float towards the surface of a liquid-applied self-leveling sealant, displacing the sealant or decreasing its required depth. It should be installed without stretching, since if stretched it may return to its original length thereby affecting sealant installation. Under no circumstances should sealant backing that is too small for the joint opening be doubled up or braided together to fit the opening. Doing so will result in an inadequate and deficient sealant profile. Additionally, it must be installed to the proper depth for the sealant joint design. Inconsistent installation of sealant backing, for depth, can result in a sealant profile that is too thin or too thick. Both conditions are unacceptable and can result in premature deterioration of the sealant as a weather seal. Where cut ends of a sealant backing butt, they should be fitted tightly together. This is especially important for a horizontal joint that will receive a self-leveling sealant to prevent its leakage past the sealant backing.

16.4.8 *Joint Filler*—After installation of joint filler, there should be sufficient remaining space for installation of sealant backing or bond breaker tape and the sealant. Some joint fillers, for concrete construction, are installed flush with the face of

the construction. They have a pull strip that is then removed to permit sealant backing or bond breaker tape installation prior to sealant application. It should be verified that there is sufficient depth after the tear strip is removed for sealant and required accessory installation. Some joint fillers are fabricated of a material that can function as sealant backing or bond breaker for some sealants, thereby precluding the need for these materials.

16.4.9 *Bond Breaker*—Installation of a bond breaker tape should only be on the surface where adhesion is not desired. A bond breaker tape should not lap over onto an adjacent sealant adhesion surface. Frequently, a colored self-adhesive tape is used as a bond breaker. The color assists in determining that the tape has been installed in the correct location. The tape should be installed continuously with no skips or voids in tape application. If the joint opening varies in width, two overlapping tapes can be installed to control the width of tape to fit the opening. The adhesion of a bond breaker tape to some substrates can be poor. Care should be taken in its installation and when installing sealant so as to not move the tape out of position.

16.4.10 *Sealant*—To obtain proper sealant adhesion to a substrate, it is essential that the sealant come into direct contact with the substrate and that the sealant wet the substrate surface. If any of these conditions are not met, poor or no adhesion will usually result. A sealant should be installed in a manner that will completely fill the cavity formed in the joint opening by the substrates and sealant backing or bond breaker. Some sealant applicators can accomplish this by pushing the sealant bead ahead of the nozzle of the gun, others with the nozzle bridging the joint opening, although there is increased risk of incomplete filling with this approach. Once sealant has been installed in the joint opening cavity it must be tooled. When sealant is installed in an opening with a porous substrate, the sealant must enter the pores of the material if good adhesion is to be obtained. A non-sag sealant is thixotropic and will resist flow into the pores unless an external force is applied. Proper filling of the cavity with sealant accomplishes this in part, followed by proper sealant tooling. Sealant should be installed in accordance with a manufacturer's written recommendations.

16.4.11 *Guns and Nozzles*—A sealant is generally applied with hand or air-powered guns from cartridges, sausage packs, or bulk containers. Bulk containers should be kept tightly closed except when sealant is being removed for use. The plastic nozzles of cartridges should be cut to an opening size and shape to fit the intended joint opening width, which will confine sealant to the joint and aid in building pressure to force sealant into the cavity, filling it, and attaining intimate contact with joint substrate surfaces. Matching the nozzle size to the joint opening is very important. Bulk gun nozzles are available in a wide variety of sizes and shapes and should be selected to attain the same results as for plastic nozzles. Guns and nozzles should be rinsed and cleaned periodically during the day and at day's end, when stopping for lunch, and when changing sealant color. Care should be taken to ensure that cleaning material or solvent evaporates and does not mix with the sealant. When filling a gun from a container air should not be introduced into the gun with the sealant.

16.4.12 *Tooling*—Tooling a non-sag sealant is essential to force sealant into the joint opening and eliminate air pockets. It should be accomplished as soon as possible after sealant application and must be completed before skinning or curing of the sealant begins. Tooling also ensures contact of the sealant with the substrate surfaces of a joint (See Fig. 10). Several joint sealant configurations are possible, depending on the selection of the sealant backing and the shape of the tools used. For a butt type joint, these are classified as a concave, flush, or recess tooled joint (See Fig. 8). When determining the location of the sealant backing, consideration should be given to a reduction in sealant depth that occurs with a concave and recess tooled joint, and the joint designed accordingly. During the curing process, some sealants shrink, resulting in a naturally formed concavity to a cured sealant exposed surface. This should also be considered when locating the sealant backing to provide the desired sealant depth. In some cases, it may be advisable to flush tool the sealant, so that after it has cured, the desired concavity of the cured sealant is attained. A water-based or solvent-release sealant is most susceptible to shrinkage since volatile materials are lost during the curing process. A project site trial installation would assist in determining the tooling procedure to use. Tooling is generally achieved as follows.

16.4.12.1 *Concave Joint*—Fig. 8A illustrates a concave joint, which is the most commonly used sealant configuration. Depending on the width of the joint, an appropriately rounded tool is used to contact the joint opening edges. As a tool is moved along the length of the joint the sealant is forced into the cavity and into intimate contact with the substrate surfaces while forming a concave surface. This procedure is applicable even if there are slight variations in joint width. An experienced applicator can successfully install sealant in a concave joint without the use of masking tape to keep adjacent surfaces clean. A concave tooled joint, in conjunction with a round shape sealant backing, will achieve an hourglass sealant cross-section shape for greatest movement capability; however, this may not necessarily be the optimum shape for a particular application.

16.4.12.2 *Flush Joint*—Fig. 8B illustrates a flush joint. A flat shape tool is used, similar to a concave joint profile, to strike the sealant off flush with the substrate surface, forcing the sealant into intimate contact with the substrates. Even with

an experienced applicator, flush tooling usually will require masking tape along the edges of the joint opening to keep the edges and surfaces clean. This is a satisfactory sealant configuration for most applications. However, once cured and during hot weather, narrowing of a joint will cause a sealant bulge, which is not recommended for horizontal traffic joints and may not be visually acceptable for other applications.

