Thermal Barrier Task Group Approval	Architectural Products Council Approval	Technical Steering Committee Approval
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AAMA TIR-A8-XX

DRAFT #3

DATED 2/23/2026

Structural Performance of Composite Thermal Barrier Framing Systems

DRAFT

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1.0 FOREWORD

The worldwide manufacturers of fenestration products have several materials from which to produce their component products. Aluminum is one of the preferred materials of choice. However, because of aluminum's high thermal conductivity, improved thermal performance for this material is of prime importance. Many thermal barrier designs, which accomplish this end, have been used or are in use currently. The method used in all cases is to interrupt the continuity of the framing system with the inclusion of a low conductance material. This is commonly referred to as a thermal barrier. With a properly designed thermal barrier product, the transfer of the thermal energy through an architectural framing system is reduced. This interruption of energy flow has obvious benefits in substantially reducing the total energy consumption of the building of which the end product is a part. The thermal barrier will also effectively improve the resistance of the framing members to condensation or frost formation. These thermal barrier systems allow aluminum to provide thermal performance comparable with other framing materials.

Though there are several thermal barrier systems in use today, the scope of this document will address the composite thermal barrier systems that are the most widely used, as known by this document's authors. Guidelines for these framing systems are offered on cavity design, thermal barrier material, selection, testing manufacturing, fabrication, installation and environmental performance. The intent of this report is to provide the design professional with sufficient information to intelligently evaluate composite thermal barrier systems.

2.0 INTRODUCTION

2.1 The primary units of measure in this document are metric. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for reference only.

2.2 This document was developed in an open and consensus process and is maintained by representative members of FGIA as advisory information.

2.3 Definition of Framing with a Structural Thermal Barrier

An aluminum composite framing member consisting of an interior and exterior extruded aluminum section. The two sections are joined by a structural thermal barrier material to improve the thermal performance of the composite section.

2.3.1 Definition of Poured and Debridged Design

An aluminum composite framing member, consisting of single extruded aluminum sections separated by a thermoset material providing a structural thermal barrier. The thermoset material is poured into the cavity of the extrusion. After curing, the extruded bridge is removed. The resultant framing member is a composite member consisting of interior and exterior aluminum sections separated by a structural, insulating thermal barrier. (See Figures 1, 2a and 2b).

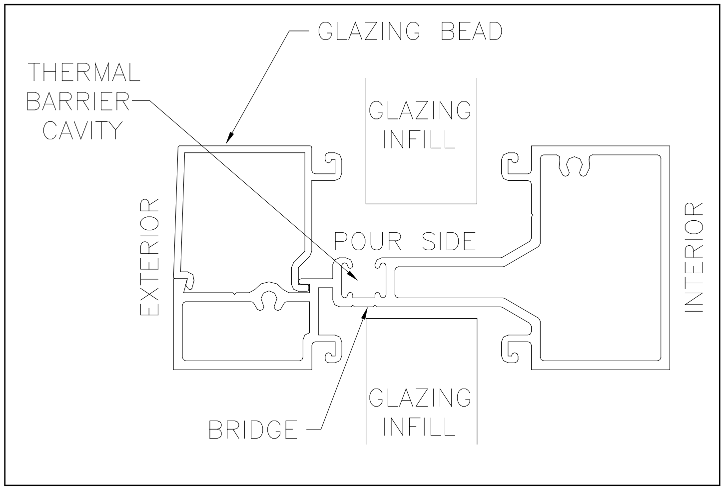


FIGURE 1: Typical Poured and Debridged Thermal Barrier Aluminum Extrusion

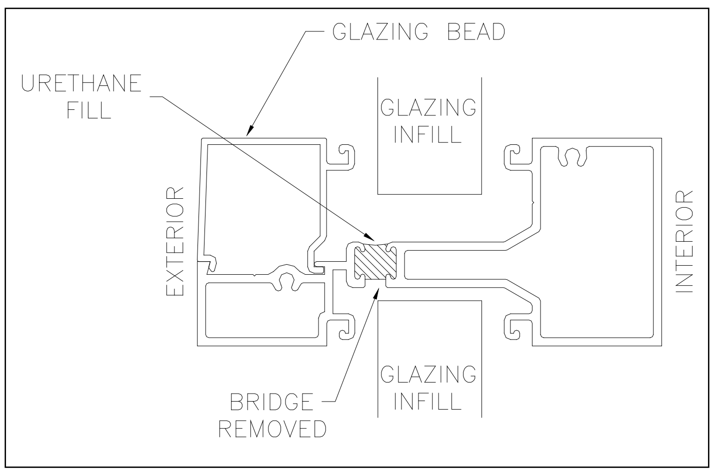


FIGURE 2a: Typical Poured and Debridged Single Cavity Thermal Barrier Composite Profile

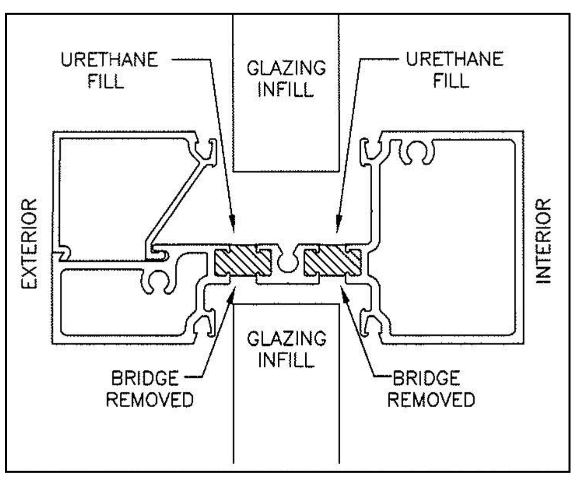


FIGURE 2b: Typical Poured and Debridged Dual Cavity Thermal Barrier Composite Profile

2.3.2 Definition of Mechanically Locked Design

An aluminum composite framing member, consisting of individual interior and exterior extruded aluminum sections separated by a preformed thermal barrier. First, both the interior and exterior aluminum extrusions are knurled. The structural thermal barrier material is then inserted into the knurled extruded cavity of both the interior and exterior portions and after rolling (crimping) the mechanical locking process is complete. (See Figures 3 and 4).

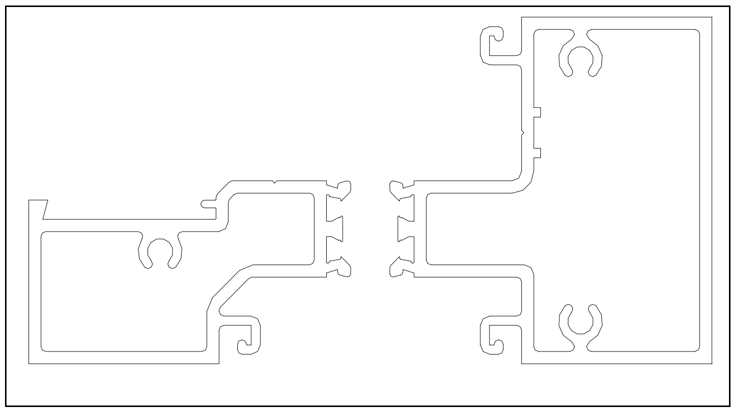


FIGURE 3:Typical Mechanically Crimped in Place Thermal Barrier Extrusions

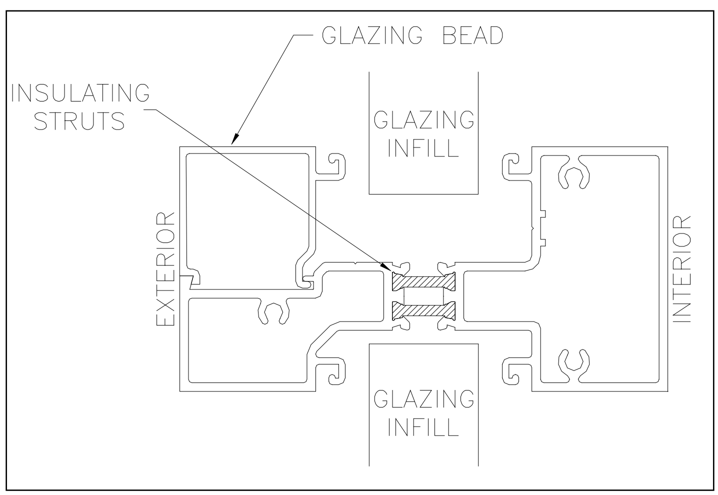


FIGURE 4:Typical Mechanically Crimped in Place Thermal Barrier Composite Section

2.4 History

Throughout the world, aluminum extrusions have become the preferred construction material for windows and doors. The reasons for the popularity of aluminum are many. Aluminum extrusions are lightweight with one of the highest strength to weight ratios of any material. For the designer, they offer an unlimited variety of shapes. They are produced at close dimensional tolerances, providing for excellent operational fit and structural stability. Aluminum is not subject to warping, rust or vermin damage. Aluminum accepts many finishes allowing for a wide variety of color applications. Aluminum is the most recycled material used for framing.

However aluminum is one of the most thermally conductive metals. This high thermal conductance has been a cause of concern related to the use of aluminum in fenestration products, principally energy loss and associated condensation. In response to these concerns, designers have devised methods to separate the exterior metal surfaces from the interior metal surfaces, thus greatly reducing the heat and cold transfer. These techniques generally incorporated some type of insulating medium with structural properties.

2.4.1 History of Poured and Debridged Thermal Barriers

In 1962, the Soule Steel Company of San Francisco announced a "new method of insulating aluminum windows and curtain-wall systems, which eliminates internal frost build-up in cold climates and is up to 50 percent cheaper than former, less efficient techniques." Soule called this system Artic Wall. This development was an important milestone, because the Soule technique resulted in the first window product to be produced economically with excellent control of dimensional tolerance. The first notable application of this technology which later became known as poured and debridged was for windows and curtain-walls in the construction of the State Office Building in Fairbanks, Alaska, in 1962.

2.4.2 History of Mechanically Locking Thermal Barriers

The mechanical locking thermal barrier system originated in Europe in the early 1970's, by Ensinger GmbH and Wicona, in order to meet the needs of a specific project, developed the structural thermal barrier system. The first known installation of a mechanical locking thermal barrier was in 1978. The first usage in the United States came a little over ten years later, in the spring of 1991. The thermal barrier was used in the Jackson County Public Hospital. It was the first use of a mechanical locking thermal barrier that had been produced in the United States. These windows went into service in the spring of 1991 and are still in service as of the date of this printing.

Along with the advancements in insulating glass, improved sealants, weather stripping and high performance finishes, thermal barriers have provided a great impetus for the growth of aluminum as the preferred material for architectural framing. Since the early seventies, thermal barriers have achieved such universal acceptance that they are now considered a standard way to produce energy efficient fenestration framing products.

To ensure continued reliability and technical improvements of thermal barriers, AAMA organized the Thermal Barrier Structural Task Group at its October 1981 Annual Meeting. This committee was comprised of experts in the field, including design engineers, process engineers, corporate and marketing managers and chemists. It was decided at this meeting that the main responsibility of the task group would be to prepare a Technical Information Report (TIR) for the manufacturers of windows, doors, curtain walls, storefronts, skylights and other glazed architectural products that would establish guidelines, performance standards, processing recommendations and test methods for thermal barriers.

Given the significant innovations and changes in thermal barrier design, AAMA charged the Thermal Barrier Task Group to update the current TIR-A8-90. The mission of the Task Group was to revise and expand the TIR-A8-90 document to include innovations in products and testing. This document is the result of that effort.

2.5 Effect on Condensation Resistance Factor (Crf) and Thermal Transmittance (U-f)

The thermal barrier serves to isolate the aluminum on the exterior of the framing system from the aluminum on the interior. A properly designed system will still maintain the structural integrity of the framing while not permitting a thermal short circuit between exterior and interior metal.

A thermal barrier provides an effective method of limiting the formation of condensation and frost on the interior frame. Condensation at this point can damage interior trim and wall covering or at the very least be a nuisance to the building owner. The ability of a framing system to resist condensation formation is expressed by the Condensation Resistance Factor (CRF). AAMA document 1503, "Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Systems" provides guidance to the design professional on determining the proper Condensation Resistance Factor requirements for a project. In general, framing systems with thermal barriers have significantly better condensation resistance than those without.

Like CRF, the coefficient of thermal transmittance (U-f) for the glazed framing system will also improve when thermally broken sections are utilized. The thermal barrier effectively reduces the amount of heat transfer from one side of the extrusion to the other. The effect of thermal sections on the U-f of the composite glazed product will depend upon the ratio of the metal area to the glass area.

3.0 THERMAL BARRIER MATERIALS

Any material that improves the thermal performance of an aluminum window frame without compromising the structural integrity of the window may be used as a thermal barrier. All products used for thermal barrier applications must have a set of minimum performance properties. Properties such as tensile strength, elongation, impact resistance, thermal conductivity, flexural modulus, adhesion properties and heat deflection temperatures should all be considered during the design and application stage.

After reviewing all of the technical data, a product that meets the general product parameters should be selected and then run under typical plant conditions in extrusions designed for the particular application. Samples of these extrusions should then be tested to confirm that the product will perform to the expected level.

Regardless of the type of thermal barrier product or material chosen, care must be taken in its design and application as the performance properties needed for each application can vary significantly. The manufacturer should be consulted throughout all aspects of this process. This remains the key to the success of any product chosen.

It is important to note that an excellent material will not perform in a poorly designed thermal barrier cavity, nor will a poor material perform in a properly designed cavity. Both the cavity design and the material must be correct. In this specification we will discuss two thermal barrier materials, one being a poured urethane (a mix of two components, used in a poured-and-debridged system) and the other being a preformed, engineered profile extruded into a thermal barrier shape. There are other materials that may be used as composite thermal barrier materials but they will not be discussed here in detail; however the analytical procedures in this document would still be applicable.

The final thermally separated composite extrusion must exhibit the following properties:

1. Resistance to deflection must be adequate to meet the requirements of the intended application at the anticipated loads and ambient conditions.

2. Resistance to torsion must be greater than the expected forces caused by the loads on the frame.

3. Resistance to shear must be greater than the expected forces caused by the differences in inside and outside temperatures, weight of the glazing material and structural composite action of the assembly.

4. Resistance to wind loading must be adequate to withstand the continuous pumping action caused by variations in wind loadings.

5. It must be able to support static loads caused by the weight of the glazing material or hardware hung on the window.

6. It must be designed so as to minimize dry shrinkage. (If applicable.)

7. Resistance to distortion and impact loading must be adequate to the end use of the product.

4.0 DESIGN GUIDELINES

4.1 Material Selection

The information contained in this section is garnered from the shared experiences of AAMA members involved in supplying and/or manufacturing of thermal barrier products. They are not intended to be prescriptive or all inclusive. Commonly accepted engineering practices should be followed in the design of any component of a framing system.

Following are cavity design guidelines for structural thermal barrier sections. These guidelines are based on time-tested design parameters and are not intended to stifle design innovation or creativity, but merely to present those features, which have worked well in the past.

4.1.1 Poured in Place Cavity Design

Profile thermal barrier cavities of the general shape shown in Figures 5 through 9 are addressed. These are not intended to limit. the acceptable profiles to those show however the scope of this document is limited to cavities of these general shapes Design criteria range from thermal to structural to extrudability which are often at odds with each other, and are summarized as follows:

4.1.1.1 Maintain an appropriate width-to-depth ratio on cavity dimensions as shown in Figure 8. This helps promote good flow into the cavity during pouring and develops optimum structural strength in tension and torsion for any given amount of thermal barrier material. Other profiles may involve significant deviations in structural integrity. In addition the design must stay within extrudability limits of the aluminum by employing gap width ratios (cavity area divided by the square of the gap width) less than 3.5.

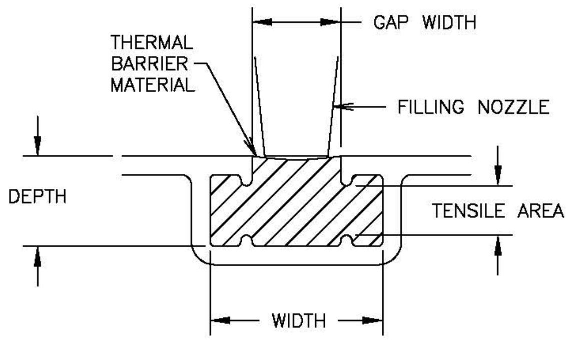


FIGURE 5: Poured in Place Cavity Design

4.1.1.2 Design the temporary aluminum bridge for removal without removing thermal barrier material in the throat area "F" as shown in Figure 9 or creating indentations for standing water as shown in Figures 6 and 7.

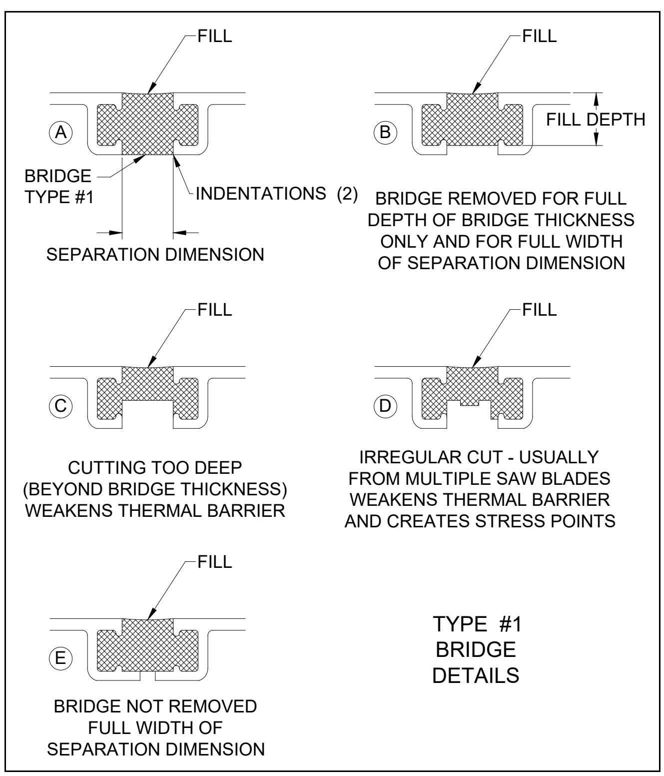


FIGURE 6: Pour and Fill

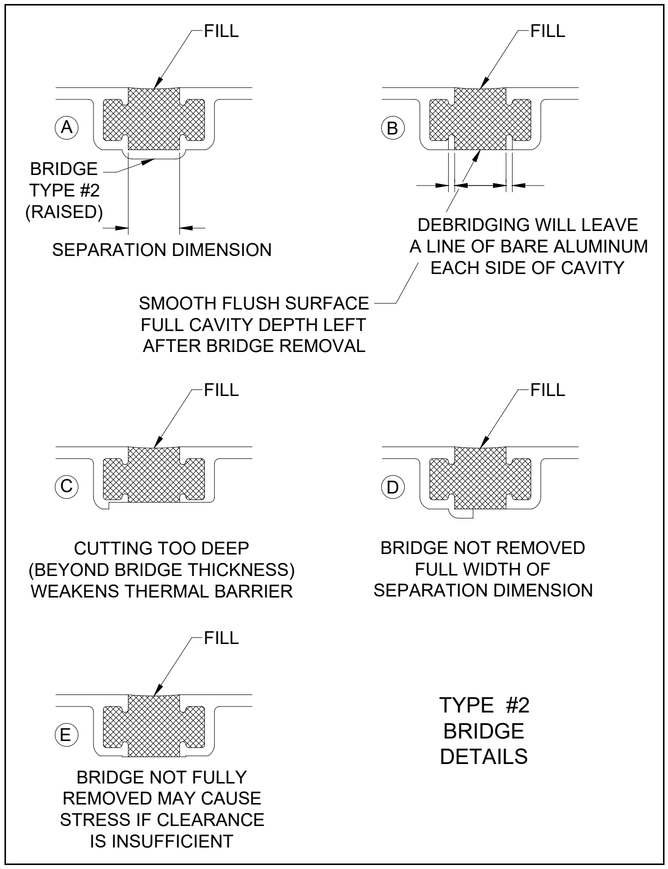


FIGURE 7: Pour and Fill

In removing the bridge avoid irregular cuts or cutting too deep as shown in Figures 6C, 6D and 7C as this will weaken the structural integrity of the thermal barrier. Failure to fully remove the bridge as shown in Figure 6E may affect the thermal transmittance of the section and may cause clearance problems as shown in Figures 7D and 7E.