16.4.12.3 *Recessed Joint*—Fig. 8C illustrates a sealant profile where a conspicuous joint is desired that is obtainable by recessing a sealant. Tooling this profile is difficult unless a joint is of uniform width, which is difficult to attain with some materials and forms of construction. Also, joint width changes make tool widths variable and tooling difficult to perform. A curved tool could also be used to give the sealant a surface shape identical to that in Fig. 8A. A recessed joint is applicable where the outer face of a substrate is irregular, such as at the edge of an exposed aggregate concrete panel. For this and similar conditions, tooling requires more care to control depth of the recess since an irregular substrate surface prevents gauging tool depth on that surface. For this and similar applications, recessing a sealant helps control the joint width and greatly improves its appearance.

16.4.12.4 *Fillet Joint*—Fig. 5 illustrates typical fillet joint applications. Tooling this profile, usually with a tool designed for the particular installation, requires an experienced applicator. This profile is harder to control tooling and thickness since there are no guiding substrate edges or surfaces for the tool. The surface can be tooled flat, convex, or, if required, with a slightly concave surface. The thickness (depth) of the sealant over sealant backing or bond breaker, depending on a generic sealant type, can be from 3 to 6 mm ($\frac{1}{8}$ to $\frac{1}{4}$ in). Depending on applicator skill level, a minimum of 6 mm ($\frac{1}{4}$ in) may be desirable to insure a minimum of 3 mm ($\frac{1}{8}$ in) is maintained. Tooling should be carefully performed to ensure that the required sealant thickness is attained. The sealant manufacturer should be consulted for written guidelines for the thickness of their sealant for a particular fillet joint application. The sealant adhesion surface to a substrate should be a minimum of 6 mm ($\frac{1}{4}$ in) wide. The sealant adhesion width and the required sealant thickness are interrelated. Attaining a minimum width of 6 mm ($\frac{1}{4}$ in) must be coordinated with the minimum thickness required by the sealant manufacturer. Both the

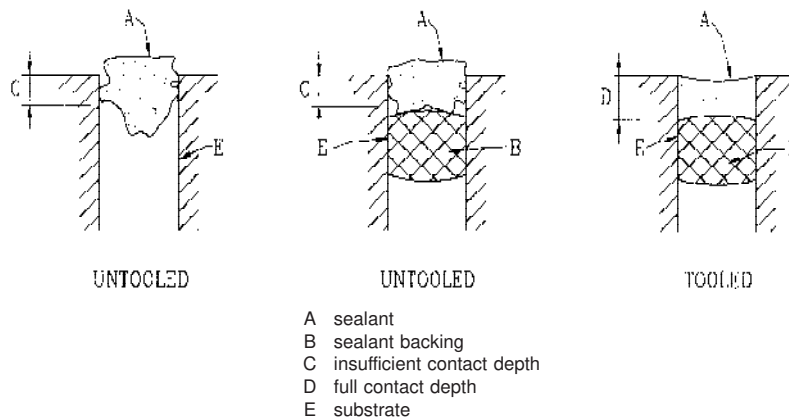


FIG. 10 Importance of Sealant Backing and Sealant Tooling

minimum sealant thickness and minimum sealant adhesion width must be satisfied by the design for the joint profile.

16.4.12.5 *Bridge Joint*—Fig. 6 illustrates typical bridge sealant joint applications. This type of joint is sometimes inappropriately referred to as a “band aid” sealant joint. As for a fillet joint, an experienced sealant applicator is required to successfully install an aesthetically pleasing bridge joint. The thickness (depth) of the sealant over sealant backing or bond breaker, depending on a generic sealant type, can be from 3 to 6 mm ($\frac{1}{8}$ to $\frac{1}{4}$ in). Tooling should be carefully performed to ensure that the required sealant thickness is attained. The sealant manufacturer should be consulted for written guidelines for the thickness of their sealant for a particular bridge joint application. One technique that can be used to control depth and aesthetic appearance is to use a foam tape with a pressure sensitive adhesive to form a cavity within which to install the sealant. The tape is installed along both joint edges to the face dimension of the required joint. The tape is also of a size to create the required thickness (depth) of sealant. Immediately after sealant tooling the foam tape is carefully removed. Another technique is to have a special notched tool made that will create the required sealant width and thickness profile when the sealant is tooled. Frequently, to avoid sealant smears, masking tape is used to define the edges of the sealant joint, which is subsequently removed immediately after tooling the sealant. The width of the sealant adhesion to the substrate surface should be a minimum of 6 mm ($\frac{1}{4}$ in), with some sealant manufacturers and design professionals recommending a minimum of 9 mm ($\frac{3}{8}$ in).

16.4.13 *Tools*—Typically, an appropriately shaped plastic or metal tool is used. Applicators have proven to be most inventive in developing a tool for a particular application. Table knives, cake decorating spatulas, and stiff cardboard have been used successfully to tool a sealant joint. Most sealant manufacturers and applicators recommend and use dry tools, which may be surface-treated with a permanent coating to prevent adhesion of the sealant. Tools should be cleaned periodically to prevent build-up of old sealant and especially when changing colors to prevent contamination.

16.4.14 *Tooling Liquid*—A tool should be used dry to apply the sealant and to preclude any possibility of substrate contamination by a tooling liquid. However, where permitted by the sealant manufacturer, a tool can be used wetted by an approved liquid. Dipping a tool in certain liquids decreases adhesion of a sealant to the tool. A liquid proposed for use with a particular sealant should first be tested and approved for use by the sealant manufacturer. The use of some tooling liquids may cause a surface discoloration of the exposed substrate surface along the edges of a joint or attract dust to the still tacky sealant surface where it can change the sealant color. It is advisable to test the joint substrate material with the proposed tooling liquid to determine if there will be any permanent discoloration of the substrate. When using a tooling liquid, care should be taken to ensure that it does not contact a joint substrate surface prior to sealant application. This can occur especially with vertical sealant joints, where the liquid can drip downward and potentially contaminate the substrate

surfaces. If a substrate is contaminated with a tooling liquid, sealant adhesion to the substrate is usually adversely affected.