4.1.1.3 All interior corners of the cavity should be radiused 0.8 mm (1/32 in) minimum as shown in Figure 8.

These radii help eliminate voids and pin holes in the fluid during the viscous flow pouring process.

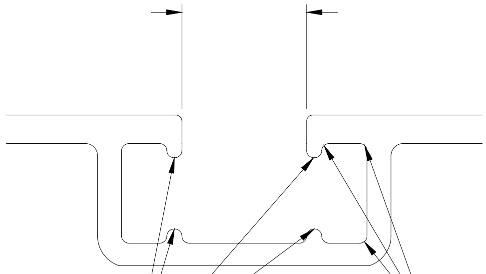


FIGURE 8: Extruded Cavity

4.1.1.4 Provide a "fluid head" to force the viscous fluid into all recesses of the cavity when pouring.

4.1.1.5 Keep the thermal barrier cavity profile symmetric whenever practical. This avoids eccentric loading in tension and torsion.

4.1.1.6 Ensure that the cross-sectional profile and location of the thermal barrier cavity does not create thermal "short circuits" at joinery whenever practical. In doing this, the basic design of the system must be reviewed, i.e., square cut vs. mitered construction, etc.

4.1.1.7 In situations where sections are dependent on adhesion for shear strength, maximize the surface area within the cavity.

Greater surface area will result in lower shear stresses being developed at the bond line during flexure. Surface treatment is addressed in Section 4.2.

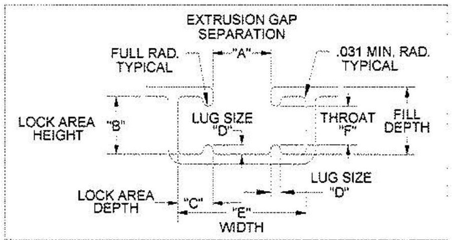
4.1.1.8 Prevent disengagement of the thermal barrier material under tensile and torsional loads by providing a positive mechanical interlock in the cavity profile.

4.1.1.9 Position the thermal cavity where it will perform most effectively thermally. This requires the careful study of the temperatures and longitudinal shear forces in flexure, which will occur at different locations within the system. Such analysis would usually result in a cavity located at or near the glazing pocket. In many instances, a thermal barrier location yielding optimal condensation resistance will not yield the lowest possible frame U-f. Thermal barrier location near the exterior minimizes the possibility of hardware "short circuits" resulting in better thermal performance.

4.1.1.10 Position the thermal barrier to avoid direct exposure to the elements. This assures thermal integrity, avoids appearance problems and minimizes the possibility of ultraviolet degradation.

4.1.1.11 Cavities smaller than those shown in Figure 9 are outside of normal industry practice, therefore use of such a cavity should be justified by a complete set of physical and thermal tests of the composite section to demonstrate that the section meets or exceeds the minimum strength and thermal performance requirements.

STANDARD & CONCEPTUAL CAVITY DESIGNS

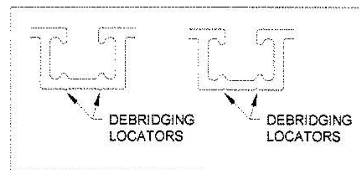


CAVITY DATA

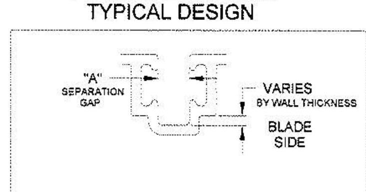
STANDARD DESIGNATIONS	"A"	"B"	"C"	"D"	"E"	"F"	AREA mm² (in²)	VOLUME ml/m (in³/ft)
AA	5.18 (0.204)	6.86 (0.270)	2.79 (0.110)	1.02 (0.040)	10.77 (0.424)	4.83 (0.190)	70.96 (0.110)	71 (1.320)
BB	6.35 (0.250)	7.14 (0.281)	4.06 (0.160)	1.14 (0.045)	14.48 (0.570)	4.85 (0.191)	100.65 (0.156)	101 (1.872)
CC	6.35 (0.250)	7.92 (0.312)	4.78 (0.188)	1.27 (0.050)	15.90 (0.626)	5.38 (0.212)	123.23 (0.191)	123 (2.292)
DD	7.92 (0.312)	8.89 (0.350)	5.49 (0.216)	1.57 (0.062)	18.90 (0.744)	5.74 (0.226)	165.81 (0.257)	166 (3.084)
EE	9.53 (0.375)	9.53 (0.375)	5.74 (0.226)	1.57 (0.062)	21.01 (0.827)	6.38 (0.251)	199.35 (0.309)	199 (3.708)
FF	11.10 (0.437)	11.10 (0.437)	6.68 (0.263)	1.85 (0.073)	24.49 (0.964)	7.39 (0.291)	264.52 (0.410)	281 (5.196)
GG	11.54 (0.453)	11.54 (0.453)	6.93 (0.273)	1.91 (0.075)	25.40 (1.000)	7.67 (0.302)	278.71(0.432)	301 (5.568)
HH	12.70 (0.500)	9.53 (0.375)	5.74 (0.226)	1.57 (0.062)	24.18 (0.952)	6.35 (0.250)	251.61 (0.390	241 (4.464)
II	12.70 (0.500)	12.70 (0.500)	7.65 (0.301)	2.11 (0.083)	28.00 (1.102)	8.48 (0.334)	369.68 (0.573)	366 (6.780)
JJ	19.05 (0.750)	19.05 (0.750)	11.48 (0.452)	3.18 (0.125)	41.99 (1.653)	12.70 (0.500)	809.68(1.255)	791 (14.640)
KK	25.40 (1.000)	25.40 (1.000)	15.29 (0.602)	4.24 (0.167)	56.00 (2.205)	16.94 (0.667)	1518.71(2.354)	1466 (27.130)
LL	VARIES WITH CAVITY SIZE - REFER TO SINGLE CAVITY DESIGNATIONS FOR CAVITY DIMENSIONS.							

NOTES:
AA - EE STANDARD AAMA CAVITY SIZES
FF-KK SCALED VARIATION OF AAMA POCKETS FOR WIDTH "E"

TYPE #1 DEBRIDGING
DEBRIDGING LOCATOR DESIGNS



TYPE #2 DEBRIDGING
TYPICAL DESIGN



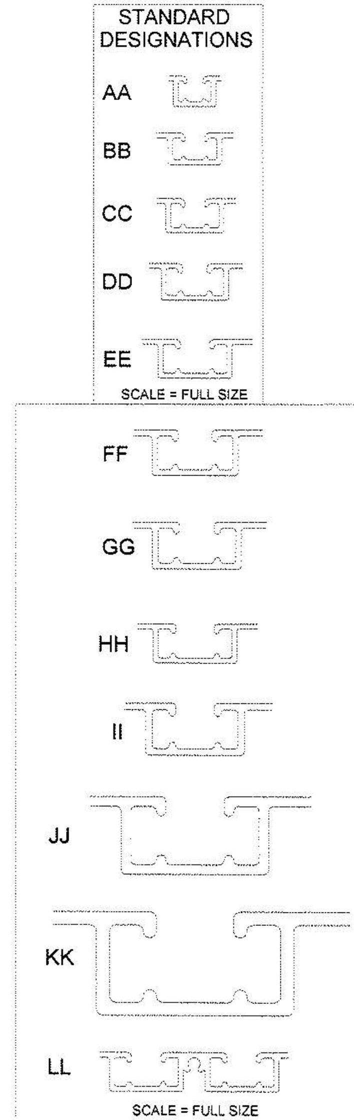


FIGURE 9: Standard and Conceptual Cavity Designs and Data

4.1.1.12 Test all design variations for structural integrity. Whenever testing new variations ensure that a statistically valid sample size is tested.

The design guidelines noted previously are not meant to be all inclusive. Commonly accepted engineering practice should be followed in the design of any component of a framing system. However, following these design guidelines should avoid most problems, when used in conjunction with guidelines for application and material quality presented elsewhere in this report.

4.1.2 Mechanically Locked, Preformed Thermal Barriers, Cavity Design

The cavity shown in Figure 10 is for a single thermal barrier strut. Normal use of mechanical locking thermal barrier systems has the profiles being used in pairs. This allows for one thermal strut to be in compression and the other in tension to provide the maximum strength for fenestration products.

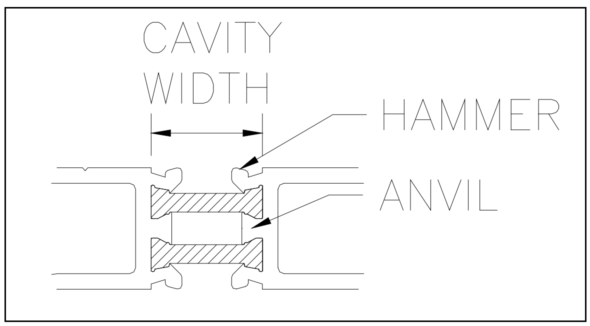


FIGURE 10: Typical Thermal Barrier Cavity

The cavity allows for the structural thermal barrier to be inserted into the aluminum extrusion. The design of the cavity is slightly oversized to allow for the knurling of the sidewalls before the profile is inserted. The profile can be inserted into the aluminum either by hand or by an insertion machine.

The knurled surface on both the hammer and anvil side of the aluminum cavity create the mechanical lock between the aluminum and the thermal barrier holding the window product together.

4.1.2.1 Knurling of the Aluminum Cavity

Before the thermal barrier is inserted into the aluminum extrusion both the interior and exterior sides of the extrusion need to be knurled. The key to the strength of a mechanical locking, pre-formed thermal barrier system is a proper knurl on the aluminum extrusions. A proper knurl will have sharp edges that allow the notches to be rolled into the thermal barrier to make contact and hold it in place. A knurling machine is used to place notches on the aluminum extrusion. Figure 11 shows the difference between a proper and an incorrect knurl on the aluminum cavity.

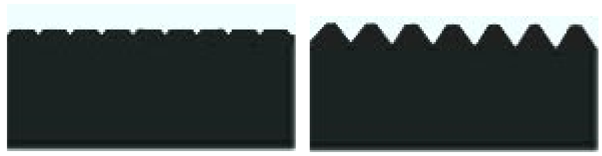


FIGURE 11: Knurl on the Aluminum Cavity

Besides having a knurling on both sides of the aluminum cavity, the knurling needs to be of equal depth on both sides of the cavity. Unequal knurling on the two sides of the aluminum cavity will produce inconsistent shear strength values across the aluminum assembly. Also, uneven knurling will create problems inserting the thermal barrier into its pocket. The knurling being too deep on the one side will grab the thermal barrier and not allow for the thermal barrier to be inserted into the aluminum cavity whether it be inserted by hand or machine.

4.1.2.2 Inserting the Thermal Barrier into the Aluminum Cavity

The thermal barrier is inserted into the pocket in the aluminum cavity by sliding it in from one end of the extrusion. This can be done by hand or by machine, one profile at a time or both at the same time. The degree of difficulty in inserting the thermal barrier into its cavity depends on the depth of the knurling in the cavity.

An aluminum extrusion without sufficient knurling will allow for the thermal barrier to be inserted very easily. The knurling will not provide any resistance in sliding the thermal barrier profiles into the respective aluminum cavities. However, without the proper knurling on the aluminum cavity a high shear strength value for the aluminum extrusion with a thermal barrier cannot be achieved.

However, an aluminum extrusion with the knurling too deep will not allow for the thermal barrier to be inserted into its cavity. The teeth on the aluminum from the knurling process will grab and hold onto the thermal barrier preventing it from being slid into the aluminum extrusion. But, more important than the depth of the knurling is the shape of the teeth on the knurl, if the knurling has sharp edges like in the proper example from Figure 11 then a high shear strength can be achieved during the crimping process on the aluminum extrusion.

4.1.2.3 Rolling of the Aluminum-Thermal Barrier Composite

After the Thermal Barriers (2) have been inserted between the two halves of the aluminum extrusion, the assembly is now ready for the rolling process. The mechanical lock is created when the aluminum cavity passes between the rolling discs and the “hammer” on the aluminum is forced into the thermal barrier.

When rolling the aluminum composite, the window manufacturer needs to be sure there is enough pressure on the rolling wheels to create the mechanical lock between the thermal barrier and the aluminum extrusion. The fabricator should consult the instruction manual on his specific insertion equipment for setting up the machine to ensure the rolling machine will crimp the aluminum with enough force to create the necessary shear strength for your fenestration products.

Also, the rolling wheels need to be properly aligned on the aluminum extrusion to ensure the hammer is rolled into the insulating strut. If the rolling wheels are not positioned properly, the aluminum can be cracked during the rolling process. Also, if the discs are not positioned properly, the hammer on the aluminum cavity will not be rolled into the insulating strut creating the shear strength for the product.

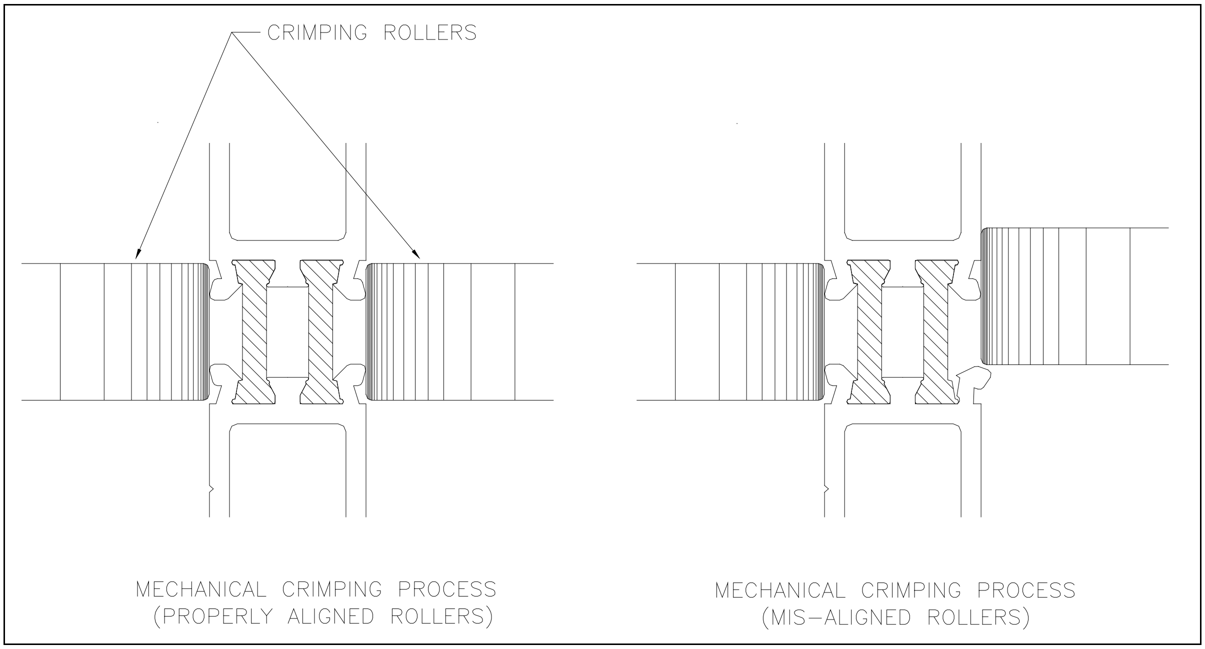


FIGURE 12: Crimping Roller Alignment

After the rolling of the aluminum extrusion, the profile is ready for use. Random testing of the assembly is recommended to ensure the quality and consistency of the insertion process.

The design guidelines previously noted are not meant to be all-inclusive. Commonly accepted engineering practice should be followed in the design of any component of a framing system. However, following these design guidelines should avoid most problems, when used in conjunction with guidelines for application and material quality presented elsewhere in this report.

4.1.3 Shrinkage

Some thermal barrier systems can experience two kinds of shrinkage, wet and dry. Wet shrinkage is the end-to-end shrinkage of freshly poured material as it gels, sets up and cools within the extrusion. Dry shrinkage is the end-to-end contraction of the thermal barrier after the composite section has been cut to size. Dry shrinkage may occur after the composite has experienced repeated thermal cycling.

4.1.3.1 Poured and Debridged Shrinkage

There are a number of factors that are known to contribute to wet shrinkage. These factors are gel time, peak exotherm temperature reached by the resin in the cavity, cavity size, extrusion mass, and the temperatures of the resin and the aluminum at the time of pouring. These factors are also dependent on the specific resin formulation used. Physically, what happens is the material in the center of the pour solidifies faster than the material near the walls of the aluminum cavity. This is due to a lower temperature at the channel wall created by the heat sink effect of the aluminum. The rate of cure, or speed of solidification, is temperature dependent. The hotter the temperature is, the faster the cure. As a result, the material near the channel remains more fluid than the core material and permits wet shrinkage to occur. Advances in urethane resin formulations have reduced the potential for wet shrinkage.

When dry shrinkage occurs, it is a result of poor adhesion of the thermal barrier to the substrate with which it is in contact. Dry shrinkage is an end-to-end exposure of cavity walls after curing and thermal cycling. Typically, the cut end of the thermal barrier, which is initially flush with the end of the extrusion cavity, pulls back or retracts evenly leaving a gap at the end. No thermal barrier material is apparent on the exposed cavity walls, hence the term 'dry shrinkage'. Since dry shrinkage occurs after the extrusion is cut and fabricated into window and door units, gaps could open up at the corners causing water and air leakage.