16.4.15 *Removal of Masking Tape*—As soon as a sealant has been tooled to the desired shape the masking tape should be carefully removed. Waiting until a sealant has started to skin over and cure will usually make removal more difficult and can cause damage to the sealant joint surface. Leaving masking tape in-place for an extended period of time can also result in very difficult tape and adhesive removal and in some instances damage to the finish of certain substrates.

16.4.16 *Cleanup*—Cleanup of hands, tools, and other items is easiest to accomplish as soon as possible, while the sealant is fresh and uncured. A water-based sealant is cleaned from hands and tools with water to which a liquid cleaner can be added, if necessary. Other types of sealant require a solvent such as toluene, xylene, methyl ethyl ketone (MEK), acetone, or mineral spirits for cleanup. Solvents described are toxic and flammable. The solvent manufacturer’s written precautions should be observed during storage, use, and disposal of solvents. Cloths, rags, or paper wipes that are used with solvents are always a fire hazard and should be disposed of in a safe manner. Sealant manufacturers can provide cleanup recommendations. Guns and tools should be cleaned daily and between sealant color changes. It is not advisable to clean inadvertently spilled sealant from porous surfaces using a solvent. Solvents will tend to drive the sealant deeper into the porous substrate and may leave a permanent stain on the substrate. Scrape, wipe, or scrub the spill using dry tools or rags. Alternatively, if a serious consideration, tarps or other barriers can be installed to prevent other surfaces from becoming contaminated with sealant smears or droppings.

16.5 *Precured Sealant:*

16.5.1 *General*—The following sections generally describe the various procedures associated with a typical liquid-applied adhesive-sealant and precured sealant installation. Each installation should be evaluated for any changes or additions to these procedures required by that particular application.

16.5.2 *Adhesive-Sealant Adhesion Test*—The adhesive-sealant that will be used to adhere the precured sealant to the substrate should be verified for adhesion and compatibility with the substrate. Adhesion can be determined with small-scale samples in a laboratory or in situ similar to as described in 5.3.1. Compatibility can be determined as described in 5.4.1.

16.5.3 *Joint Preparation*—Frequently, a precured sealant is used to repair or replace a failed liquid-applied sealant joint. Occasionally, the failed sealant will protrude from or be falling out of the joint opening representing an obstacle to adequate placement of the precured sealant. Also, previous applications of liquid-applied sealant as a remedial repair may contaminate the substrate surfaces adjacent to the joint opening. Removal of these excess materials is usually required to facilitate adhesive-sealant and precured sealant application. At times, the substrate can be in a damaged condition due to failure of the sealant or to environmental effects from normal weathering. Damage should be repaired so that an acceptable substrate surface is available for the adhesive-sealant.

16.5.4 *Surface Cleaning*—Once removal of excess sealant or other materials has occurred and the substrate surface is in

an acceptable condition, the substrate should be cleaned to permit proper application of the adhesive-sealant. Cleaning can be conducted using materials described in 7 and procedures described in 16.4.4.

16.5.5 *Primer*—If a primer is required to obtain adequate adhesion of the adhesive-sealant it can be applied using materials described in 8 and procedures described in 16.4.6.

16.5.6 *Bond Breaker*—Occasionally, a bond breaker is installed over a previously installed and usually failed liquid-applied sealant to provide a barrier between that sealant and the precured sealant. This is done to preclude incompatibility from occurring between the two sealants and adversely affecting the precured sealant. A bond breaker is also used to establish the unadhered length of the precured sealant needed to accommodate the expected movement.

16.5.7 *Masking Tape*—The installation of masking tape (See 16.4.5) may be necessary to prevent sealant from being applied or inadvertently coming into contact with visible substrate surfaces. Masking tape is applied to the substrate at the location where the edge of the precured sealant will be located.

16.5.8 *Adhesive-Sealant*—A bead of adhesive-sealant is applied along both sides of the joint where the precured sealant will be adhered to the substrate. The bead should be applied approximately 6 mm (1/4 in.) inward from the edge of the masking tape. Size of the applied adhesive-sealant bead is dependent on the degree of roughness of the substrate surface and the desired installed width of adhesive-sealant. The size of the bead is usually determined by evaluating a test mockup. Precured sealant manufacturers generally recommend a minimum installed adhesive-sealant width of at least 6 to 9 mm (1/4 to 3/8 in.). This can vary depending on a particular application.

16.5.9 *Precured Sealant Shape:*

16.5.9.1 *Extruded*—In general, depending on environmental conditions, a precured sealant should be installed as soon as possible. If the adhesive-sealant skins over or becomes tack-free, inadequate or no adhesion of the precured sealant to the adhesive-sealant will result (See Fig. 3). The precured sealant is pressed into the applied beads of adhesive-sealant wetting the precured sealant and substrate surfaces.

16.5.9.2 *Molded*—With a molded shape, the adhesive-sealant beads, depending on the particular application, can be applied to the substrate or to the molded shape. In general, depending on environmental conditions, the molded shape should be installed as soon as possible. If the adhesive-sealant skins over or becomes tack-free, inadequate or no adhesion of the adhesive-sealant to the molded shape will occur. The molded shape is pressed into the applied beads of adhesive-sealant wetting the molded shape and substrate surfaces.

16.5.10 *Tools*—To assist in pressing the precured sealant into the applied adhesive-sealant beads a tool such as a roller is often used and is recommended. A roller will permit more consistent pressure to be applied to ensure intimate and uniform adhesive-sealant contact with the substrate and precured sealant.

16.5.11 *Cleanup*—After installation (See 16.4.16), the extruded excess adhesive-sealant will have accumulated on the masking tape. Masking tape removal should occur before the

adhesive-sealant has started to cure to prevent stringing of the sealant and to make clean up easier to accomplish.

17. Sealant Joint Maintenance

17.1 Often, periodic maintenance of a sealant joint is not performed. It cannot be stated enough that a sealant joint requires maintenance, especially for a horizontal application, just as for other components of a building. A building owner or manager should have periodic inspections performed to identify areas where remedial sealant repair or maintenance work is required. Foregoing periodic maintenance will usually result in additional sealant joint failure, hidden deterioration of materials, and an accelerated failure of the sealant weather seal function. Many communities, at least for multi-story structures, require a periodic facade inspection at an interval of about 5 years. This periodic code or regulation required inspection should be used to also help identify sealant joint conditions needing repair, although some of these facade inspections do not involve the entire facade—just selected areas. To facilitate repair and maintenance, the building owner or manager should maintain adequate records related to the sealant joints on or adjacent to the building, including information such as the original sealant type, joint cleaning and priming requirements, required joint accessories, and any other information important to maintenance and repair.

18. Certification, Marking, Shipping, Preservation, and Safety

18.1 *General*—Information from the following general guidelines, appropriately modified where required for a specific application, should be incorporated into the method of procurement of the various materials required for a sealant installation.

18.2 *Certification*—Certification from the sealant manufacturer should be available before the delivery of material to the project site, attesting that the sealant and primer materials conform to the specification requirements. Certification should include complete test results performed on representative materials (same formulation) within a twelve-month period preceding the date of submission of certification to the purchaser. Test data more than twelve months old may be submitted provided the sealant manufacturer indicates in the certification that the tested sealant and primer have not changed in formula or manufacture sufficient to produce a different result.

18.3 *Package Marking and Shipping*—Material should be delivered to the project site in original sealed containers. A container should be marked with the appropriate information, including supplier, material name and number, and specification number to which it conforms. Additionally, for a sealant and primer, color, expiration period (shelf life), and pot life and curing time at standard laboratory test conditions (when applicable) should be indicated. A multi-component sealant should also have mixing and handling instructions clearly indicated.

18.4 *Preservation*—Material should be stored and protected in accordance with a manufacturer's printed instructions. An outdated material should not be used unless recertified by the manufacturer as suitable for use.

18.5 *Safety*—If potentially hazardous or regulated materials are necessary, special precautions and handling and disposal recommendations by the manufacturer should be followed.

19. Keywords

19.1 bond breaker; guide; joint accessories; joint filler; precured sealant, primer; sealant; sealant backing; sealant design; sealant geometry; sealant installation; sealant joint

APPENDIXES

(Nonmandatory Information)

X1. TEST METHODS TO DETERMINE SEALANT ADHESION CHARACTERISTICS IN SITU

X1.1 Method A, Field-Applied Sealant Joint Hand Pull Tab

X1.1.1 Scope

X1.1.1.1 This adhesion test is a simple screening procedure for a field applied sealant that may help detect field application problems, such as improper substrate cleaning, use of an improper primer, poor primer application, improper joint configuration, and many of the other field application problems that can affect adhesion. As a check for adhesion, this simple hand pull test is performed at the project site after a sealant has cured (usually within 7 to 21 days). This test is destructive to a portion of the sealant joint, which following testing is repaired. It is recommended that a minimum of one test be performed for each 305 m (1,000 ft) of each type of sealant joint.

X1.1.2 Apparatus

X1.1.2.1 *Knife*—Of appropriate length with a thin sharp blade.

X1.1.2.2 *Sealant*—Same sealant material as is being tested.

X1.1.2.3 *Spatula*—A suitable item to permit tooling of the sealant.

X1.1.3 Procedure

X1.1.3.1 Make a knife cut horizontally across the width of the sealant joint from one substrate of the joint to the other.

X1.1.3.2 Make two vertical cuts (downward starting at the horizontal cut) approximately 75 mm (3-in.) long, at both sides of the joint next to the substrates.

X1.1.3.3 Grasp the 75 mm (3-in.) sealant tab firmly 25 mm (1 in) from its bonded edge and pull at a 90 degree angle (Fig. X1.1).

X1.1.4 Results

X1.1.4.1 If substrate adhesion is acceptable, the sealant should tear cohesively within itself or elongate to a manufacturer determined extension value from the 25 mm (1 in) gauge length indicated in X1.1.3.3, before releasing from either substrate adhesively.

X1.1.5 Repair of Sealant at Adhesion Test Area

X1.1.5.1 Repair the sealant pulled from the test area by applying new sealant to the test area. Assuming good adhesion was obtained, use the same application procedure to repair the area as was used originally for the joint. Care should be taken to ensure that the original sealant surfaces are clean and that the new sealant is in contact with the original sealant.

X1.1.6 Report

X1.1.6.1 File the adhesion test number, date, sealant lot number(s), test results (cohesive or adhesive failure), and other pertinent information in a quality control document for future reference.

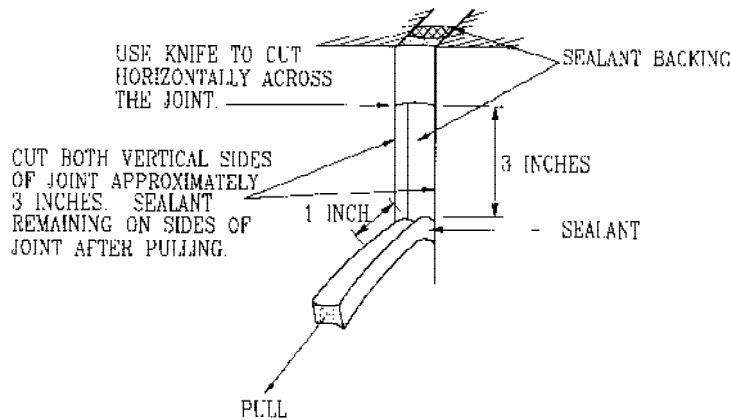


FIG. X1.1 Hand Pull Test

X1.2 Method B, Exposed Surface Finish Hand Pull Tab

X1.2.1 Scope

X1.2.1.1 This is a simple screening test that is performed on a flat surface. It is applicable to those situations where it is difficult or not possible to test a sealant joint for adhesion by Method A. Test for adhesion on an exposed surface finish that is the same finish as the substrate to which the sealant is adhered.

X1.2.2 Apparatus

X1.2.2.1 *Substrate*—Same finish as installed for the project. This method can be performed on a surface on a building or on a small-scale sample removed from a building.

X1.2.2.2 *Primer*—As used for the joint, if required.