Dry shrinkage will typically occur after repeated exposure to environmental cycling. The large difference in coefficients of thermal expansion, between the aluminum and the thermal barrier, is one factor that creates stresses that can initiate dry shrinkage. Aluminum has a coefficient of thermal expansion of 2.3×10^{-5} mm/mm • °C (1.3×10^{-5} in/in • °F) while typical thermal barrier resins are of 9.0 to 12.6×10^{-5} mm/mm • °C (5 to 7×10^{-5} in/in • °F) or four to five times more than aluminum. As a result, the thermal barrier attempts to change dimensions more than the aluminum with the same temperature changes. At elevated temperatures the thermal barrier tries to expand more than the surrounding aluminum while at lower temperatures the thermal barrier will try to contract more. A second factor, which could affect dry shrinkage, is the temperature difference between the exterior and interior aluminum facing sections. There are ways to eliminate the potential for dry shrinkage. Surface preparation, mechanical staking, chemical adhesion, and proper selection of finish and surface treatments are the primary ways to avoid dry shrinkage. Conditions that promote dry shrinkage are cavity surfaces contaminated with grease, oil, dirt or die lubricants, metal surface pretreatments and seal coats that do not achieve adequate adhesion to the aluminum, or thermal barrier material that does not adhere to the finish. For a discussion of finishes see Section 4.2.1. Generally, dry shrinkage has always been attributed to the thermal barrier. The critical role of proper seal coat and finish selection and preparation cannot be ignored. Typically, finishes have coefficients of thermal expansion closer to the thermal barrier than the aluminum. If there is poor adhesion of the finish to the metal, dry shrinkage will occur as the bond fails at the finish-metal interface. Cavity design also influences the potential for dry shrinkage. Some designs are more resistant to shrinkage than others. When in doubt, the framing designer or manufacturer should consult the thermal barrier resin supplier about shrinkage.

4.1.3.2 Mechanical Locking Shrinkage

Mechanical Locking Thermal Barrier Systems do not experience either wet or dry shrinkage. In terms of wet shrinkage, the mechanical locking thermal barrier is usually an extruded engineering plastic that does not have a set up or gel time. The material is extruded to shape and then installed in the fenestration product.

The dry shrinkage problem occurs over thermal cycling of the fenestration product. The material chosen for the mechanical locking thermal barrier will determine if there will be any dry shrinkage. In cases, where the mechanical locking thermal barriers are glass-reinforced polyamides, there will not be any dry shrinkage. Glass reinforced polyamides have a coefficient of thermal expansion almost identical to aluminum. This results in expansion and contraction of the thermal barrier and the aluminum at the same rate during thermal cycling. This results in no dry shrinkage in a mechanical locking thermal barrier system.

4.1.3.3 Aluminum Cavity Distortion

Distortion can be the result of a number of contributing factors:

1. Cavity size and shape
2. Metal thickness of the cavity walls
3. Extrusion design
4. Processing parameters

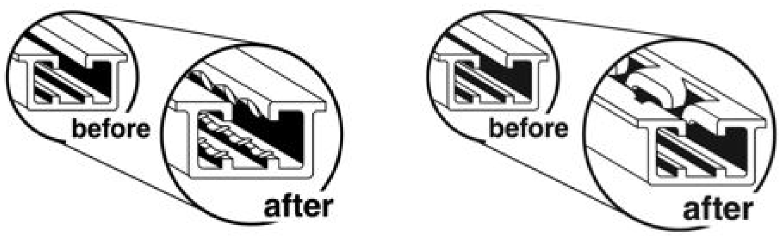


FIGURE 13: Mechanical Locking

4.1.3.4 Mechanical Locking Distortion of Aluminum

During the crimping process the aluminum extrusion can be distorted. However, the affects of the distortion are negligible if the insertion process is done properly. Most crimping machines provide three specific steps within the crimping process.

Step 1 – Straightening of the aluminum composite with the thermal barrier installed

After the thermal barrier is inserted in the aluminum extrusions the composite section is ready for the crimping process. The first step in crimping is to align the composite section to ensure it is in the right position to complete the crimping process.

Step 2 – Crimping of the Aluminum Extrusions

Once the profile is aligned properly, it is ready to pass through the main crimping stage. This is where the mechanical lock between the thermal barrier and the aluminum extrusions is actually created. During this stage, the hammer side of the aluminum extrusion is pushed into the thermal barrier profiles creating the lock between the aluminum and the thermal barrier.

Step 3 – Profile Correction Stage

The final stage of the crimping process is the correction stage to ensure that the aluminum is not distorted during the crimping process. The final stage ensures that the aluminum is straight in both the up and down direction and the left right direction. This ensures that the fenestration product will be able to be manufactured from the aluminum lineal containing the thermal barrier.

Over crimping in stage 2 could also cause distortion to the aluminum cavity. The window manufacturer needs to be sure that they are following the insertion equipment instructions on the crimping of the aluminum extrusions to ensure that they are not applying to much pressure during the crimping which could distort the aluminum cavity.

Finally, in a mechanically crimped thermal barrier system, the aluminum cavity is always changed during the crimping process. The initial design of the aluminum cavity should take this in account so that the aluminum cavity after crimping will allow for the fenestration product to be manufactured into its finished dimensions.

4.2 Cavity Surface Treatment

The cavity should be clean, dry and oil-free before installing the thermal barrier material.

4.2.1 Poured in Place Materials

Most designs rely on adhesion between polyurethane and aluminum to maximize bending stiffness, minimize dry shrinkage and prevent water from penetrating the polyurethane-aluminum interface causing leakage or freeze-thaw damage.

Due to variations inherent in manufacturing processes and project requirements, the surface treatment present on interior cavity surfaces can vary widely from one manufacturer, project or section to another. It is important that all possible surface treatments be tested for adequate adhesion to polyurethane, for example:

*Mill Finish
Conversion Coating
Primer
Paint "overspray"
Organic Paints

- Acrylic
- Polyester
- Enamel
- Polyurethane
- *Fluoropolymer

Anodic Finishes

- Clear
- Integral Color
- Electrolytically deposited color

Anodic Finish Sealing Processes

- Boiling Water Seal
- *Nickel Acetate Sealing Additives
- Anti-smut Additives

*Mill finish, fluoropolymer paint finishes and nickel acetate sealing additives within the cavity have been shown to adversely affect adhesion under some conditions and hence should be carefully evaluated.

Some designs employ a mechanical interlock and/or chemical surface preparations to limit differential longitudinal movement between polyurethane and aluminum. In all cases where adhesion is required for proper performance, it is strongly recommended that the finishing process be done before filling and debridging. On occasion poured and debridged extrusions require refinishing. Finishing processes may involve temperatures and/or chemicals which can adversely affect system performance. The supplier of the thermal barrier material should be consulted when analyzing the adhesive properties of the thermal barrier material with the various surface finishes listed previously.

4.2.2 Mechanically Locked, Preformed Profiles

In a mechanically locking, preformed thermal barrier system, the type of finish on the material does not directly affect the mechanical lock. However, the thickness of the finish on the aluminum can affect the shear strength of the assembly. Knurling wheels must not only penetrate the thickness of the finish but also the aluminum extrusions.

After the thermal barrier is installed some finishes can be applied to the aluminum without affecting the shear strength of the system. Powder coating and anodizing should not hurt the mechanical lock between the thermal barrier and the aluminum. However, before any finishing operation is performed on the aluminum, the thermal barrier supplier should be consulted to ensure that the mechanical lock between aluminum and thermal barrier will not be weakened.

Once the thermal barrier is inserted into the aluminum cavity, the complete section is ready to go through the rolling process. As the aluminum and thermal barrier pass through the rolling machine the hammer on the aluminum cavity is forced into the thermal barrier. The knurling on the aluminum is crimped into the thermal barrier creating the shear strength of the fenestration product.

4.3 Manufacturing Poured and Debridged Thermal Barriers

When applying polyurethane thermal barrier products, it is important to follow all of the manufacturers' recommendations. For this document, the manufacturing has been sub-divided into three separate and distinct phases:

1. Processing.

2. In-plant Handling and Fabrication.
3. Transportation and Installation of the Finished Product

The following sections will summarize generally acceptable procedures currently in use.

4.3.1 Material Processing

General processing parameters for polyurethane thermal barrier systems are contained in the following sections. Applicators should follow the AAMA QAG-1, “Quality Assurance Processing & Monitoring Guide for Poured and Debridged Polyurethane Thermal Barriers,” for processing and record maintenance and all of the suppliers quality control guidelines.

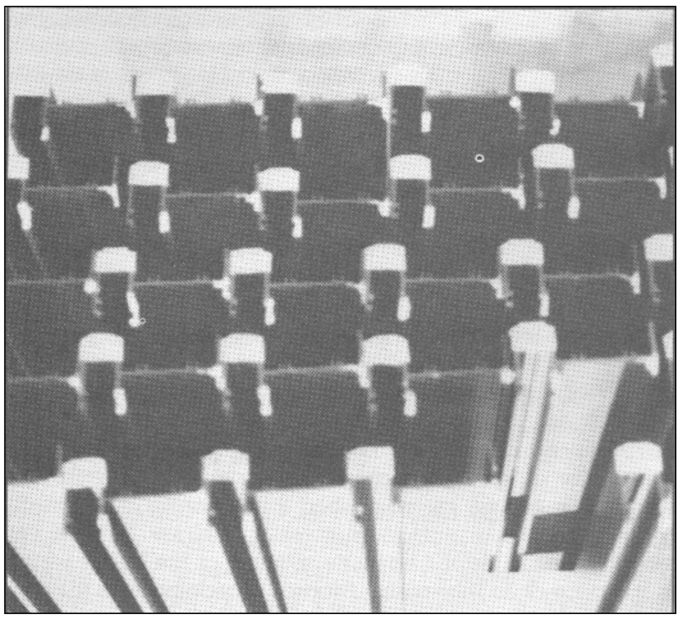


FIGURE 14: Taped Extrusions Before Pouring (When required)

4.3.1.1 Color, Mixed

A general description of color, e.g., black, clear, brown, blue, etc.

4.3.1.2 Mixing Ratio

By weight, or by volume, according to supplier's recommendations.

4.3.1.3 Viscosity, Mixed

Determine viscosity according to ASTM D2849, the mixed viscosity is determined on uncatalyzed materials. Viscosity on auto-catalytic materials may be impossible to determine.

4.3.1.4 Gel Life

Gel time in seconds is the time for mixed materials to change from a liquid to a solid.

4.3.1.5 Debridging Time

The minimum time for the mixed material to develop sufficient hardness to facilitate debridging should be determined according to ASTM D2240, “Standard Test Method for Rubber Property—Durometer Hardness.”

4.3.1.6 Cure Time

The time needed for the product to develop maximum physical properties. This will vary from material to material and should be according to the supplier's recommendations.

4.3.2 Thermal Barrier Material Quality Control

A quality control check should be made on the chemical and equipment at each start-up, and recorded. These procedures should be per the AAMA QAG-1, and consist of checks contained therein.

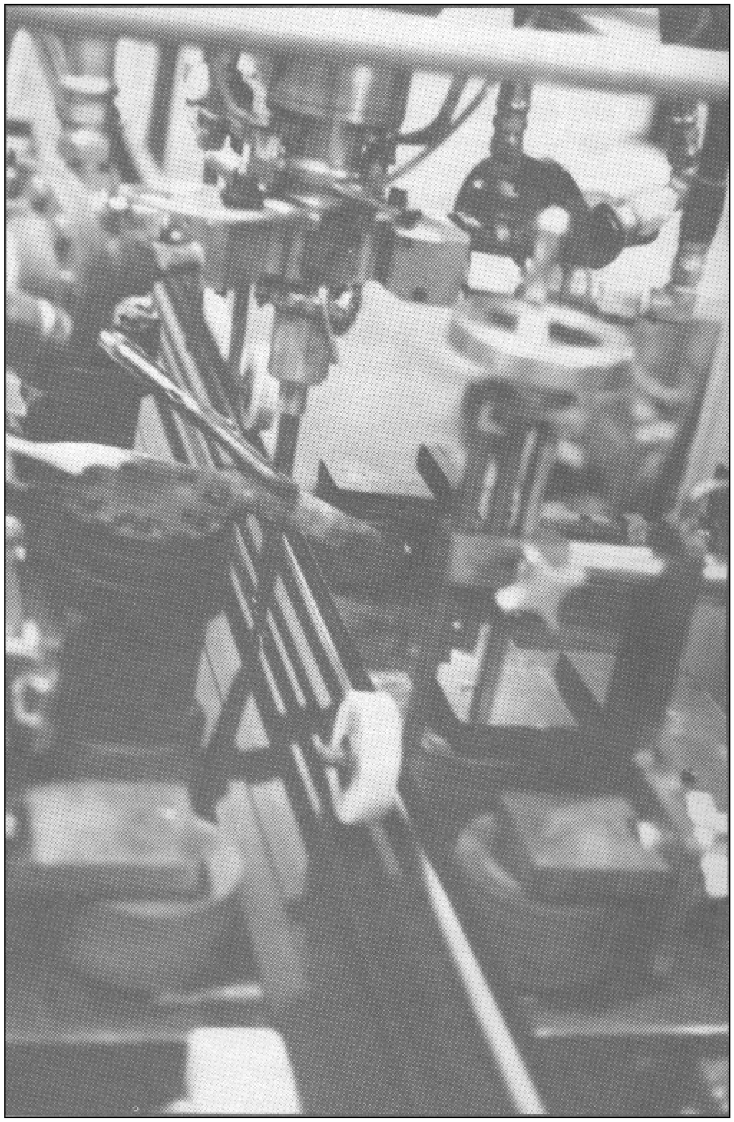


FIGURE 15: Pouring of Thermal Barrier

4.3.3 Pouring

General pouring procedures to be followed by the manufacturer:

1. Material should be level and filled to the top of the cavity.

2. Nozzle settings and pour speeds should be such that little or no air will be entrapped in the liquid fill material.

3. Appearance of the liquid surface should be smooth and free of bubbles.

4. Processing should be done in a manner such that the cavity is held upright and level until solidification has occurred.

4.3.4 Cure Time and Debridging

Debridging time is largely dependent upon the chemical characteristics of the material as provided by the supplier. Debridging time may range from 3 minutes to 24 hours for safe debridging after pouring. Proper debridging technique is largely dependent upon the following factors:

1. Poured extrusion temperature prior to debridging.

2. Aluminum mass vs. cavity size and location.

3. Cure time is affected by curing conditions, such as metal temperatures, plant conditions; and should be in accordance with the supplier's recommendations.

4. The hardness of the thermal barrier material in the cavity should not be less than a durometer reading of 65 Shore D recommended by the supplier. It is important to maintain dimensional stability during and after debridging. Stability is affected by the plastic flow characteristics of the fill material. Extrusion "kick back" at the saw is another very real danger of debridging material that is too soft.

NOTE 1: *Hardness must be measured on a smooth cut surface.*

5. Centering of the debridging cut should be between the retention lugs of the extrusion to provide maximum mechanical interlocking of the profile.

6. Debridging should be done in such a manner as not to cut into or otherwise notch the thermal barrier material to provide maximum mechanical strength to the profile while removing all of the aluminum bridge to maximize thermal performance.

7. The width of the debridging cut should range between 75% and 100% of the gap between the mechanical interlocks.

4.3.5 Handling, Care and Maintenance

Because of the unique properties of thermal barrier materials and the different handling requirements in the industry, this section will be divided into three separate areas: Handling in the Plant, Handling During Storage, and Handling During Packing and Shipping. As in any industry, certain common practices apply; the following statements could be used as a common guideline in all three categories:

1. The thermal barrier material needs time to develop its proper physical properties. This time period may vary depending on specific formulations.

2. After this period, the filled and debridged extrusions should be handled per the suppliers recommendations.

4.3.5.1 Handling in the Plant

This section is designed for the manufacturer who keeps filling, debridging, and fabrication operations in-house. The filled extrusions should not be abused after debridging. The appropriate debridging time will be supplied by the thermal barrier resin supplier. The extrusions should be stacked in such a manner as to protect their dimensional stability during cure. The extrusions should be fabricated only after recommended physical properties of the thermal barrier are reached.

4.3.5.2 Handling During Storage

This section can be used by both extruders and fabricators. Though the reasons for storage may vary, it is important to ensure quality parts are available when needed, thus the following guidelines should be observed:

Care must be taken when extrusions are going to be stored in inventory. Extrusions need to be protected from damage to the finish and distortion. Extrusions should be stored in symmetrical, banded bundles. Care must be exercised to ensure proper band tensioning and extrusions should be interleaved with paper. It should also be noted that putting excessive weight on these bundles can cause distortion and other damage.

4.3.5.3 Handling During Packing and Shipping

In addition to the concerns of the previous two sections, there are conditions specifically related to shipping: heat, cold, shock, and vibration are major considerations. Because of these factors, it is important to keep the extrusions in symmetrical bundles, with proper band tension and paper interleaf to protect surfaces to ensure dimensional stability. In addition, the bundles should be placed on the truck in such a way as to avoid excessive weight on the extrusions. Due to transporting across different geographical/climatic regions, great temperature fluctuations are likely to occur. Extreme cold or heat may affect shock resistance and dimensional stability of the extrusions.

After removing the extrusions from the vehicle at the destination, a stabilization period should be observed to bring the extrusions to room temperature. Once room temperature has been reached, follow the guidelines in the previous two sections, 4.3.5.1, Handling in the Plant and 4.3.5.2, Handling During Storage.

4.4 Installation of Poured and Debridged Thermal Barriers

4.4.1 Fabrication

Generally, the fabrication operations which are performed on thermal barrier sections are the same as those which are performed on conventional, non-thermally improved sections. These processes consist of punching, drilling, milling, sawing, shearing, curving, and straightening. The designer must consider each section with the appropriate operations in mind during initial product design. Whenever possible, these operations should be done in areas of the extrusion away from the thermal barrier cavity. If it becomes necessary to perform one or more of these fabrication operations in the cavity area, the following issues should be addressed where appropriate:

1. Provide sufficient clearance for the tooling (punch head, drill bit, milling head, etc.) to perform the desired operation without marring or distorting the surrounding section.

2. Provide direct support on the back or underside of the section behind the thermal barrier cavity so that abnormal deflections or stress concentrations do not occur, especially during punching and shearing operations.

3. Provide sufficient provision in the tooling design for chip and slug removal. Thermal barrier materials can quickly plug fabrication tooling if allowances are not made for waste material removal.

4. Make provisions to prevent saw kick-back when cutting thermal barrier material along the length of the cavity as in end notching.

5. Adjust the speed of operation, particularly punching, speed should be adjusted so as to minimize impact loading stresses.

With the cautions previously listed, fabrication of thermal barrier extrusions is not appreciably different than the fabrication of non-thermally improved sections if the designer takes into account the properties of the thermal barrier materials as well as the properties of the aluminum extrusions. In most cases common sense design and a knowledge of fabrication tooling and operations are sufficient. The only real exception to this statement is in the curving or bending of thermally improved extrusions.

Because of the unique distribution of stresses and the possibility of excessive distortion, curving of thermally improved shapes should be approached with caution by the designer. Stress concentrations and distributions can vary widely between a straight section and the same section which has been curved. Factors such as the radius and degree of curvature, the location of the thermal barrier cavity, the specific formulation of the thermal barrier the direction of curvature, the design function of the curved piece and the allowable distortion after fabrication will cause widely varying results. Often the easiest way to determine the effect of the combination of these factors is simply to have a test piece curved and then carefully examined for evidence of excessive distortion or structural failure. Occasionally design of a new section or pouring after curving may be required for curved applications.