X1.2.2.3 *Bond breaker Tape*—Polyethylene or Teflon self-adhesive tape.

X1.2.2.4 *Sealant*—Same sealant material as installed in the sealant joint.

X1.2.2.5 *Spatula*—A suitable item to permit tooling of the sealant.

X1.2.2.6 *Knife*—Of appropriate length with a thin sharp blade.

X1.2.3 Procedure

X1.2.3.1 Clean and, if required, prime the adhesion surface following the project-specific recommended procedures.

X1.2.3.2 Place a piece of bond breaker tape on the surface.

X1.2.3.3 Apply a bead of sealant approximately 200 mm (4-in.) long, 25 mm (1-in.) wide and 3 mm (1/8-in.) thick. At least 50 mm (2-in.) of the sealant should be applied over the bond breaker tape (Fig. X1.2.A).

X1.2.3.4 Tool the sealant to ensure good sealant contact with the adhesion surface.

X1.2.3.5 After cure (usually within 7 to 21 days), lift the sealant tab off the bond breaker tape, hold the sealant tab at about 25 mm (1 in.) from the adhered edge, and pull firmly at a 90 degree angle.

X1.2.4 Results

X1.2.4.1 If substrate adhesion is acceptable, the sealant will tear cohesively (Fig. X1.2B), with no adhesive failure from the substrate (Fig. X1.2C), or elongate to a manufacturer determined extension value from the 25 mm (1 in) gauge length indicated in X1.2.3.5, with no adhesive failure.

X1.2.5 Report

X1.2.5.1 File the adhesion test number, date, sealant lot number(s), test results (cohesive or adhesive failure), and other pertinent information in a quality control document for future reference.

X1.3 Method C, Field-Applied Sealant Joint Hand Pull Flap

X1.3.1 Scope

X1.3.1.1 This adhesion test is a simple screening procedure (similar to X1.1, Method A) for a field applied sealant that may help detect field application problems, such as improper substrate cleaning, use of an improper primer, poor primer application, improper joint configuration, and many of the other field application problems that can affect adhesion. As a check for adhesion, this simple hand pull test is performed at the project site after a sealant has cured (usually within 7 to 21 days). This test is destructive to a portion of the sealant joint, which following testing is repaired.

X1.3.2 Apparatus

X1.3.2.1 *Knife*—Of appropriate length with a thin sharp blade.

X1.3.2.2 *Sealant*—Same sealant material as is being tested.

X1.3.2.3 *Spatula*—A suitable item to permit tooling of the sealant.

X1.3.3 Procedure

X1.3.3.1 Make a knife cut horizontally across the width of the sealant joint from one substrate of the joint to the other.

X1.3.3.2 Make one vertical cut (downward starting at the horizontal cut) approximately 75 mm (3-in.) long, along one side of the joint next to the substrate.

X1.3.3.3 Make a second knife cut horizontally across the width of the sealant joint from one substrate of the joint to the other at the opposite end of the 75 mm (3 in.) cut.

X1.3.3.4 Grasp the 75 mm (3-in.) sealant flap firmly from its bonded edge and pull at a 90 degree angle.

X1.3.4 Results

X1.3.4.1 If substrate adhesion is acceptable, the sealant should tear cohesively within itself or elongate to a manufacturer determined extension value before releasing from the substrate adhesively.

X1.3.5 Repair of Sealant at Adhesion Test Area

X1.3.5.1 Repair the sealant pulled from the test area by applying new sealant to the test area. Assuming good adhesion

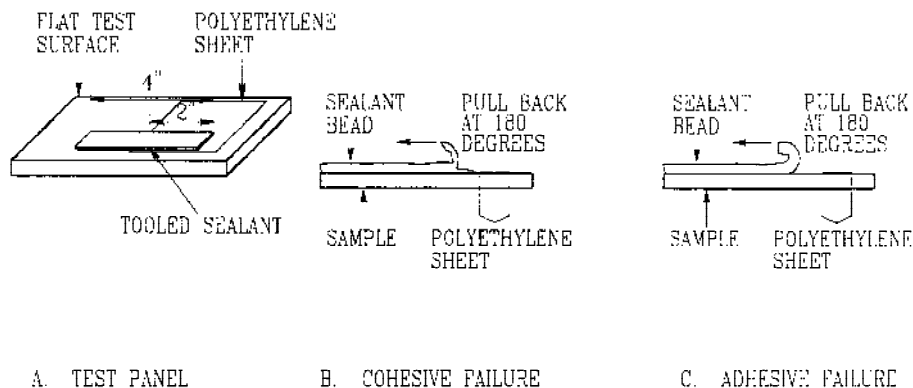


FIG. X1.2 Hand Pull Test

was obtained, use the same application procedure to repair the area as was used originally for the joint. Care should be taken to ensure that the original sealant surfaces are clean and that the new sealant is in contact with the original sealant.

X1.3.6 Report

X1.3.6.1 File the adhesion test number, date, sealant lot number(s), test results (cohesive or adhesive failure), and other pertinent information in a quality control document for future reference.

X1.4 Method D, Water Immersion

X1.4.1 Scope

X1.4.1.1 Both Method A and B can include a water immersion and another pull test step with appropriate use of in situ water containing devices. If the sample for Method A and B did not fail adhesively, it can be used for this Method.

X1.4.2 Apparatus

X1.4.2.1 *Container*—A suitable size that can be attached in situ to the surface and capable of immersing the sample while containing water for the period of immersion. If a small-scale sample from Method B is used the container should be a suitable size for immersion of the sample.

X1.4.3 Procedure

X1.4.3.1 Following successful completion of Method A, B, or C the sample is immersed in water. An alternate procedure

for Method A and C is to immerse the sample prior to performing a pull tab or flap test. The pull test is then performed once during this method. If performed on a building surface, environmental conditions may require protection of the water immersion device to preclude freezing of the water or its heating to high temperature. The specifying authority should establish the water temperature. For example, an acceptable range could be $22 \pm 6^{\circ}\text{C}$ ($72 \pm 10^{\circ}\text{F}$).