4.4.2 Job Site Storage/Handling

Many problems that can occur with thermal barrier sections at the job site can be eliminated by proper storage and handling during installation. Whether stock length material or fabricated and partially assembled framing, the sections must not be abused. In no instance should the material be dropped onto a hard surface or subjected to sudden impact loads. If long lengths of material are handled either singly or in bundles, care should be taken to prevent excessive bending of the framing. More than a single load bearing point may be required when using slings or cables when shipping. Care must be exercised to prevent excessive distortions of the framing in bundles due to the use of "chocker slings" or other handling devices. Assembled frames should be unloaded and stored so as to prevent racking or twisting. The stacking of material should be properly blocked and piles held to a limited height to avoid the application of excessive weight to the material. Material which is received banded should be stored in this manner until actual installation is begun. All framing products should be stored in an area free from traffic and other construction activities and out of direct exposure to the sun and other elements.

Care must be exercised when anchoring the framing to the surrounding structure. Because of possibly high impact loading, power actuated fastener guns should not be used to anchor thermal barrier extrusions especially in the cavity area. Proper shimming of anchors will prevent excessive distortion of the framing as well as reduce the bending stresses in the fastener. Whenever possible fasteners, particularly perimeter anchors, should be located no closer than 75 mm (3 in) to the cut ends of the framing.

The use of excessive amounts of some solvents or cleansing agents to clean the thermal barrier sections prior to or during glazing may cause deterioration of the material. The installation contractor should check with the manufacturer of the framing for recommendations for cleaning thermal barrier sections. The compatibility of sealants with thermal barrier compounds is another matter which should be checked prior to application with either the framing manufacturer or the sealant supplier. As in the case of fabrication of thermal barrier framing, the use of common sense and strict adherence to the guidelines furnished by the framing manufacturer will eliminate most installation problems before they can occur.

4.5 Manufacturing of Mechanically Locking Preformed Thermal Barriers

When inserting mechanically locking preformed thermal barriers into aluminum extrusions, one should follow the recommendations on the insertion equipment manufacturer as well as the supplier of the thermal barrier. The manufacturing of mechanically locked preformed thermal barriers can be separated into the following subjects:

1. Knurling
2. Assembly
3. Crimping

The following sections will summarize generally acceptable procedures currently in use.

4.5.1 Knurling

1. Knurling – the notching of the aluminum cavity creating tiny points on the inside walls of the aluminum cavity. (See Figure 16)

2. The knurling should be even on both sides of the aluminum cavity holding the thermal barrier in place.

3. The knurl should be as deep as possible, but not too deep resulting in a condition where the thermal barrier profiles cannot be inserted into the aluminum cavities.

4. The knurling machine should be set up to follow all instructions as stated by the manufacturer of the insertion equipment.

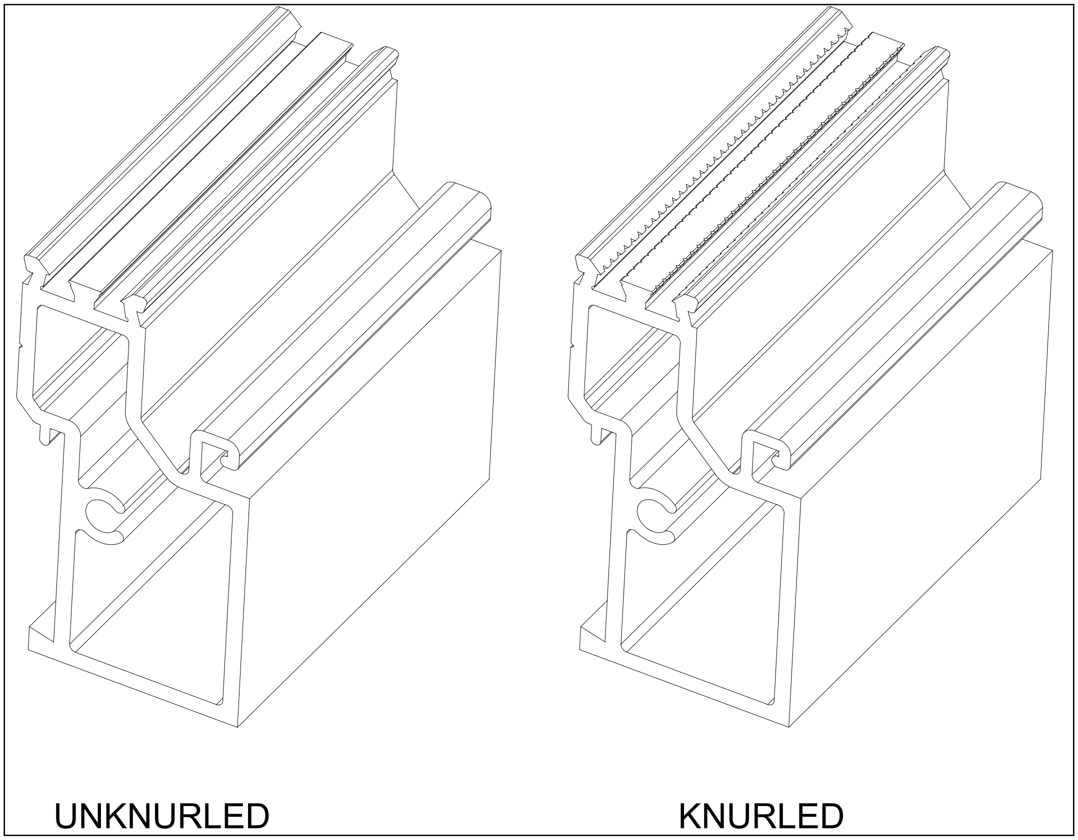


FIGURE 16: Unknurled and Knurled Profiles

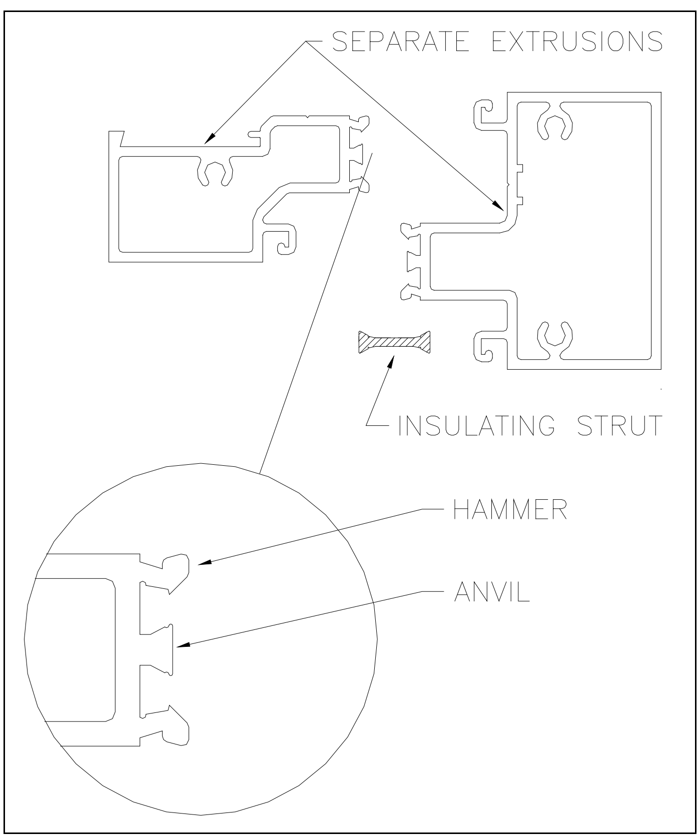


FIGURE 17: Typical Insulating Strut Thermal Barrier Parts

4.5.2 Assembly

The insulating struts are inserted into their cavities in both sections of the aluminum extrusions.

The result is one composite assembly consisting of the two separate aluminum extrusions and the thermal barrier profiles. Assembly of the aluminum composite (two aluminum extrusions and thermal barrier) can be done by two methods:

1. By hand

   If inserting by hand, one needs to simply slide the thermal barrier profiles into their respective cavities in the aluminum extrusions. As soon as the thermal barrier profiles are inserted the entire length of the aluminum extrusions, the aluminum composite is ready for the crimping process.

2. Assembly Machine

   While operating the Assembly Machine all the standard operating procedures from the equipment manufacturer should be followed.

   The equipment manufacturer will specify the configuration of the aluminum composite exiting the assembly process for transfer to the crimping process.

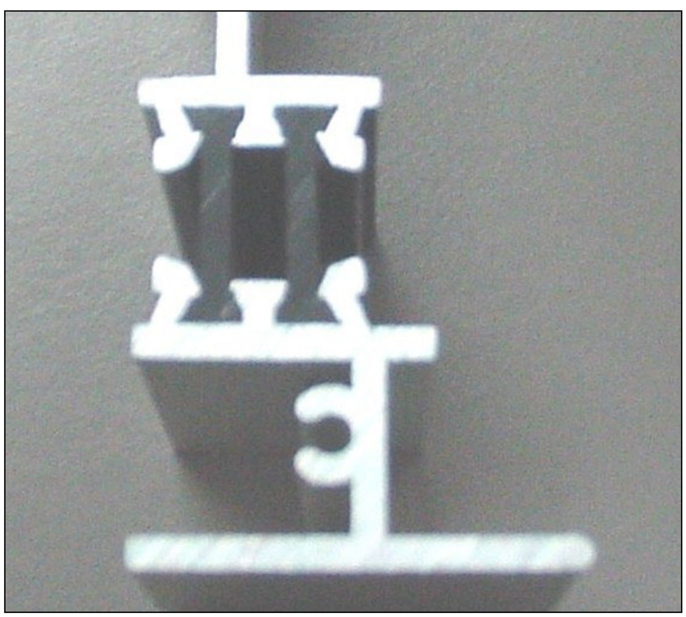


FIGURE 18: Close-Up Picture of Crimped Thermal Barrier Section

4.5.3 Crimping

1. Crimping – the squeezing of the sidewalls of the aluminum cavity to force the knurling on the inside walls of the aluminum cavity to penetrate and lock the aluminum and the thermal barrier into one assemble section.

2. During crimping, one needs to be sure that the force crimping the aluminum into the thermal barrier is even on both sides of the aluminum composite. The crimping machine will take care of this if properly adjusted.

3. One also needs to be sure that the crimping wheels are crimping the aluminum at the correct locations and squeezing the aluminum hammer into the thermal barrier.

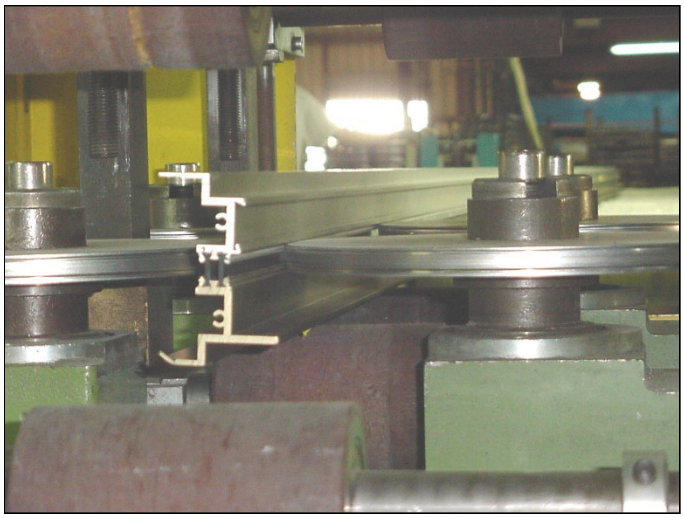


FIGURE 19: Picture of Rolling Process

4. The crimping machine can correct minor distortions of the completed aluminum composite. Consult the crimping machine instruction guide to correct minor distortion of the aluminum composite during the crimping process.

5. After completion of the crimping process, the insertion process is complete. The aluminum extrusions with the mechanically locking preformed thermal barriers are complete, there is no setup, drying, or curing time needed. The aluminum extrusions are now ready to be manufactured in to the fenestration product of choice.

While operating the crimping machine all the standard operating procedures from the equipment manufacturer should be followed.

4.5.4 Handling, Care, and Maintenance

4.5.4.1 Handling in the Plant

The Mechanically Locked Preformed Thermal Barriers should be handled just as the individual aluminum extrusions to prevent damage during handling. The mechanically locked thermal barrier has no special guidelines that need to be followed because of the insertion of the thermal barrier.

4.5.4.2 Handling During Storage

The thermal barrier extrusions should be stored and handled to prevent damage to the finish on the aluminum extrusions. One wants to make sure that no cosmetic damage occurs to the extrusions so that they can be used in the field. Care must be taken when extrusions are going to be stored in inventory. Extrusions need to be protected from damage to the finish and distortion. Extrusions should be stored in symmetrical, banded bundles. Care must be exercised to ensure proper band tensioning and extrusions should be interleaved with paper. It should also be noted that putting excessive weight on these bundles can cause distortion and other damage.

4.5.4.3 Handling During Shipping

The Mechanically locked Preformed Thermal barriers should be handled during shipping just as they are handled in the plant. They need to be shipped to avoid damage to the finishes on the aluminum extrusions during shipping.

4.6 Installation of Mechanically Locked Preformed Thermal Barriers

4.6.1 Fabrication

Generally, the fabrication operations performed on thermal barrier sections are the same as those performed on conventional, non-thermally improved sections. These processes consist of punching, drilling, milling, sawing, shearing, curving, and straightening. The designer must consider each section with the appropriate operations in mind during initial product design. Whenever possible, these operations should be done in areas of the extrusion away from the thermal barrier. If it becomes necessary to perform one or more of these fabrication operations on the thermal barrier, the following issues should be addressed where appropriate:

1. Provide sufficient clearance for the tooling (punch head, drill bit, milling head, etc.) to perform the desired operation without marring or distorting the surrounding section.

2. Provide direct support on the back or underside of the section behind the thermal barrier so that abnormal deflections or stress concentrations do not occur, especially during punching and shearing operations.

3. Provide sufficient provision in the tooling design for chip and slug removal. Thermal barrier materials can quickly plug fabrication tooling if allowances are not made for waste material removal.

4. Adjust the speed of operation, particularly punching, speed should be adjusted so as to minimize impact loading stresses.

With the cautions previously listed, fabrication of thermal barrier extrusions is not appreciably different than the fabrication of non-thermally improved sections if the designer takes into account the properties of the thermal barrier materials as well as the properties of the aluminum extrusions. In most cases common sense design and a knowledge of fabrication tooling and operations are sufficient. The only real exception to this statement is in the curving or bending of thermally improved extrusions.

Because of the unique distribution of stresses and the possibility of excessive distortion, curving of thermally improved shapes should be approached with caution by the designer. Stress concentrations and distributions can vary widely between a straight section and the same section which has been curved. Factors such as the radius and degree of curvature, the location of the thermal barrier, the direction of curvature, the design function of the curved piece and the allowable distortion after fabrication will cause widely varying results. Often the easiest way to determine the effect of the combination of these factors is simply to have a test piece curved and then carefully examined for evidence of excessive distortion or structural failure. Occasionally design of a new section may be required.

4.6.2 Job Site Storage and Handling

Proper handling of the thermal barriers sections should be followed as in the sections for poured and debridged thermal barriers Job Site Storage/Handling. Stock length material whether it be just aluminum extrusions or assembled sections with the thermal barrier should not be abused. In no instance should the material be dropped onto a hard surface or subjected to sudden impact loads. If long lengths of material are handled either singly or in bundles, care should be taken to prevent excessive bending of the framing. More than a single load bearing point may be required when using slings or cables when shipping. Care must be exercised to prevent excessive distortions of the framing in bundles due to the use of "chocker slings" or other handling devices. Assembled frames should be unloaded and stored so as to prevent racking or twisting. The stacking of material should be properly blocked and piles held to a limited height to avoid the application of excessive weight to the material. Material that is received banded should be stored in this manner until actual installation is begun. All framing products should be stored in an area free from traffic and other construction activities and out of direct exposure to the sun and other elements.

Care must be exercised when anchoring the framing to the surrounding structure. Because of possibly high impact loading, power actuated fastener guns should not be used to anchor thermal barrier extrusions especially in the cavity area. Proper shimming of anchors will prevent excessive distortion of the framing as well as reduce the bending stresses in the fastener. Whenever possible fasteners, particularly perimeter anchors, should be located no closer than 75 mm (3 in) to the cut ends of the framing.

The use of excessive amounts of some solvents or cleansing agents to clean the thermal barrier sections prior to or during glazing may cause deterioration of the material. The installation contractor should check with the manufacturer of the framing for recommendations for cleaning thermal barrier sections. The compatibility of sealants with thermal barrier compounds is another matter which should be checked prior to application with either the framing manufacturer or the sealant supplier. As in the case of fabrication of thermal barrier framing, the use of common sense and strict adherence to the guidelines furnished by the framing manufacturer will eliminate most installation problems before they can occur.

5.0 ENVIRONMENTAL IMPACT

5.1 Effect of the Environment on the Design

The effect of environmental conditions on thermal barriers should be considered in design, application and incorporation into fenestration products.

The environmental conditions to be most concerned about on exterior building products are exposure to ultraviolet light, water immersion, high humidity, high temperature, low temperature, thermal cycling and cyclic bending. While each of these should be considered on its own, it might be advisable to combine two or more when testing.

5.1.1 UV Exposure

All thermal barrier materials are resistant to structural degradation from UV exposure. Slight color change and/or surface crazing may be experienced, but this will have little effect on the strength or impact resistance of the material. In cases where there will be full, direct, exposure to the sun, it would be advisable to verify the performance with the thermal barrier supplier.

5.1.2 Water Immersion and Humidity Resistance

Thermal strut materials and polyurethane materials *based on polyether polyols* have adequate resistance to high humidity and the water immersion that would result from ponding in the sill members. Long term adhesion in chemically bonded thermal barriers may be affected with prolonged ponding of water on the thermal barrier.

5.1.3 Temperature Extremes

The extremes of temperature likely to be encountered in service will not degrade the thermal barrier material, but both high and low temperatures will affect the properties while the material is at those temperatures.

In general, temperatures encountered in normal fenestration service applications, will not subject thermal barriers to structural degradation. These extremes include both high and low temperature limits of the thermal barrier products.

5.1.4 Thermal Cycling

Alternate high and low temperatures may result in a reduction of adhesion or degradation, at interfaces between the poured and debridged type of thermal barrier, and the aluminum and the finish coats. This is a result of the difference in expansion and contraction rates between the aluminum and the thermal barrier. The coefficients of linear thermal expansion will help to determine whether or not thermal cycling may case a loss in shear strength

To determine if this phenomenon is occurring in a specific design, it is recommended that a thermal cycling test be conducted in accordance with AAMA 505, “Dry Shrinkage and Composite Performance Thermal Cycling Test Procedure.”

In the past, thermal barrier extrusions were analyzed assuming adhesion or other interlocking forces between the aluminum and the barrier material. This composite action results in a calculated moment of inertia that approaches the theoretical I value of the exterior and interior aluminum portions of the extrusions adjusted for shear deformation of the thermal barrier material itself. If a reduction in adhesion due to thermal cycling occurs during the AAMA 505 test, this shall be accounted for in calculations performed by a qualified engineer to ensure the system will not pose a safety hazard.

The AAMA 505 thermal cycling test may reveal a condition called "shrink back" or “dry shrinkage”. This is a condition where the thermal barrier shrinks back from the end causing a potential for air and water leakage. This cannot occur without a reduction in shear strength. See Section 4.1.3 for an explanation of dry shrinkage.

5.1.5 Cyclic Bending

This refers to the repeated stresses that will occur when a composite section is subjected to positive and negative wind load reversals. Experience and testing have shown that the thermal barrier materials currently being used are not adversely affected by this kind of action. If a material with a much higher modulus or a very low ultimate elongation is being considered, cyclical flexure testing should be performed.

5.1.6 Compatibility with Sealants

Materials used for thermal barriers have a good record of compatibility with all types of building sealants. For compatibility, neither the sealant nor the thermal barrier shall be adversely affected by the other. Manufacturers can provide data on compatibility of materials presently in use. Only new or untested materials need be tested for compatibility.

5.2 Effect of Thermal Barrier Materials on the Environment

Thermal barrier materials can impact on the environment in several ways, both in the manufacturing process and disposal. MSDS and Product Data sheets for the products processed should be consulted and followed. Federal, State and local laws should be reviewed to determine proper processing and disposal for the thermal barrier products being produced and handled.

6.0 TESTING

6.1 Thermal Barrier Material Properties

6.1.1 Scope

This section covers the preparation of standard-sized test samples and basic tests to determine the physical properties of thermal barrier materials (solid or cellular). The thermal barrier component supplier typically provides this data. For pour and debridge quality checks at point of application refer to AAMA QAG-1. For point of application quality checks for other thermal barrier systems, refer to the thermal barrier component manufacturer.

6.1.2 Significance

The following tests can be of value in comparing physical properties of different materials. Material properties will vary widely depending on the thermal barrier material used.

6.1.3 Description of Terms

The reader's attention is drawn to the glossary in Section 7.7. It is essential that the terms used in the body of the document be clearly understood if the document is to have full meaning.

6.1.4 Sampling of Poured Polyurethane

6.1.4.1 Test samples can be made in any suitable mold. The following two sizes are recommended: 305 mm x 150 mm x 6 mm (12 in x 6 in x 1/4 in), and 305 mm x 150 mm x 12 mm (12 in x 6 in x 1/2 in).

6.1.4.2 The procedures used to prepare the test sample relating to component ratios, temperature, mixing direction, mold temperature, and curing conditions shall conform to the supplier's recommendations.

6.1.4.3 The test sample for reference purposes shall be allowed to age a minimum of 7 days before testing at 24°C ± 6°C (75°F ± 10°F).

6.1.5 Density

6.1.5.1 Procedure

Section density can be determined on any thickness of molded material. The minimum specimen length shall be 12 mm (1/2 in). Weigh and measure the specimen to within ±1% of the value to be determined. Calculate the density as follows:

$$\text{DENSITY} = \frac{W}{V} \ (\text{kg/m}^3)$$

Where:
W = mass of specimen, kg
V = volume of specimen, m^3

6.1.5.2 Report

The report shall include the following:

1. Density, to the nearest 1.6 kg/m^3 (0.10 lbf/ft^3).
2. Thickness, Height, Length and Weight.

6.1.6 Specific Gravity

Specific Gravity of regularly or irregularly shaped materials shall be determined according to ASTM D792, “Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement.”

6.1.7 Tensile Properties

6.1.7.1 Determine the tensile strength and elongation according to ASTM D638, “Standard Test Method for Tensile Properties of Plastics.”

6.1.7.2 The following test parameters are recommended: The test specimen shall be a 19 mm wide by 6 mm thick (3/4 in wide by 1/4 in thick) sample and the crosshead speed shall be 5 mm (0.2 in) per minute. Report the tensile strength, elongation, any yield point, and % strain at the yield point if present.

6.1.8 Hardness

Determine the hardness in accordance with ASTM D2240 on the 6 mm (1/4 in) thick sample. Report the initial and a 5 second drift value as determined on the top and the bottom surfaces. If the determination is to be made at subnormal temperatures, condition the instrument at the same temperature. To prevent moisture from damaging the instrument, it is advisable to place the tester directly in a desiccator after removing it from the cold box.

6.1.9 Compression Strength

Determine the compression strength in accordance with ASTM D695, “Standard Test Method for Compressive Properties of Rigid Plastics.” Cut the specimen from the 12 mm (1/2 in.) sample, retaining the molded surfaces.

6.1.10 Impact Strength

Determine the notched Izod impact properties in accordance with ASTM D256, “Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics.” on the 12 mm (1/2 in.) sample with the mold surface in accordance with either method A or B.

6.1.11 Flexural Modulus

6.1.11.1 Determine flexural modulus, using the general procedure in ASTM D790, “Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials,” Method I.

6.1.11.2 The following test parameters are recommended for thermal plastic materials:

1. Specimen size - Length 75 mm ± 0.5 mm (3.0 in ± 0.02 in), Width 25 mm ± 0.5 mm (1.0 in ± 0.02 in) and thickness 6.4 mm ± 0.2 mm (0.250 in ± 0.01 in).

2. Span - 50 mm (2 in).

3. Rate of Crosshead Motion - 0.20 mm/sec ± 0.02 mm/sec (0.50 in/min ± 0.05 in/min).

4. Calculation - Calculate the tangent modulus of elasticity. See Section 12.5.1 of ASTM D790.

NOTE 2: *When calculating slope, use the steepest tangent as shown in Figure X1.1 of ASTM D790.*

NOTE 3: *The crosshead rate of 0.2 mm/sec (0.50 in/min) differs from the rate of 0.02 mm/sec (0.05 in/min) specified in ASTM D790. Test data has shown that the faster rate provides a lower coefficient of variation than does the slower rate.*

5. Condition a specimen at the test temperature for a minimum of 30 minutes before testing.

6.1.12 Thermal Conductivity

Determine the thermal transmission properties according to ASTM C177, "Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus," or C518, "Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus." Depending upon the size requirement of the tester, special samples may need to be prepared. [The minimum recommended size is 305 mm x 305 mm (12 in x 12 in)]. The manufacturer shall specify the mean temperature and Delta T.

6.1.13 Thermal Expansion

Determine the coefficient of thermal expansion according to ASTM D696, "Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between -30°C and 30°C with a Vitreous Silica Dilatometer," using the 3 mm (1/4 in.) thick sample. This test specifies a temperature range of -66°C to 30°C (-86°F to 86°F); a broader temperature range may be tested, however the results may not be linear.

6.1.14 Heat Deflection Temperature

Determine the deflection temperature according to ASTM D648, "Standard Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position," applying 455 kPa (66 psi) on the 12 mm (1/2 in.) specimen. The load shall be applied to the surface not in contact with the mold.

6.2 Composite Performance

Thermally improved framing members typically consist of two aluminum sections joined together along their lengths by a thermally insulating material. Poured and debridged and mechanically crimped in place thermal barriers are two commonly used designs to improve the thermal efficiency of aluminum fenestration products. For poured and debridged designs, the insulating material is usually polyurethane in composition and is poured in place over a thin metal bridge that temporarily connects the sections together. This bridge is later removed by cutting or sawing after the thermal insulation has hardened sufficiently to permit handling of the extrusions. In its final form the filled and debridged extrusion is in essence a composite structure see Figures 1 and 2). Mechanically crimped thermal barriers are assemblies which are comprised of thermal barrier struts and aluminum extrusions joined together mechanically. They are also considered composite assemblies s Figure 8). The kinds of tests required to determine the performance of thermal barrier extrusions can be divided into two groups. The first group consists of structural properties such as bending strength, shear strength, tensile strength and torsional strength. These are the kinds of properties normally required in engineering calculations. The second group consists of properties such as impact strength, creep resistance, resistance to UV, humidity, ozone and retention of bond strength. While not normally used in engineering calculations, this second group is none-the-less significant in determining the fabricating qualities of extrusions and their long term performance in the environment.

Successful extrusion design requires knowledge of the basic structural properties of the thermal barrier composite. Moment of inertia (second area moment) is important because it is a measure of stiffness and, hence, of the deflection under load of the composite. In particular it is desirable to know if the connection between the semi-sections of the extrusion can be characterized as slip-resistant (i.e., little or no slipping between sections) and stiff (i.e., very little distortion due to shear force). If it is a slip-resistant and stiff connection, then the effective moment of inertia will be higher than if the connection is not and a more cost-effective design can be achieved.

In many window and door designs much of the load is carried in shear in members designed to resist bending. Thus, shear strength of the thermal barrier composite is a significant consideration.
Tensile loads on the thermal barrier material also occur frequently, especially as a consequence of negative wind pressure. Torsional loads are placed on the thermal barrier material either as a direct function of design considerations or as a result of gasket pressures in dry glazing systems.

The reader may refer to Section 7.5 for a method to calculate design values for effective moment of inertia (I'_e), effective section modulus (S_e) and core shear for a thermal barrier composite. The beam span, section properties of each aluminum component, load type (uniform, concentrated, triangular or trapezoidal), cavity dimensions and the shear modulus of the thermal barrier are needed for input.

Thermal barrier properties may be temperature dependent. Thus, the beam's design properties must be evaluated with a shear modulus value corresponding to the highest appropriate temperature expected at the mid-depth of the thermal barrier. See Section 6.5 and note that the average of the metal temperatures of the exterior and the interior sides of the window frame may be conservatively taken as the average thermal barrier temperature.

A calculation tool based on the design method in Section 7.5 has been developed to ~~allow~~ reduce possible calculation mistakes. This makes the method practical for quick, simple and suitably accurate evaluation of composite properties for many shapes and sizes of extrusions. The method is based on original research done by John A. Hartsock.

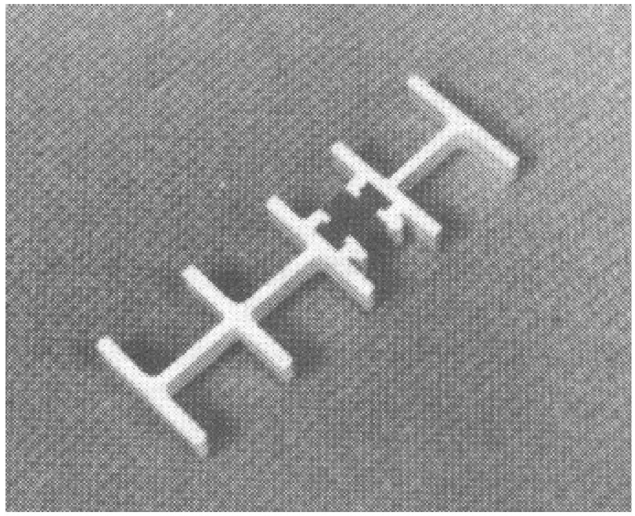


FIGURE 20: Profile with Thermal Barrier System

The AAMA test extrusions were developed to provide the AAMA Thermal Barrier Structural Systems Task Group with useful and adaptable test samples at a minimal amount of cost, for promulgation of viable test procedures and parameters. The modified I-beam is easily gripped in fixtures for structural tests. Webs and/or flanges can be removed by sawing, to change the moment of inertia and location of the thermal barrier with respect to the neutral axis. They also provide a "standard" cavity for thermal barrier material suppliers' evaluation of various polyurethane formulations "in place". The AAMA Test Extrusions are NOT representative of typical thermal barrier window shapes, were NOT intended for verification of product performance, and should NOT be used as such. Manufacturers' standard extrusion shapes and cavity configurations in general make the most appropriate samples for this type of testing.

6.3 Comparative Testing

There are many reasons for testing products with thermal barriers. Testing can be performed to verify composite performance as previously outlined. Testing can also be used as a means of comparing various aspects of the design of thermal barrier products. If the designer is interested in evaluating different thermal barrier materials, he may choose to perform a series of tests using a standard cavity such as the AAMA test extrusion filled with different barrier materials under various testing conditions. This would be very useful in ascertaining which thermal barrier compound or design best fits the design conditions.

Another type of comparison might be obtained by testing several prospective cavity designs utilizing the same thermal barrier compound or design. This type of testing is very helpful in optimizing cavity design for the anticipated design service conditions. Normally, the manufacturer does this type of testing during the initial development of a new product.

Comparison testing of entire product lines, one against another, is seldom done due to the high cost of testing. Suppliers and manufacturers of thermal barrier products generally publish complete data on the performance levels that can be expected from their products. This information is usually sufficient to evaluate and select the optimum product for a particular installation. The cost-conscious user of architectural framing specifies mock-up testing only when unique or special job conditions warrant the cost of additional testing.

6.4 Testing Procedures

There are many procedures that can be used to test thermal barrier products and materials. AAMA has developed testing procedures for flexural, tensile, shear and torsional testing of thermal barrier composites. These procedures are outlined in this TIR along with other procedures for testing thermal barrier compounds. The procedures given are those that were used to develop the test data and background information presented in other sections of this TIR. (Refer to Sections 7.2, 7.3 and 7.4).

6.5 Temperature Concerns

Many factors affect the temperature of architectural metals. Ambient air temperatures tend to determine the lowest experienced metal temperatures. However, the highest temperatures experienced by the metal may be significantly higher than the highest ambient air temperatures. This phenomenon is primarily attributable to the absorption of radiant energy from the sun by exposed metal surfaces. The amount of radiant energy absorbed is affected by the color of the metal surface, shading of the metal and the angle of incidence of the sun's rays on the exposed surface. Dark surfaces that are unshaded and on the sunny side of the building will experience surface temperatures much higher than ambient air temperatures. Conversely, metal that is light colored and shaded may reach surface temperatures only slightly higher than ambient air temperatures. Since most thermal barrier systems are designed to glaze insulating glass units, the inside metal surfaces will experience a considerably smaller temperature range than the exterior faces of the framing. In addition, if the glass is coated with a reflective or Low-E coating, the inside metal is shaded as well as insulated from the sun's radiant energy. Under these conditions, inside metal surface temperatures may vary little from ambient room temperature in occupied buildings. In composite thermal barrier systems, the differential temperature between the interior and the exterior metal may cause the framing members to deflect. For example, on a hot day, the exterior will tend to expand more than the interior creating an outward deflection. Conversely, on a cold day, when the exterior metal is much colder than the interior metal the framing member will tend to deflect inward. These deflections result in additional shear stresses in the thermal barrier that are similar to the shear stresses caused by wind loads. Thermal deflections and stresses may be additive or help cancel out deflections and stresses caused by wind loads.

Consideration should be given to these deflections and stresses during the design of a project. Refer to ASHRAE’s Handbook of Fundamentals for Heating and Wind Design Conditions for various portions of the United States, Canada and other World Locations. It is very unlikely that these temperature extremes will correspond with the maximum design wind loads; therefore when combining these loads it is generally acceptable to apply a combined load reduction factor.

The flow of energy in a thermal barrier composite section must also be considered. This flow is greatly affected by the surface area to mass ratio of both the interior and exterior exposed framing members. Therefore, even though an exposed exterior face may become very hot from radiant energy in still air, if the mass is relatively low compared to the exterior surface area it will tend to cool very rapidly convectively when the wind blows. This is particularly true of a material with high thermal conductivity such as aluminum. This means that when a wind load is applied to the framing, the temperature of the external face will be much closer to ambient air temperature than when there is no wind. The temperature on the interior surface is difficult to predict but it will sometimes reach a temperature in excess of 11°C (20°F) above ambient depending on interior conditions such as drapes, blinds and recesses. This moderates the effect of radiant energy on the temperature gradient through the framing. This effect should also be of prime concern to the design professional when analyzing the appropriateness of a particular framing application.

6.5.1 Thermal Performance Factors

When choosing a particular framing system, the design professional should address the following minimum set of factors affecting thermal performance:

1. What is the color of the framing?
2. Where is the glazing located with respect to the depth of the frame?
3. Where is the thermal barrier located with respect to the depth of the frame?
4. Is the glazing material insulating
5. Is the glazing material coated with a reflective film?
6. What is the orientation of the framing with respect to the sun?
7. Is the glazing system shaded by an overhang or shrubs and for what period of time?
8. What will be the ambient air temperature(s) on the inside of the occupied building?
9. What is the lowest outside air temperature for the building location from past climate data?
10. What is the highest outside air temperature for the building location?
11. Is the climate predominately sunny or predominately cloudy?
12. Will the building be exposed to gusting winds?
13. Has the proposed system been tested for the expected conditions listed?
14. Are there any special conditions or factors that may adversely affect the performance of the product?
15. What is the CRF (Condensation Resistance Factor) of the proposed system?
16. What is the Thermal Transmittance (U Value) of the proposed system?
17. What is the Solar Heat Gain Coefficient (SHGC) of the proposed system?
18. Are there insulated spandrel areas included in this installation?

After all of the applicable factors have been determined, the designer can delineate the appropriate thermal performance specifications.

6.5.2 Guidelines

The following guidelines were derived from the experiences of and the testing done by the members of FGIA, the National Research Council of Canada, the American Society of Heating, Refrigeration and Air Conditioning Engineers and other sources involved in the glazing industry and related fields. They should not be construed as absolutes but rather as guidelines to assist the design professional who will make the ultimate specifications decision based on knowledge and experience.

6.5.3 Examples

The following examples indicate the method of determining the approximate surface temperatures for various geographical locations:

6.5.3.1 Example #1:

Location: Indianapolis, Indiana
Ambient outside air temperature (OAA): -32°C (-25°F) in the winter, 41°C (106°F) in the summer.

Building is glazed on all four sides and oriented with one axis north to south and the other axis east to west. The framing will be clear anodized (Condition 6) with reflective insulating glass (Condition 1). Tempered air inside the building will be maintained at approximately 21°C (70°F) both winter and summer (IAA).

Condition		SUMMER	WINTER
1	Any Inside Metal with Coated/Insulating Glass	IAA + {11°C (20°F)} to IAA + {17°C (30°F)}	IAA - {11°C (20°F)} to IAA - {6°C (10°F)}
2	Any Inside Metal with Clear/Insulating Glass	IAA + {17°C (30°F)} to IAA + {22°C (40°F)}	IAA - {28°C (50°F)} to IAA - {6°C (10°F)}
3	Any Inside Metal with Coated/Monolithic Glass	IAA + {28°C (50°F)} to IAA + {33°C (60°F)}	IAA - {11°C (20°F)} to IAA - {6°C (10°F)}
4	Any Inside Metal with Clear/Monolithic Glass	IAA + {39°C (70°F)} to IAA + {44°C (80°F)}	IAA - {11°C (20°F)} to IAA - {6°C (10°F)}
5	Any Outside Metal which is Shaded with Any Glazing	OAA + {6°C (10°F)} to OAA + {11°C (20°F)}	Equal to OAA
6	Any Outside Metal with a Light or Reflective Coating with Any Glazing	OAA + {17°C (30°F)} to OAA + {22°C (40°F)}	Equal to OAA
7	Any Outside Metal with a Medium Shade Coating with Any Glazing	OAA + {22°C (40°F)} to OAA + {28°C (50°F)}	Equal to OAA
8	Any Outside Metal with a Dark or Black Coating with Any Glazing	OAA + {28°C (50°F)} to OAA {33°C + (60°F)}	Equal to OAA

CHART 1: Temperature Concerns

From Chart 1, the inside surface temperatures (Condition 1) would be:

IST_S = IAA + (11°C) to IAA + (17°C) = (21°C + 11°C) to (21°C + 17°C) = 32°C to 38°C (90°F to 100°F) in summer.