X1.4.3.2 The sample is immersed for a period of time as determined by the specifying authority, for example 1, 3, or 7 days.

X1.4.3.3 After immersion for the specified time period, pat dry, and immediately lift the sealant tab or flap and, as described in the applicable procedure, pull firmly at a 90 degree angle.

X1.4.4 Results

X1.4.4.1 If substrate adhesion is acceptable, the sealant will tear cohesively with no adhesive failure from the substrate or elongate to a manufacturer determined extension value with no adhesive failure.

X1.4.5 Report

X1.4.5.1 File the adhesion test number, date, sealant lot number(s), test results (cohesive or adhesive failure), and other pertinent information in a quality control document for future reference.

X2. General Index to Topics and Headings as Listed in the Guide

X2.1 Index

1. Scope

2. Referenced Documents

2.1 *ASTM Standards*

3. Terminology

3.1 *Definitions*

3.2 *Definitions of Terms Specific to This Standard*

3.2.1 *durability*

3.2.2 *durability limit*

3.2.3 *precured sealant*

3.2.4 *premature deterioration*

3.2.5 *service life*

4. Significance and Use

5. General Considerations

5.1 *General*

5.2 *Durability*

5.2.1 *Durability Testing*

5.3 *Adhesion*

5.3.1 *Adhesion Testing*

5.4 *Compatibility*

5.4.1 *Compatibility Testing*

5.5 *Substrate Staining*

5.5.1 *Stain Testing*

5.6 *Sealant Color Change*

5.6.1 *Color Change Testing*

5.7 *Liquid Immersion*

5.7.1 *Liquid Immersion Resistance Testing*

5.8 *Environmental Influences*

5.8.1 *Low Temperature*

5.8.2 *High Temperature*

5.8.3 *Moisture*

6. Substrate

6.1 *General*

6.2 *Types*

6.2.1 *Porous*

6.2.2 *Non-Porous*

6.2.3 *EIFS*

7. Cleaner

7.1 *General*

7.2 *Procedure*

7.2.1 *Porous Substrate*

7.2.2 *Non-Porous Substrate*

8. Primer

8.1 *General*

8.2 *Materials*

8.2.1 *Color*

8.2.2 *Clarity*

8.3 *Application*

8.3.1 *General*

8.3.2 *Porous Substrate*

8.3.3 *Non-Porous Substrate*

9. Sealant Backing

9.1 *General*

9.2 *Function*

9.2.1 *Normal*

9.2.2 *Temporary Joint Seal*

9.3 *Material*

9.3.1 *Open Cell Foam*

9.3.2 *Closed Cell Foam*

9.3.3 *Bicellular Foam*

9.3.4 *Others*

9.4 *Shape and Form*

9.4.1 *Round*

9.4.2 *Rectilinear*

9.4.3 *Triangular*

9.5 *Application*

9.5.1 *Vertically Oriented Surface*

9.5.2 *Horizontal Surface*

9.5.3	<i>Temporary Joint Seal</i>	14.1.5.4	<i>Liquid Immersion</i>
10.	Joint Filler	14.2	<i>Precured Sealant</i>
10.1	<i>General</i>	14.2.1	<i>Extruded Shape</i>
10.2	<i>Function</i>	14.2.2	<i>Molded Shape</i>
11.	Bond Breaker	15.	Designing a Sealant Joint for Movement
11.1	<i>General</i>	15.1	<i>General</i>
11.2	<i>Compatibility and Adhesion Testing</i>	15.2	<i>Performance Factors</i>
11.2.1	<i>Adhesion Test Method</i>	15.3	<i>Movements</i>
12.	Liquid-Applied Sealant	15.3.1	<i>Thermal Movement</i>
12.1	<i>General</i>	15.4	<i>Tolerances</i>
12.2	<i>Cure Time</i>	16.	Sealant Installation
12.3	<i>Type</i>	16.1	<i>General</i>
12.3.1	<i>Single-Component</i>	16.2	<i>Environmental Conditions</i>
12.3.2	<i>Multi-Component</i>	16.3	<i>Remedial Sealant Work</i>
12.4	<i>Formulation</i>	16.4	<i>Liquid-Applied Sealant</i>
12.4.1	<i>Modulus</i>	16.4.1	<i>General</i>
12.4.1.1	<i>Low</i>	16.4.2	<i>Joint Opening</i>
12.4.1.2	<i>Medium</i>	16.4.2.1	<i>Inspection</i>
12.4.1.3	<i>High</i>	16.4.2.2	<i>Substrate</i>
12.4.2	<i>Movement Capability</i>	16.4.3	<i>Sealant Adhesion Tests</i>
12.4.3	<i>Non-Sag</i>	16.4.3.1	<i>Laboratory Test</i>
12.4.4	<i>Self-Leveling</i>	16.4.3.2	<i>In situ Test</i>
12.4.5	<i>Extrudability</i>	16.4.4	<i>Joint Preparation</i>
12.4.6	<i>Conditioning</i>	16.4.4.1	<i>Surface Cleaning</i>
12.4.7	<i>Painting</i>	16.4.4.2	<i>Porous Material</i>
12.5	<i>Movement-During-Cure</i>	16.4.4.3	<i>Non-Porous Material</i>
12.5.1	<i>Damage Potential</i>	16.4.5	<i>Masking Tape</i>
12.5.2	<i>Potential Causes</i>	16.4.6	<i>Primer</i>
12.5.3	<i>Test Method Limitations</i>	16.4.6.1	<i>Application</i>
12.5.4	<i>Sealant type and Cure Rate</i>	16.4.6.2	<i>Dry Time</i>
12.5.5	<i>Damage assessment</i>	16.4.7	<i>Sealant Backing</i>
12.5.5.1	<i>General</i>	16.4.8	<i>Joint Filler</i>
12.5.5.2	<i>Physical Observation</i>	16.4.9	<i>Bond Breaker</i>
12.5.5.3	<i>Laboratory Tests</i>	16.4.10	<i>Sealant</i>
12.5.6	<i>Joint Movement</i>	16.4.11	<i>Guns and Nozzles</i>
12.5.6.1	<i>General</i>	16.4.12	<i>Tooling</i>
12.5.6.2	<i>Use of a Mock-up</i>	16.4.12.1	<i>Concave Joint</i>
12.5.6.3	<i>Thermal Movement</i>	16.4.12.2	<i>Flush Joint</i>
12.5.6.4	<i>Movement Combinations</i>	16.4.12.3	<i>Recessed Joint</i>
12.5.7	<i>Reducing Movement-During-Cure</i>	16.4.12.4	<i>Fillet Joint</i>
12.5.7.1	<i>General</i>	16.4.12.5	<i>Bridge Joint</i>
12.5.7.2	<i>Sealant Cure</i>	16.4.13	<i>Tools</i>
12.5.7.3	<i>Sealant Backing</i>	16.4.14	<i>Tooling Liquid</i>
12.5.7.4	<i>Joint Movement</i>	16.4.15	<i>Removal of Masking Tape</i>
12.5.7.5	<i>Precured Sealant</i>	16.4.16	<i>Cleanup</i>
13.	Precured Sealant	16.5	<i>Precured Sealant</i>
13.1	<i>General</i>	16.5.1	<i>General</i>
13.2	<i>Type</i>	16.5.2	<i>Adhesive-Sealant Adhesion Test</i>
13.3	<i>Movement Capability</i>	16.5.3	<i>Joint Preparation</i>
13.4	<i>Environmental Conditions</i>	16.5.4	<i>Surface Cleaning</i>
13.5	<i>Color</i>	16.5.5	<i>Primer</i>
13.6	<i>Painting</i>	16.5.6	<i>Bond Breaker</i>
14.	Sealant Joints	16.5.7	<i>Masking Tape</i>
14.1	<i>Liquid-Applied</i>	16.5.8	<i>Adhesive-Sealant</i>
14.1.1	<i>General</i>	16.5.9	<i>Precured Sealant Shape</i>
14.1.2	<i>Width</i>	16.5.9.1	<i>Extruded</i>
14.1.3	<i>Depth</i>	16.5.9.2	<i>Molded</i>
14.1.3.1	<i>Porous Substrate</i>	16.5.10	<i>Tools</i>
14.1.3.2	<i>Non-Porous Substrate</i>	16.5.11	<i>Cleanup</i>
14.1.4	<i>Sealant Joint Type</i>	17.	Sealant Joint Maintenance
14.1.4.1	<i>Concave Butt Joint</i>	18.	Certification, Marking, Shipping, Preservation, and Safety
14.1.4.2	<i>Flush Butt Joint</i>	18.1	<i>General</i>
14.1.4.3	<i>Recessed Butt Joint</i>	18.2	<i>Certification</i>
14.1.4.4	<i>Fillet Joint</i>	18.3	<i>Packaging Marking and Shipping</i>
14.1.4.5	<i>Bridge Joint</i>	18.4	<i>Preservation</i>
14.1.5	<i>Sealant Joint Application</i>	18.5	<i>Safety</i>
14.1.5.1	<i>Vertical Surface</i>	19.	Keywords
14.1.5.2	<i>Sloping Surface</i>		
14.1.5.3	<i>Horizontal Surface</i>		