IST_W = IAA – (11°C) to IAA – (6°C) = (21°C - 11°C) to (21°C - 6°C) = 10°C to 15°C (50°F to 60°F) in winter.

From Chart 1, the outside surface temperatures (Condition 6) would be:

OST_S = OAA + (17°C) to OAA + (22°C) = (41°C + 17°C) to (41°C + 22°C) = 58°C to 63°C (136°F to 146°F) in summer.

OST_W = Equal to OAA = -32°C (-25°F) in winter.

The inside thermal range (hottest summer inside surface temperature to coldest winter inside surface temperature) would be:

ISR = 38°C – 10°C = 28°C (50°F)

The outside thermal range (hottest summer outside surface temperature to coldest winter outside surface temperature) would be:

OSR = 63°C – (-32°C) = 95°C (171°F)

The thermal barrier temperatures (average of hottest inside and hottest outside surface temperatures) would be:

TBT_S = (38°C + 63°C)/2 = (101°C)/2 = 50.5°C (123°F) in summer.

TBT_W = [15°C + (-32°C)]/2 = (-17°C)/2 = -8.5°C (17.5°F) in winter.

The temperature range for the thermal barrier material would be:

TBR = 50.5°C to -8.5°C or a range of 59°C (105.5°F)

6.5.3.2 Example #2:

Location: Seattle, Washington
Ambient outside air temperature (OAA): -16°C (3°F) in the winter, 37°C (98°F) in the summer.

Building is glazed on the north and west sides and oriented with one axis northeast to southwest and the other axis northwest to southeast. The framing will be light bronze anodized (Condition 7) with clear insulating glass (Condition 2). The glazed openings are shaded under a 2 m (6 ft) overhang with coniferous ground shrubs. Tempered air inside the building will be maintained at approximately 18°C (65°F) in the winter and 24°C (75°F) in the summer (IAA).

From Chart 1, the inside surface temperatures (Condition 2) would be:

IST_S = IAA + (17°C) to IAA + (22°C) = (24°C + 17°C) to (24°C + 22°C) = 41°C to 46°C (105°F to 115°F) in summer.

IST_W = IAA – (28°C) to IAA – (6°C) = (18°C - 28°C) to (18°C - 6°C) = -10°C to 12°C (15°F to 55°F) in winter.

From Chart 1, the outside surface temperatures (Condition 7) would be:

OST_S = OAA + (22°C) to OAA + (28°C) = (37°C + 22°C) to (37°C + 28°C) = 59°C to 65°C (138°F to 148°F) in summer.

OST_W = Equal to OAA = -16°C (3°F) in winter.

The inside thermal range (hottest summer inside surface temperature to coldest winter inside surface temperature) would be:

ISR = 46°C – (-10°C) = 56°C (100°F)

The outside thermal range (hottest summer outside surface temperature to coldest winter outside surface temperatures) would be:

OSR = 65°C – (-16°C) = 81°C (145°F)

The thermal barrier temperatures (average of hottest inside and hottest outside surface temperatures) would be:

TBT_S = (46°C + 65°C)/2 = (116°C)/2 = 55.5°C (131.5°F) in summer.

TBT_W = [12°C + (-16°C)]/2 = (-4°C)/2 = -2°C (29°F) in winter.

The temperature range for the thermal barrier material would be:

TBR = 55.5°C to -2°C or a range of 57.5°C (102.5°F)

6.5.3.3 Example #3:

Location: Phoenix, Arizona
Ambient outside air temperature (OAA): -9°C (16°F) in the winter, 48°C (119°F) in the summer.

Building is glazed on all four sides and oriented with one axis north to south and the other axis east to west. The framing will be black anodized (Condition 8) with clear monolithic glass (Condition 4). Tempered air inside the building will be maintained at approximately 24°C (75°F) in the winter and 18°C (65°F) in the summer (IAA).

NOTE 4: *Because the southern exposure is next to a highly reflective surface (the swimming pool), the designer may wish to increase the outside summer surface temperature. The winter outside surface temperature would be unaffected because at -9°C (16°F) the pool would either be drained or covered. A summer outside surface temperature of 88°C (190°F) will be used for this example.*

From Chart 1, the inside surface temperatures (Condition 4) would be:

IST_S = IAA + (39°C) to IAA + (44°C) = (18°C + 39°C) to (18°C + 44°C) = 57°C to 62°C (135°F to 145°F) in summer.

IST_W = IAA – (11°C) to IAA – (6°C) = (24°C - 11°C) to (24°C - 6°C) = 13°C to 18°C (55°F to 65°F) in winter.

From Chart 1, the outside surface temperatures (Condition 8) would be:

OST_S = OAA + (28°C) to OAA + (33°C) = (48°C + 28°C) to (48°C + 33°C) = 76°C to 81°C (169°F to 179°F) in summer. (The designer has chosen to use an outside surface temperature of 88°C (190°F) for this project.

OST_W = Equal to OAA = -9°C (16°F) in winter.

The inside thermal range (hottest summer inside surface temperature to coldest winter inside surface temperature) would be:

ISR = 62°C - 13°C = 49°C (90°F)

The outside thermal range (hottest summer outside surface temperature to coldest winter outside surface temperature) would be:

OSR = 81°C – (-9°C) = 90°C (163°F)

Since the designer has decided to use an altered outside summer surface temperature for this project, his specification would produce an outside surface temperature range of:

OSR_P = 88°C – (-9°C) = 97°C (174°F)

The thermal barrier temperatures (average of hottest inside and hottest outside surface temperatures) would be:

TBT_S = (62°C + 81°C)/2 = (143°C)/2 = 71.5°C (162°F) in summer.

Since the designer has decided to use an altered outside summer surface temperature for this project, his specification would produce a thermal barrier temperature of:

TBT_{SP} = (62°C + 88°C)/2 = (150°C)/2 = 75°C (167.5°F) in summer.

TBT_W = [18°C + (-9°C)]/2 = (9°C)/2 = 4.5°C (40.5°F) in winter.

The temperature range for the thermal barrier material would be:

TBR = 71.5°C to 4.5°C or a range of 67°C (121.5°F).

Since the designer has decided to use an altered outside summer surface temperature for this project, his specification would produce a thermal barrier temperature range of:

TBR = 75°C to 4.5°C or a range of 70.5°C (127°F).

The previous examples indicate how the factors mentioned earlier can affect the required performance of the thermally broken framing system. It is up to the person writing the thermal specifications for the installation to clearly outline the applicable factors and intelligently interpret the manner in which these factors impact thermal specifications. Only in this manner can poorly written, incomplete or unrealistic thermal specifications be avoided.

The examples provided approximate cases with a low solar effect, with a moderate solar effect and with an extreme or severe solar effect on the temperature of the thermal barrier material. The following Table 1 summarizes the results:

Solar Exposure	Project Conditions	Thermal Barrier Temperature

Low (Example #1)	Clear anodized framing with reflective insulating glass in Indianapolis, Indiana.	50.5°C (123°F) to -8.5°C (17.5°F)
Moderate (Example #2)	Light Bronze anodized framing with shaded clear insulating glass in Seattle, Washington.	55.5°C (131.5°F) to -2°C (29°F)
Severe (Example #3)	Black anodized framing with clear monolithic glass in Phoenix, Arizona.	71.5°C (162°F) to 4.5°C (40.5°F)
Altered Severe (Example #3 with modification)	Black anodized framing with clear monolithic glass next to a reflecting pool in Phoenix, Arizona. (Architect has specified higher outside metal temperatures.)	75°C (167.5°F) to 4.5°C (40.5°F)

TABLE 1: Results of Thermal Analysis

6.6 Testing Temperatures

The temperatures, temperature ranges and thermal guidelines given in Table 1 are very useful to those selecting or specifying thermally broken framing systems. They can also be of considerable use to manufacturers of framing systems and suppliers of system components. Suggested test methods for determining the bending, tensile, shear and torsional properties of thermally broken sections are given in this TIR. Since the properties being tested may vary widely with temperature, it is paramount that appropriate testing temperatures be determined prior to testing.

Test data should be obtained at enough different temperature settings to adequately represent the field conditions under which the design will perform. A minimum number of thermal test points would represent room temperature, 24°C (75°F), and the highest temperature which the thermal barrier material would experience under field conditions as outlined in the guidelines previously given. A complete temperature profile would include test data at -18°C (0°F), room temperature, 24°C (75°F), 60°C (140°F) and 71°C (160°F) as measured at the thermal barrier. The first temperature range would be appropriate during product testing while the second range would be more useful during product development.

The selection of temperature criteria for testing purposes should be done with caution and due consideration of the cost of testing. Care should be exercised that the test results are derived from testing done under conditions as close to anticipated field conditions as possible. If in doubt, use the guidelines previously offered or consult qualified engineering personnel. It is usually desirable to evaluate the performance of several composite designs and materials during product development. Therefore a wider range of test temperatures and the concurrent increased cost of testing is justified.

However, once the design and materials have been finalized, only those test temperatures representing the extremes of product thermal exposure are justifiable from a cost of testing standpoint. If the manufacturer has performed this minimum amount of testing and provides this data to the product user or specifier, then it is doubtful that job testing for thermal performance would serve any useful purpose. Only in situations where anticipated field conditions exceed the temperature extremes tested would additional testing be appropriate.

6.7 Safety Factors

To address longitudinal shear, eccentric load and transverse tension an appropriate safety factor should be applied to test results. The factors to be considered in determining appropriate safety factors include, but are not limited to, pocket design and expected tolerance thereof, alloy and temper or aluminum retaining features, mechanical properties of the thermal barrier material (including isotropy and homogeneity) permanent deformation (staking, knurling, or crimping), if necessary to retain the thermal barrier material (poured-and-debridged or strut), surface finish, equipment set-up and operation/calibration, speed at which the thermal barrier is poured, air pockets or other voids, change in cross-sectional area during cure, and component and environmental conditions during manufacture, testing and/or use.

In all cases the test specimens referenced in the following must be representative of the assemblies proposed for use. Only the design professional can determine if a test specimen is representative of the assemblies proposed for use.

6.7.1 Longitudinal Shear

The average values from testing are divided by an appropriate safety factor to determine the allowable values used for structural design of the composite member. The following recommendations and discussion are based on a study of the safety factor (S_F) for longitudinal shear strength. This study considered a procedure in Section 8.3 of the Aluminum Association's the "*Specifications for Aluminum Structures; Allowable Stress Design*" (7th edition) and test data for six sets of 20 specimens each. (~~This~~The updated version of this document has since been incorporated into the Aluminum Design Manual.) Each set used a different combination of cavity finish and polyurethane barrier.

Testing should be used to establish the effective shear modulus (G_{ce}) for thermal barrier assemblies (installed thermal barriers). Use of published G_c (uninstalled thermal barrier material) may be non-conservative in any calculations which should use effective shear modulus G_{ce} for the installed condition.

NOTE 5: In the event there is a lack of test data, an upper bound default value of 80 ksi effective shear modulus for strut systems could be used; for poured and debridged systems a default value of 100 ksi could be used. The upper bound values would be used to calculate maximum shear flow values. Similarly, lower bound values (10 ksi for strut systems and 20 ksi for poured and debridged systems) would be used to calculate deflections. These default values exclude any foamed products for polyurethane or polyamide materials for which values are not commonly known.

A minimum safety factor of 2.5 is given in AAMA 505. Because the thermal barrier connects the aluminum facing sections together and due to the associated need for high reliability, S_F = 2.5 is higher than values used for non-connection limit states (e.g., member yielding and buckling).

The value of 2.5 for the safety factor, for longitudinal shear strength, has been found to be appropriate for products after thermal cycling per AAMA 505 with a coefficient of variation (C_v) not exceeding 11.9%. If a product (with a particular combination of cavity surface finish, specific thermal barrier type, etc.) has a C_v greater than 11.9%, then the required safety factor, but not less than 2.5, should be computed using the Aluminum Association's specifications".

The value of 11.9% is b”sed in part on review of six sets of data (for variations and trends), but more generally on Section 8.3.1 of the Aluminum Association's Specifications (7th Edition). This value is based on the use of a 1.5 load factor to calculate a value of 0.6 (= 1.5 / 2.5) for the capacity factor (φ), and a statistical coefficient K of 3.37 for 18 specimens. The nominal value of strength ($S_{n)}$) is considered to be the average (X_m). The value 0.6 is then substituted in Equation 8.3.1-1 (see AA Specifications; 7th Edition), written in terms of C_v and φ:

$$X_a = X_m - K\, S_x = \varphi\, S_n = \varphi\, X_m$$

$$\varphi\, X_m / X_m = (X_m - K\, S_x) / X_m = 1 - K\, C_v = \varphi = 0.6$$

$$C_v = (1-0.6) / 3.37 = 0.1187$$

Both sides of Eq. 8.3.1-1 have been divided by X_m to express the equation in terms of φ and C_v. The calculated value is of C_v is 11.87%.

Some interpretation is needed to use the other method (Method 2) which is given in Section 8.3.2 of the Aluminum Association's Specifications (7th Edition), and engineers may differ on exactly what values to use for the formula in that section. If one uses the default values of input parameters plus β_0 = 3.5 (connections), V_F = 0.05 (structural members) and V_p (same as C_v) = 0.1196, then Eq. 8.3.2-1 produces a required safety factor (S_F)of 2.5002.

Note that use of Method 2 in the ADM, (Appendix 1, Section 1.3.2), using the same input parameters, also results in SF = Ω = 2.5002.

Thus, this approach supports the use of 11.9% for C_v since 0.1196 is greater than 11.9%. This approach has some conservatism in it but much less so than using V_F of 0.15 for welded connections.

The use of SF = 2.5 is also recommended for two other limit states for a thermal barrier: failure due to tensile load (perpendicular to length) and failure due to eccentric load. Refer to section 7.3 for test procedures.

6.7.2 Transverse Tension

Because of its high importance, an installed thermal barrier's resistance to transverse tension should have a greater degree of reliability. The selected reliability index is 4.0. This is the β value in ASCE/SEI 7, "Minimum Design Loads and Associated Criteria for Buildings and Other Structures," (Table 1.3-1) for Risk Category II buildings, which includes most buildings, for a component whose failure would be sudden and cause widespread progression of damage. There are some buildings that may require a higher performance level. A higher β value exists for Risk Categories III and IV.

For a 50-year reference interval, for a maximum expected wind load, ~~e~~ β = 4.0 corresponds to a failure probability of 0.003% (3×10^{-5}).

The required (calculated) safety factor, based on Appendix 1 (Method 2) in the ADM, varies depending on the number of tests (*N*) and coefficient of variation (C_v). The recommended minimum safety factor (S_F) equals 3.0. This exceeds the required value for all combinations of $N \geq 10$ and $C_v \leq 12\%$.

6.7.3 Eccentric Load

A safety factor for eccentric load has not been established. Based on the other safety factors that are used it is assumed that the safety factor for eccentric load does not need to be as high as 3.0 but the exact number has not been determined. It is the responsibility of the user of the document to determine the safety factor that is to be used, however it is suggested that the safety factor be no lower than 2.5.

6.7.4 Creep

Creep is defined in FGIA Glossary as “Time dependent part of strain resulting from stress.”

Creep is a phenomenon that exists for all materials and is dependent upon the load that is applied and the length of time that the load is applied. It is generally assumed that the higher the load and the longer the time the amount of creep will be greater than lighter loads or shorter periods of time. There is a limit to the amount of creep for materials and extending to longer times or higher temperatures may not result in a significant amount of increased deflection.
Increased strain translates to increased deflection.

Temperature can also have an impact on the potential creep thus room temperature performance may differ from elevated temperature performance.

Analysis should consider strength as well as movement, deflection or rotation which may affect serviceability in:

1. Thermal barrier material
2. Interlock between thermal barrier material and the extrusion(s)
3. Overall assembly deflection or rotation
4. Local stresses near the setting blocks

Using the concept of load path, as an example, the designer can evaluate the effect of glass weight being transferred from the glass to perimeter framing, jamb or mullion, eventually to be resolved into the substrate. (See Figure 21.) Creep may affect uniform support of both lites of the insulating glass unit, in which case the secondary seals’ ability to resist such movements and loads must be quantified.

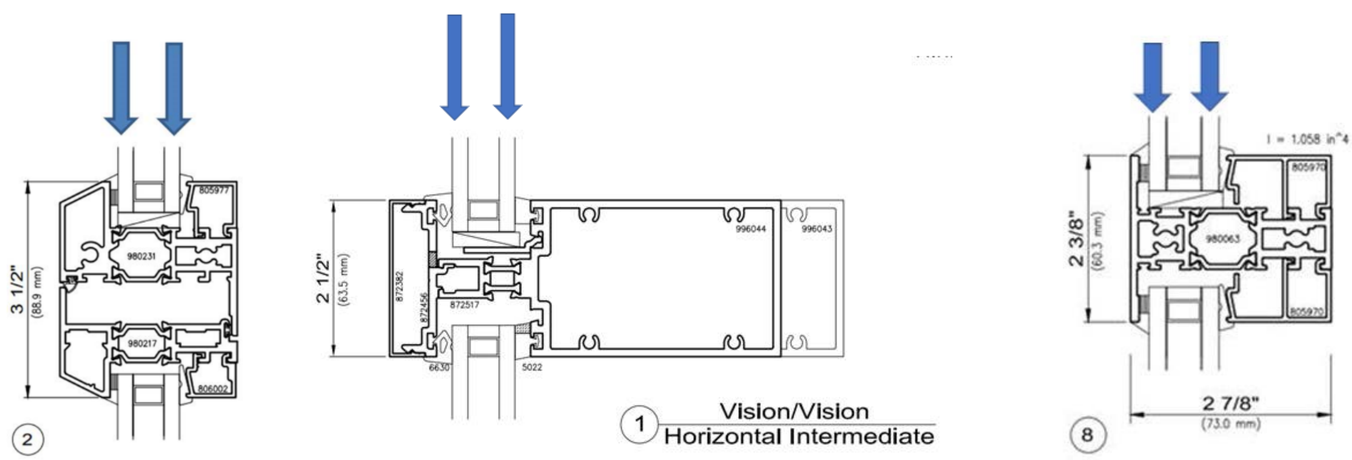


FIGURE 21: Representative Examples of Glass Load Support

Additional testing may be necessary to quantity creep in certain situations.

Creep characteristics will vary with specific thermal barrier materials.

1. While primarily of concern in eccentric load conditions, (deadload of glazing infill) other orientations and load cases may introduce concerns with creep.