REFERENCES

- (1) Gorman, P. D., "Weathering of Various Sealants in the Field – A Comparison," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Fourth Volume, ASTM STP 1243*, D. H. Nicastro, Ed., American Society for Testing and Materials, Philadelphia, PA, 1995 pp 3–28.
- (2) Pernisz, U. C. and Klosowski, J. M. "Fraction of the Global Normal Irradiance Incident From the Northern Part of a Clear Sky," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, ASTM STP 1200*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1992 pp 311–317.
- (3) Boettger, T. and Bolte, H. "Results From the University of Leipzig Project Concerning the Long-Term Stability of Elastomeric Building Sealants," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Seventh Volume, ASTM STP 1334*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1998 pp 66–80.
- (4) Klosowski, J. M. "Summary of Accelerated Weathering and Other Durability Studies and the Correlation to Real Weather," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Seventh Volume, ASTM STP 1334*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1998 pp 81–93.
- (5) Beech, J. and Beasley, J. "Effects of Natural and Artificial Weathering on Building Sealants," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Fourth Volume, ASTM STP 1243*, D. H. Nicastro, Ed., American Society for Testing and Materials, Philadelphia, PA, 1995 pp 65–76.
- (6) Bridgewater, T. J. and Carbary, L. D. "Accelerated Weathering and Heat Stability of Various Perimeter Sealants," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, ASTM STP 1200*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1992 pp 45–63.
- (7) O'Neil, V. K., and Wolf, A. T. "Effects of Weatherproofing Sealants on Building Aesthetics – Part II," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Fifth Volume, ASTM STP 1271*, M. A. Lacasse, Ed., American Society for Testing and Materials, Philadelphia, PA, 1996 pp 141–168.
- (8) Chin, I. R., Gorrell, T. A., and Scheffler, M. J. "Staining Potential of Sealants In/On Exterior Wall Substrates," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Fifth Volume, ASTM STP 1271*, M. A. Lacasse, Ed., American Society for Testing and Materials, Philadelphia, PA, 1996 pp 169–183.
- (9) Farmer, M. C. and Cechner, R. A. "Laboratory Testing of Sealants With a Marble Substrate," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Fifth Volume, ASTM STP 1271*, M. A. Lacasse, Ed., American Society for Testing and Materials, Philadelphia, PA, 1996 pp 184–206.
- (10) Gorrell, T. A., Chin, I. R., and Scheffler, M. J., "Evaluation of Accelerated Laboratory Test Methods to Predict Sealant Staining of Stone Substrates," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Seventh Volume, ASTM STP 1334*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1998 pp 197–209.
- (11) Snyder, R., Badour, R., Carbary, L. D. and Wolf, A. T. "Comparison of Various Test Methods for Assessing the Long Term Fluid Migration Potential for Sealants" *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Seventh Volume, ASTM STP 1334*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1998 pp 210–218.
- (12) Lee, T., Rees, T., and Wilford, A. "Polysulfide Sealants in Water-Retaining Structures," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, ASTM STP 1168*, C. J. Parise, Ed., American Society for Testing and Materials, Philadelphia, PA, 1992 pp 47–56.
- (13) Randazzo, S. "Sealants for Construction Joints Subjected to Continuous Water Immersion," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, ASTM STP 1168*, C. J. Parise, Ed., American Society for Testing and Materials, Philadelphia, PA, 1992 pp 57–64.
- (14) Yarosh, K. F. "Evaluation of Various Sealants With EIFS," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Seventh Volume, ASTM STP 1334*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1998 pp 169–178.
- (15) Kenney, R. J. and Piper, R. S. "Factors Affecting the Durability of Sealants in Contact With the Finish Coating of EIF Systems," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, ASTM STP 1168*, C. J. Parise, Ed., American Society for Testing and Materials, Philadelphia, PA, 1992 pp 117–127.
- (16) Williams, M. F. and Williams, B. L. "Thermal Movement Analyses for Panelized Polymer-Based Exterior Insulation and Finish System (PB EIFS) Claddings," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, ASTM STP 1168*, C. J. Parise, Ed., American Society for Testing and Materials, Philadelphia, PA, 1992 pp 128–138.
- (17) O'Connor, T. F., and Droz, H. L., "Design Considerations for Sealants When used at Horizontal Expansion Joints in Masonry Cavity Walls," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Sixth Volume, ASTM STP 1286*, J. C. Myers, Ed., American Society for Testing and Materials, Philadelphia, PA, 1996 pp 63–83.
- (18) Myers, J. C., "Performance of Fillet Sealant Joints," *Building Sealants: Materials, Properties, and Performance, ASTM STP 1069*, T. F. O'Connor, Ed., American Society for Testing and Materials, Philadelphia, PA, 1990 pp 108–121.
- (19) Myers, J. C., "Performance of Band-Aid Sealant Joints," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Fourth Volume, ASTM STP 1243*, D. H. Nicastro, Ed., American Society for Testing and Materials, Philadelphia, PA, 1994 pp 90–97.
- (20) Brower, J. R., "Deformation of Building Sealants Due to Movement During Cure," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, ASTM STP 1168*, C. J. Parise, Ed., American Society for Testing and Materials, Philadelphia, PA, 1992 pp 5–8.
- (21) Matsumoto, Y., "The Effect of Building Joint Movements on Outdoor Performance of Sealants During Their Cure," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, ASTM STP 1168*, C. J. Parise, Ed., American Society for Testing and Materials, Philadelphia, PA, 1992 pp 30–44.
- (22) Flackett, D. R., "Effect of Early Joint Movement on Oxime Silicone Sealants and Comparison to Other One-Part Silicone Systems," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, ASTM STP 1200*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1992 pp 299–310.
- (23) Lacasse, M. A. and Margeson, J. C. "Movement During Cure of Latex Building Joint Sealants," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Sixth Volume, ASTM STP 1286*, J. C. Myers, Ed., American Society for Testing and Materials, Philadelphia, PA, 1996 pp 129–145.
- (24) Margeson, J. "The Effect of Movement During Cure on Sealant Strength Development," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, ASTM STP 1168*, C. J. Parise, Ed., American Society for Testing and Materials, Philadelphia, PA, 1992 pp 22–29.
- (25) McBride, K. S. "Hybrid Weatherseals-Design and Implementation of Bridge Sealant Joints in Two and Three Dimensions," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Seventh Volume, ASTM STP 1334*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1998 pp 115–128.

- (26) Hagen, P. R., Mayville, G. E., and Klosowski, J. M. "Silicone Preformed Joint Seals (PJS) and Their Applications," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Seventh Volume, ASTM STP 1334*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1998 pp 129–141.
- (27) Chin, Y. J., "Using Three Dimensional Silicone "Boots" to Solve Complex Remedial Design Problems in Curtain Walls," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Seventh Volume, ASTM STP 1334*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1998 pp 142–156.
- (28) Klein, K. A. and Brown, M. A. "Custom Molded Silicone Flashing Shapes for Sealing Curtain Walls," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Seventh Volume, ASTM STP 1334*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1998 pp 157–168.
- (29) Piper, R. S. and Kenney, R. J. "A Case Study of the Use of Preformed, Surface-Applied Silicone Sealant Joints," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Sixth Volume, ASTM STP 1286*, J. C. Myers, Ed., American Society for Testing and Materials, Philadelphia, PA, 1996 pp 84–93.
- (30) Anderson, J.M., and Gill, J.R., *Rainscreen Cladding a Guide to Design Principles and Practice*, Butterworths, Boston, MA, 1988.
- (31) Myers, J. C., "A Comparison of Different Sealant Butt Joint Shapes," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Fifth Volume, ASTM STP 1271*, M. A. Lacasse, Ed., American Society for Testing and Materials, Philadelphia, PA, 1996 pp 42–51.
- (32) Hoigard, K. R. and Kudder, R. J. "Performance of a Modified Sealant Fillet Detail," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing, ASTM STP 1200*, J. M. Klosowski, Ed., American Society for Testing and Materials, Philadelphia, PA, 1992 pp 179–187.
- (33) O'Connor, T. F., "Recent Developments in the Design of Sealant Joints for Movement and Other Effects," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Fifth Volume, ASTM STP 1271*, M. A. Lacasse, Ed., American Society for Testing and Materials, Philadelphia, PA, 1996 pp 3–41.
- (34) Ballast, D. K., *Handbook of Construction Tolerances*, McGraw-Hill, Inc., New York, 1994.
- (35) Pagliuca, A. and Hutchinson, A. "Adhesion Properties of Sealants in Resealed Joints," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing - Sixth Volume, ASTM STP 1286*, J. C. Myers, Ed., American Society for Testing and Materials, Philadelphia, PA, 1996 pp 109–128.
- (36) Woolman, R. and Hutchinson, A., *Resealing of Buildings A Guide to Good Practice*, Butterworth-Heinemann Ltd., Oxford, United Kingdom, 1994.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).