7.0 ADDITIONAL CONSIDERATIONS

7.1 Cross Section Die Profile

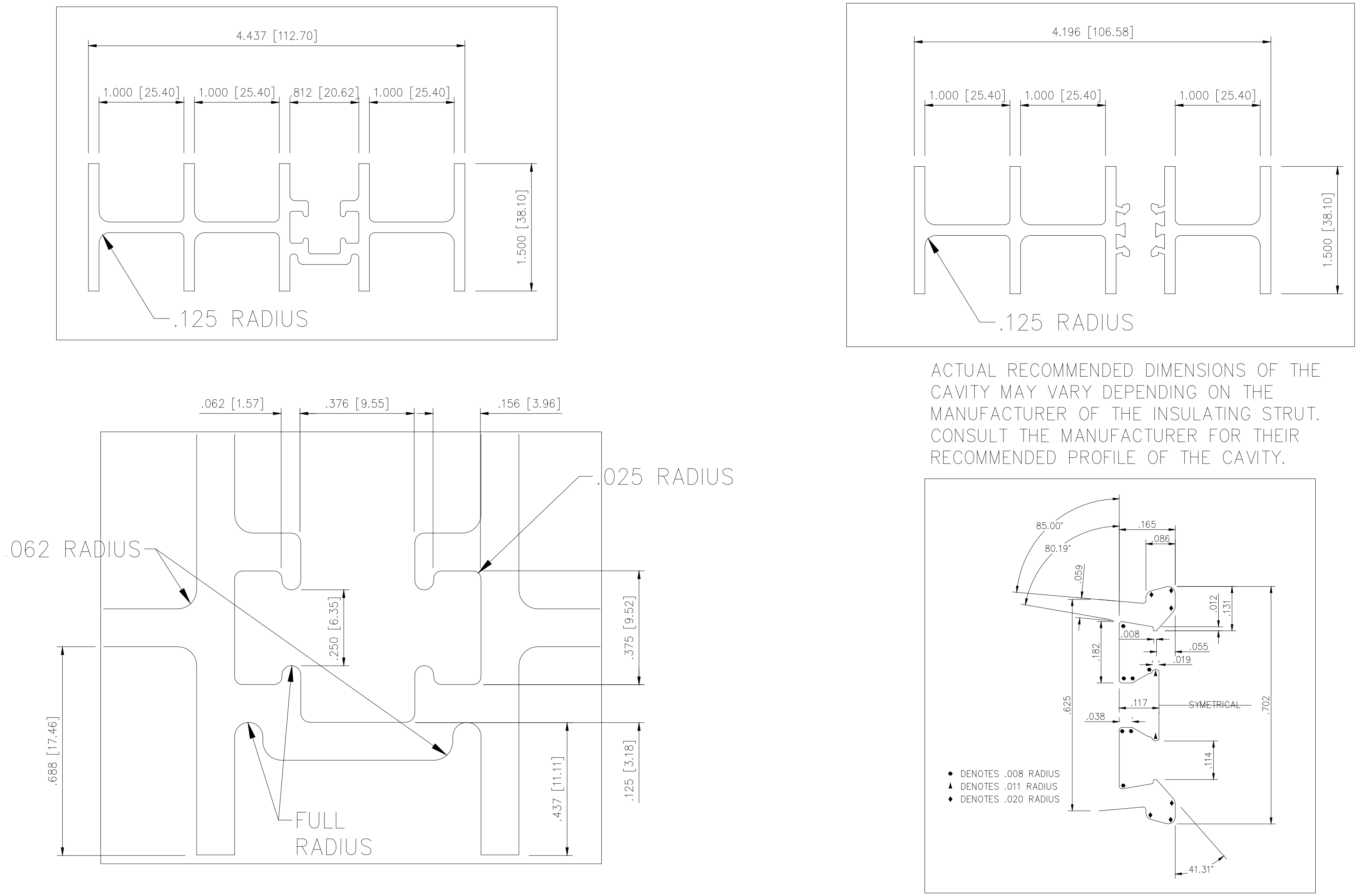


FIGURE 22a: AAMA Die Profile Drawing for Poured & Debridged and Mechanically Crimped In Place Test Cavities

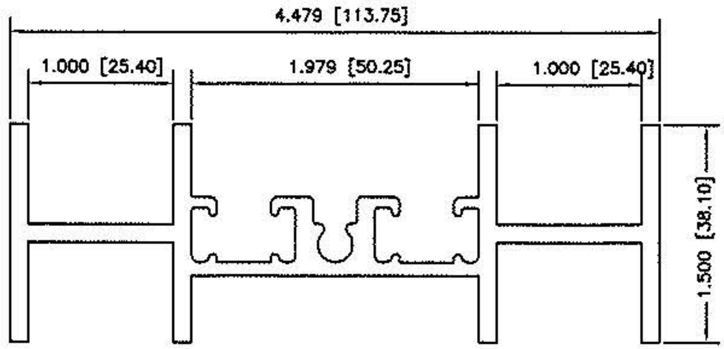


FIGURE 22b: AAMA Die Profile Drawing for Poured & Debridged

7.2 Flexural Test

7.2.1 Scope

7.2.1.1 This test method shall be used to determine the effective moment of inertia (effective second area moment) of aluminum/elastomeric composites, and complex sections, in lieu of calculations. This test method shall also be used to determine "effective" shear modulus as defined in Section 7.5.3.1.

7.2.1.2 In general, the theoretical moment of inertia (I) of a composite (assuming the aluminum sections are "fixed" in relation to each other; i.e., no shear deformation is included) will be greater than the effective moment of inertia (I_{et}) determined by this procedure. This test is designed as a useful method of determining apparent effective moment of inertia.

7.2.1.3 This test procedure may be used either to evaluate the performance of a specific thermal barrier material or to evaluate the performance of a particular thermal barrier material and extruded aluminum shape as a composite, or a combination thereof. An aluminum composite section is defined as:

Composite Section: Any combination of aluminum and one or more non-metallic materials such as elastomers, polyurethane, plastics, vinyl, etc. which are used as a thermal barrier joining the aluminum sections. The components of this structure act together in such a manner that their joint structural performance is greater than the performance of the sum of the individual components acting separately.

7.2.1.4 This test procedure is subject to several limitations:

1. The effective moment of inertia is only valid within the elastic range of the composite section. The effective moment of inertia is, in general, exactly correct only for the span and type of loading used in the test. It is approximate for other loading types (e.g., distributed vs. concentrated) and span values. Under certain physical circumstances the thermal barrier material may reach its yield or even ultimate strength before the aluminum. Factors such as temperature, cavity location and thermal barrier material selected will all affect the results of the procedure. The section being tested may behave in the field consistent with a smaller moment of inertia than the effective value calculated in the

lab. Care must be exercised that the test results are derived from testing done under conditions as close to field conditions as possible. If in doubt, consult qualified engineering personnel.

2. The structural performance of many thermal barrier materials is very temperature dependent. Specifically, the modulus of elasticity decreases with increasing temperatures (the material becomes softer). Therefore the highest temperature of the thermal barrier material encountered under actual field conditions will normally result in the smallest moment of inertia of the composite. For this reason, the effective moment of inertia derived in the lab shall be calculated from test results that closely simulate the maximum anticipated field temperatures of the thermal barrier material. While temperatures on the exterior surfaces of aluminum building products can reach 82°C (180°F) for dark colors, maximum wind loads will not occur when these high temperatures are experienced because air movement will cool the aluminum to near ambient levels. It is therefore reasonable to assume that the maximum wind loads will not occur when the exterior surface of the thermal barrier sections is over 49°C (120°F).

If this method is used to find the effective shear modulus (G_{ce}) of the installed thermal barrier, or to compare the test value of effective moment of inertia (I_{et}) to a theoretical value with shear effects (I_e or I'_e; Section 7.5), then measurements of actual widths, thicknesses and depth of the composite are needed. The actual measurements would be used to determine input for the procedure in Section 7.5.

7.2.1.5 The test method subjects the composite specimen to a small deflection from a concentrated load at the center of the span. The specimen is loaded as a simply supported beam. Care must be taken to avoid eccentric loading that could result in rotation. It is assumed for the purposes of this test method that stresses will remain within the elastic range of the materials, the restraints provided at the supports simulate a simply supported end condition and the modulus of elasticity of the composite section remains approximately equal to that of aluminum 68.9 x 10^6 kPa (10 x 10^6 psi).

7.2.1.6 By accurately measuring the concentrated load applied and the resulting center deflection, the effective moment of inertia for the composite section can be determined by using the standard deflection formula for a simply supported beam with a concentrated load at the center. Solving for the effective moment of inertia:

$$I_{et} = \frac{PL^3}{48E\Delta}$$

Where:

I_{et} is the effective moment of inertia for the composite section, based on testing.

P is the applied concentrated load at midspan.

L is the length of the span between reaction points.

Δ is the deflection of the center of the span due to the applied load.

E is the modulus of elasticity for aluminum.

7.2.2 Procedure

7.2.2.1 The test specimen shall be supported at the reaction points by a knife edge or a round rod. Free rotation of the specimen in the plane of the loading shall be permitted.

7.2.2.2 Loads shall be applied so as not to permanently distort the specimen or cause it to pass the elastic yield point. This may be accomplished by restricting the span of the specimen to a maximum (L_m) and limiting the load:

$$L \leq \frac{12\, E h_n\, R_t^{0.5}}{175\, F_{ty}}$$

$$P \leq \frac{4\, F_{ty} I R_t}{L h_n}$$

These formulae assume the composite remains within the elastic limit of the aluminum and that the maximum deflection will not exceed L/175 (a standard architectural aluminum deflection limit). Specimen lengths shorter than L when subjected to load P will result in deflections less than L/175.

Where:
L is the distance between the support points in millimeters (inches).
E is the modulus of elasticity for aluminum. It equals 68.9 x 10^6 kPa (10 x 10^6 psi).
h_n is the distance from the center of gravity of the section being tested to the farther of its extreme fibers. Thus n = 1 or 2, as shown in Figure 32 in Section 7.5.8. An initial estimate of one-half the composite's depth is acceptable if more exact section property information is not available. However, if this estimate is used it is suggested the test be run at a series of gradually increasing loads and the results plotted to ensure the test is being conducted within the elastic range of the composite.
F_{ty} is the specified minimum yield stress. The value for 6063-T5, a commonly used grade of aluminum, is 110,316 kPa (16,000 psi).

NOTE 6: *1 kPa = 0.001 N/mm^2.*

I is the calculated moment of inertia of the unpoured test specimen in mm^4 (in^4). This is an upper bound on the effective moment of inertia (I_e or I'_e in Section 7.5) of the composite.
P is the maximum permissible load, which meets deflection and stress limits, in Newtons (pounds)
R_t is a reduction factor to account for stress and deflection increases, due to shear deformation of the thermal barrier (core). A value of 0.9 is suggested for many cross-sections, not for final design but solely for this test procedure.

7.2.2.3 Testing equipment shall be calibrated in accordance with ASTM E529, "Standard Guide for Conducting Flexural Tests on Beams and Girders for Building Construction," Paragraph 9. If a testing machine is used, the speed of loading shall be 5 mm (0.200 in.) per minute ±50%.

7.2.2.4 Deflection shall be measured and recorded to the nearest 0.03 mm (0.001 in.) absolute. Deflection shall be measured at the center of the span and at each end support. The sum of the deflections at the supports shall be averaged and subtracted from the center deflection to get an overall net deflection of the beam. Deformation shall be determined both after the completion of load application and after the load has been maintained for five minutes. Care shall be taken to ensure that the deflection does not exceed the ratio L/175.

7.2.2.5 Permanent deformation of the specimen shall not exceed 0.2% of the clear span between supports. If this value is exceeded 15 minutes after the load has been removed, the test results shall be discarded, the failure recorded and the test rerun on a new specimen at a reduced load.

7.2.3 Test Cycles

7.2.3.1 The load P may be increased from zero to maximum P in any convenient increments but a minimum of 5 data points shall be obtained at zero, 1/4 P, 1/2 P, 3/4 P and maximum P. After preliminary establishment of an average effective moment of inertia it may be desirable to test a limited number of specimens at a greater number of load levels to increase the statistical significance of the results. Further testing would be indicated if one or more of the test results deviates from the average by greater than ± 5%.

7.2.3.2 Test data shall be obtained at ambient conditions that adequately represent the field conditions under which the design will perform. Temperatures of the test room, thermal barrier material and heated section of the aluminum extrusion shall be recorded if applicable.

The test specimen may be most conveniently heated with an electric heat tape. The heat tape shall be applied to the exterior face of the aluminum extrusion. Thermocouples shall be located under the heat tape, embedded in the center of the thermal barrier material and on the surface of the interior face of the aluminum extrusion (see Figure 23). The thermocouple on the exterior face shall be used to control the temperature at which the test is conducted. The thermocouple embedded in the thermal barrier material shall be the used to determine that stabilization has occurred before the test is conducted. The thermocouple on the interior face will be used to determine the temperature difference across the specimen. All three thermocouple readings shall be recorded in the test report.

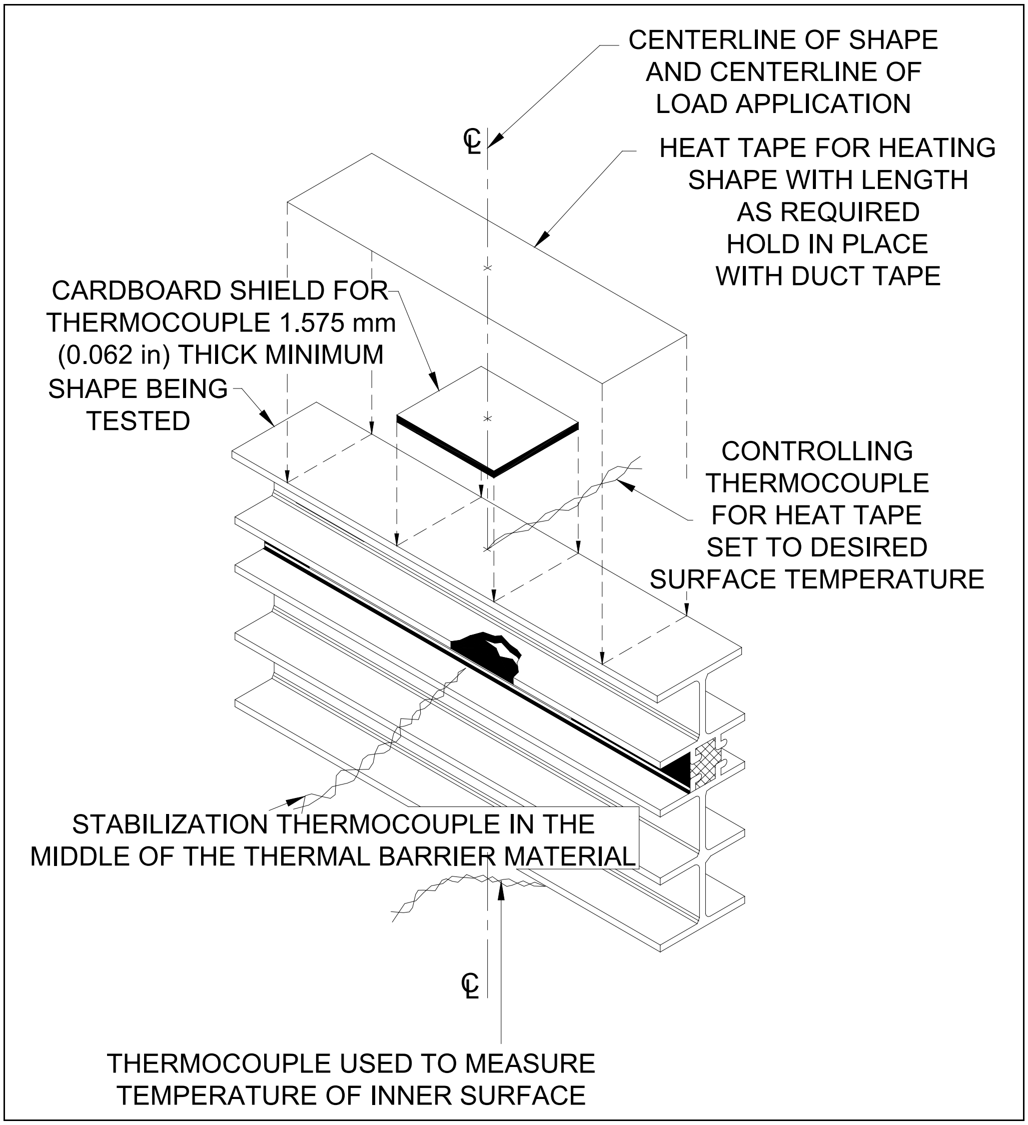


FIGURE 23: Thermocouple Placement

1. Temperature readings shall be taken as previously outlined. The load shall not be applied until three consecutive temperature readings from the thermal barrier thermocouple agree within ± 1°C (± 2°F) of the desired temperature setting. The period of temperature stabilization shall not be less than 5 minutes nor shall the time between consecutive readings be less than 1 minute. Failure to allow the test specimen to stabilize at the equilibrium temperature as measured by the thermal barrier thermocouple will result in non-reproducible results.

2. Ambient conditions during testing shall be maintained at 24°C ± 3°C (75°F ± 10°F) with minimal air flow across the specimen.

7.2.4 Report

7.2.4.1 A report of test results should generally be in accordance with ASTM E575, "Standard Practice for Reporting Data from Structural Tests of Building Constructions, Elements, Connections, and Assemblies."

7.2.4.2 As a minimum, the information included in attachment A shall be included in the report format. (Reference Section 8.2.)

7.3 Shear, Tension and Eccentric Load Tests

7.3.1 Scope

This method describes procedures for determining the ultimate test strengths (peak loads) for shear, tensile and eccentric loading of thermal barrier material and its retention as installed in extrusion. (See Chart 2.) This testing utilizes short-duration loading.

NOTE ~~6~~7: *This differs from how the yield strength of ductile metals is determined.*

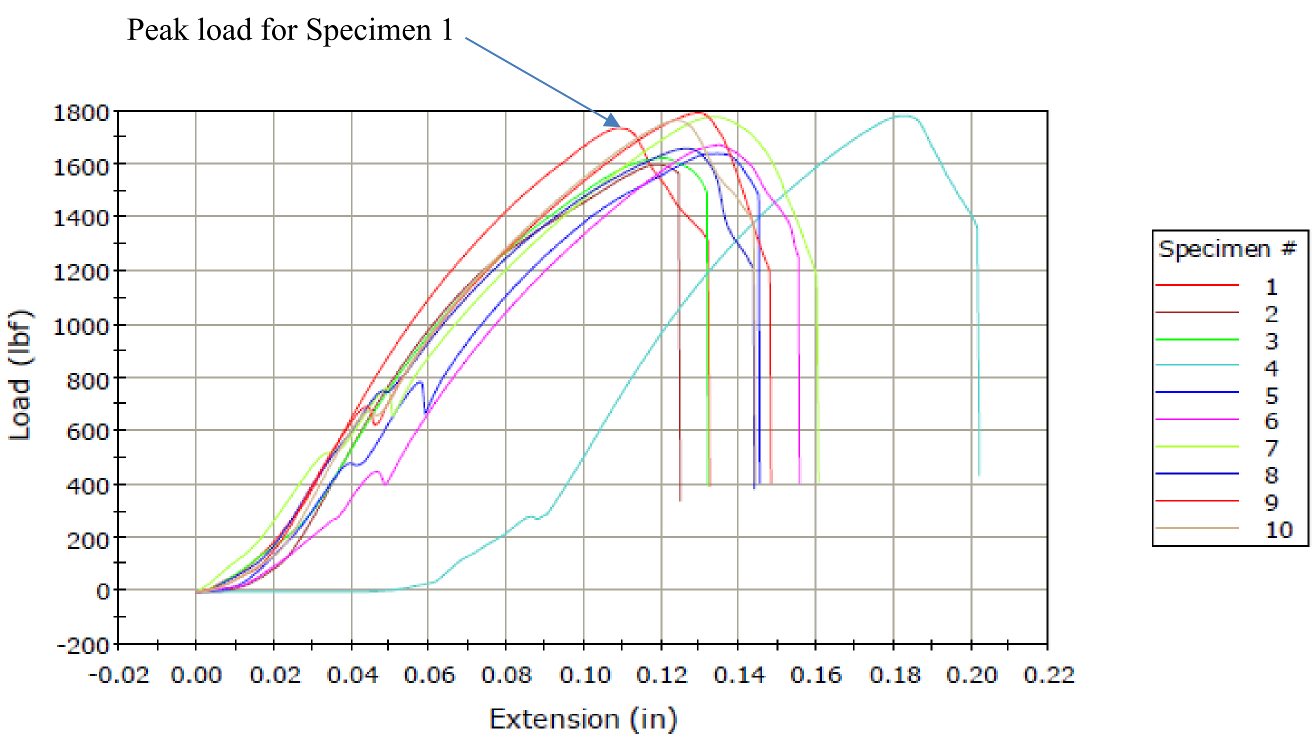


CHART 2: Peak Load Example

7.3.2 Sample

A sufficient number of pieces of test extrusions shall be selected in such a manner as to be representative of the shipment. The number of specimens required for the purpose of this test shall be cut from the pieces selected and care shall be taken to select sections that are free from obvious defects. Any samples with noticeable imperfections (cracks, bubbles, etc.) shall be discarded. For dual cavity, test each cavity separately and record lowest shear value.

7.3.3 Test Conditions

Unless otherwise specified, tests shall be conducted at 24°C ± 3°C (75°F ± 5°F). Sections 6.5 and 6.6 provide guidance to the design professional in determining the appropriate conditions for their project requirements.

7.3.4 Test Specimens

Ten specimens each 100 mm ± 1.0 mm (4.00 in ± 0.04 in) in length shall be cut with smooth, square cut edges from extrusions whose dimensions, shape and composition represent the desired test extrusion.

7.3.5 Preparation of Specimens

The thermal barrier material to be tested in the extrusion shall be poured and debridged or inserted and crimped in accordance with the supplier's recommendations. For polyurethane thermal barrier systems, special care shall be taken to ensure that the polyurethane is mixed at the correct ratio, to complete uniformity and fully fills the cavity of the extrusion. In addition, debridging shall be properly centered and done in such a manner as not to cut into or otherwise notch the thermal barrier material while completely removing the metal bridge. Unless otherwise specified, the composite assemblies shall be allowed to cure a minimum of seven days according to the supplier's recommendations. For crimped in place thermal barrier systems, care should be taken to properly knurl and crimp the preformed thermal barrier in place.

7.3.6 Apparatus

A universal testing machine capable of exerting a force of up to 2250 N (10,000 lbs) at a crosshead speed of 5.0 mm/min (0.2 in/min) shall be used.

For gripping the shear test specimens a test fixture designed for offset loading shall be required. The test fixture shall prevent rotation of the specimen under load and shall provide clearance for downward travel of the loaded side. A bearing plate shall be placed on top of the unsupported side of the test specimen.

For shear testing, the test fixture shown in Section 7.3, Figures 24 and 25 or its equivalent shall be used. It should be noted that this test fixture is the same one used in the eccentric loading test except that the top plate has been rotated 180° to provide clearance for offset loading. For gripping the tensile test specimens a slotted, self aligning test fixture shall be required. For tensile testing, the test fixture shown in Section 7.3.2, Figure 26 or its equivalent shall be used. Figures 24, 25, 26 and 27 show the test specimens mounted in the shear, tension and torsion fixtures respectively. In all cases, the applied loads shall be distributed as uniformly as possible along the unsupported section so as not to distort or bend the aluminum. In some cases, the thermal barrier will be stronger than the aluminum and distortion of the aluminum is unavoidable.

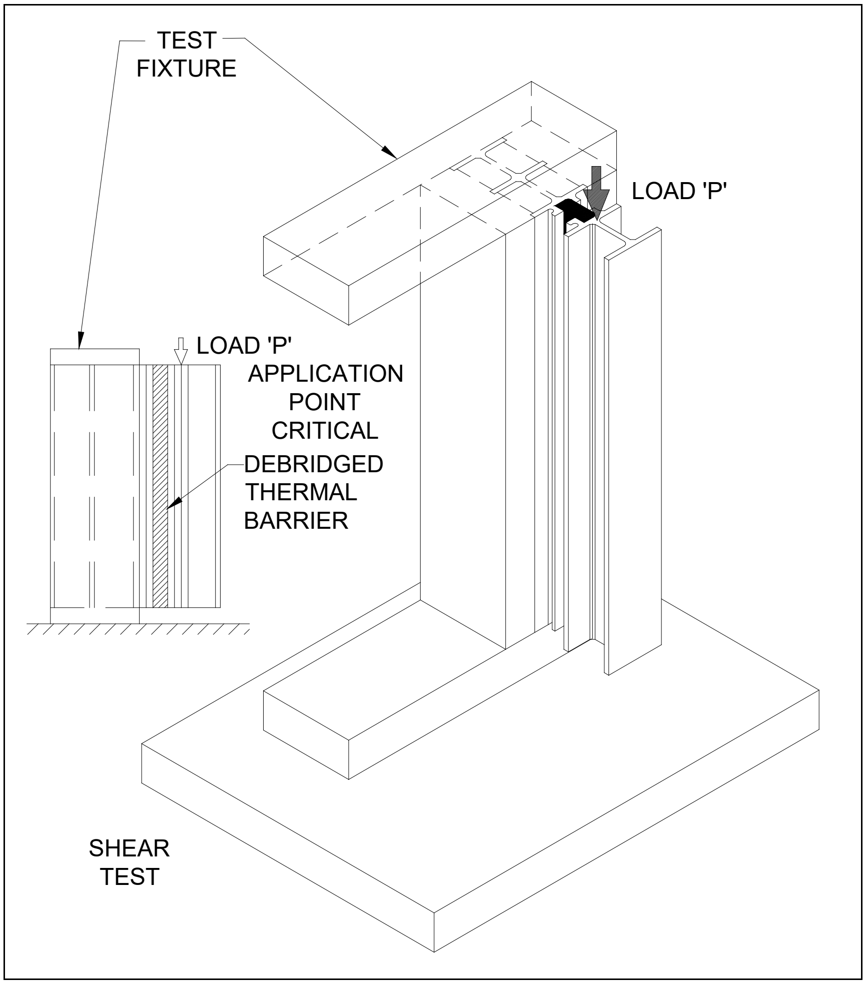


FIGURE 24: Shear Test Fixture

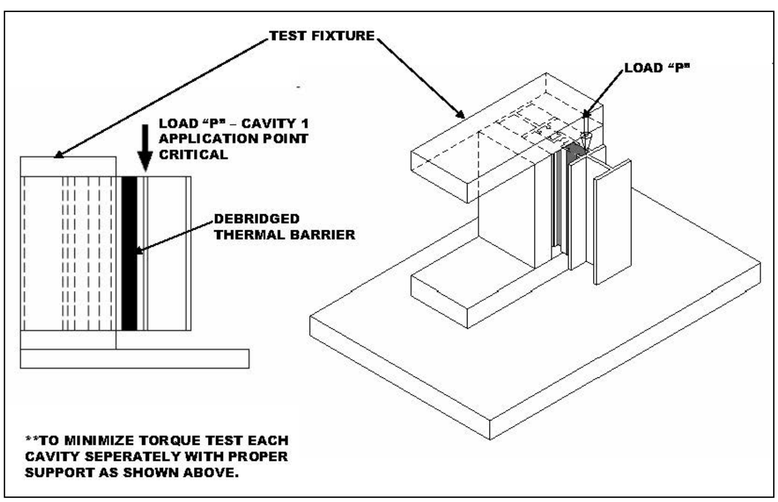


FIGURE 25: Dual Cavity

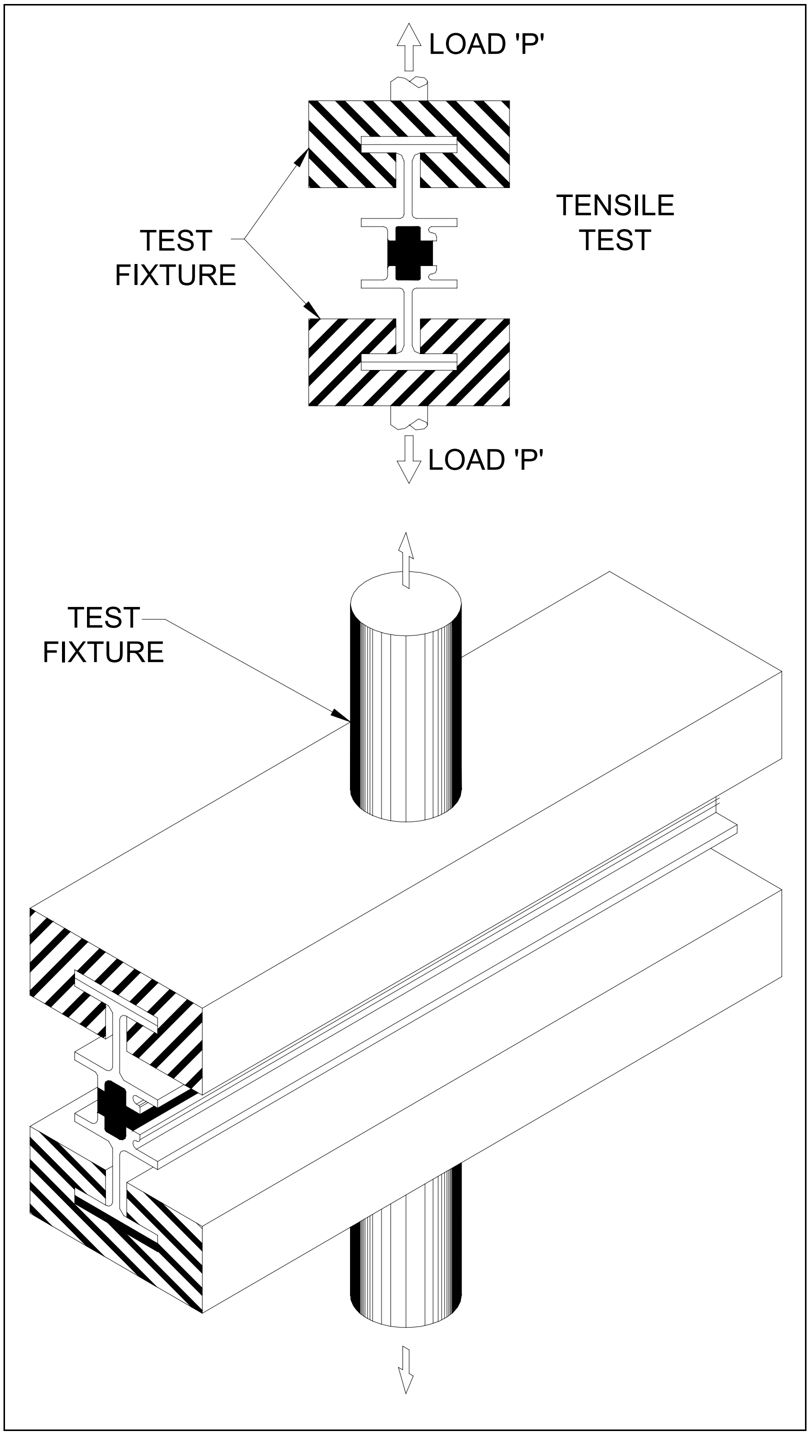


FIGURE 26: Test Fixture

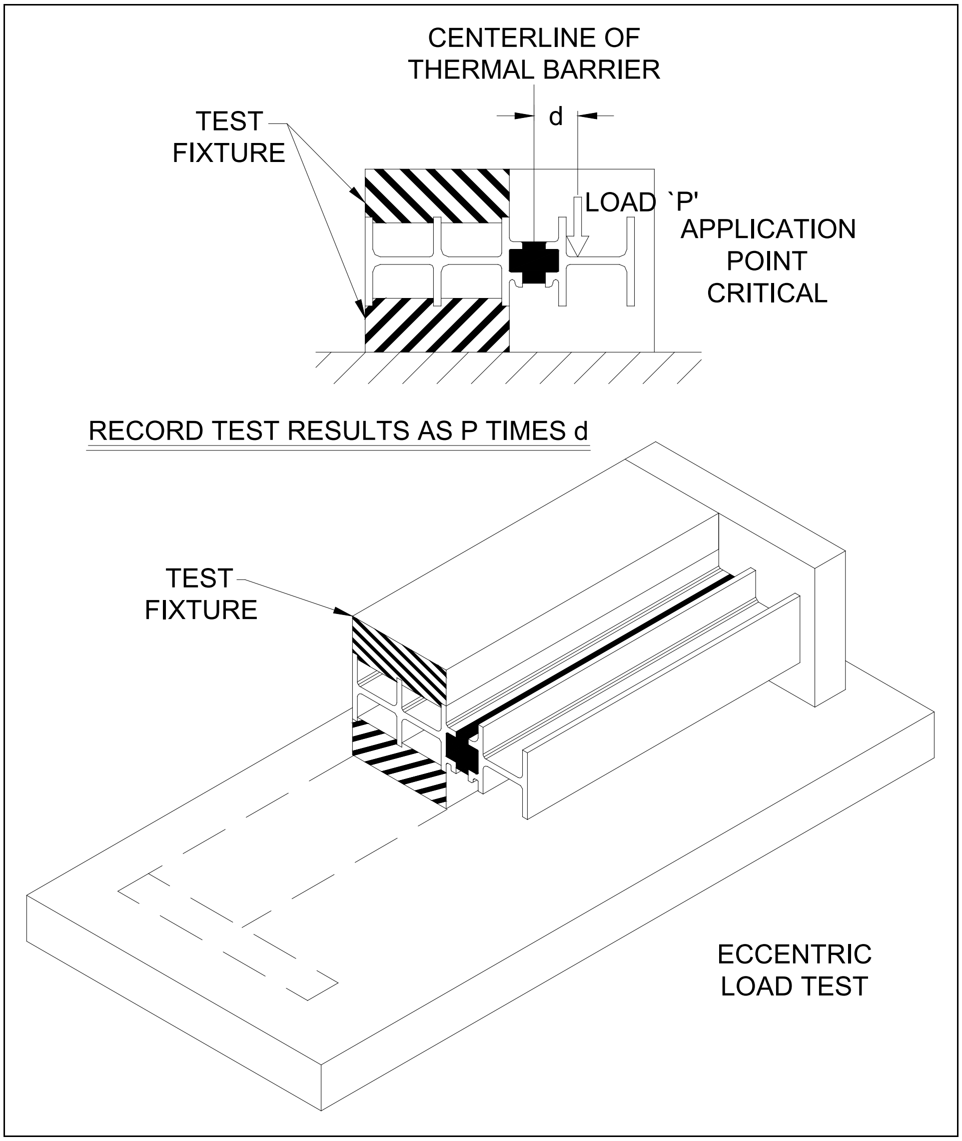


FIGURE 27: Eccentric Load Test

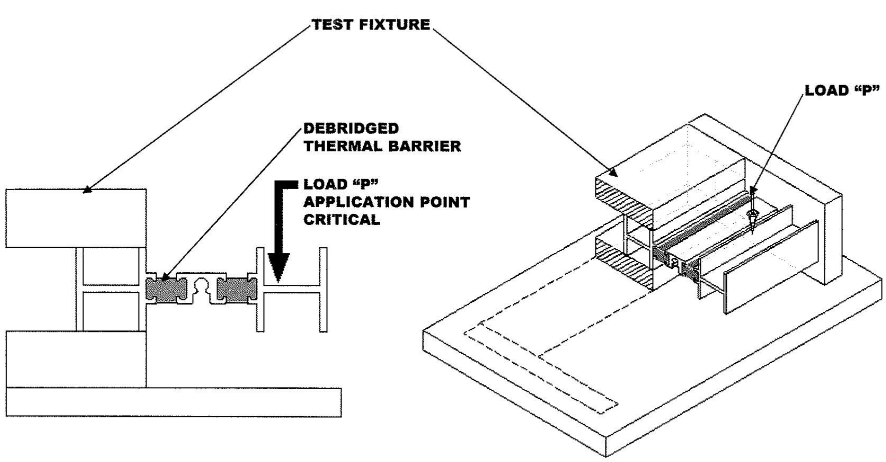


FIGURE 28: Dual Cavity Eccentric Load Test

7.3.7 Procedure

7.3.7.1 Tests at Temperatures Below Room Temperature

The test specimen and test fixture shall be placed in a suitably equipped environmental test chamber mounted on the universal testing machine. A thermocouple shall be inserted into a hole 1.5 mm (0.062 in) in diameter and 5 mm (0.2 in) deep drilled into the midpoint of the thermal barrier compound along its centerline at a point 75 mm (3 in) from the end of the specimen. When the temperature indicated by the thermocouple has stabilized at the desired value, the load shall be applied at a strain rate of 5 mm/min (0.2 in/min) until failure occurs. For torsional testing, the face of the compression rod shall be approximately centered on the fin of the extrusion closest to the thermal barrier material. Record test results as the moment developed from the applied load times the distance of the applied load to the centerline of the thermal barrier. For shear and tensile testing, record the peak load and the mode of failure (whether cohesive within the thermal barrier material or whether the thermal barrier material pulled free from the extrusion cavity projections) or, as in the case of shear testing, slipped parallel to the direction of travel.

7.3.7.2 Tests at Room Temperature

The same procedure as in Section 7.3.7.1 shall be used except that the environmental test chamber and thermocouple temperature probes are not required. Room or ambient conditions shall be maintained at 24°C ± 3°C (75°F ± 5°F).

7.3.7.3 Tests at Temperatures Above Room Temperature

The same procedure as in Section 7.3.7.1 shall be used except that the environmental test chamber shall be replaced by an electrical heat tape. The heat tape shall be applied to the exterior face of the aluminum extrusion. Thermocouples shall be located under the heat tape, embedded in the center of the thermal barrier material and on the surface of the interior face of the aluminum extrusion. The thermocouple under the heat tape shall be in direct contact with the metal surface but shall be shielded from direct contact with the heat tape by means of an insulating shim (see Figure 23). The temperature measured by the exterior face thermocouple shall be the controlling test temperature. All three thermocouple readings shall be recorded in the test report.

Temperature readings shall be taken as previously outlined. The load shall not be applied until three consecutive temperature readings from the thermal barrier thermocouple agree within ± 1°C (± 2°F) of the desired temperature setting. The period of temperature stabilization shall not be less than 5 minutes nor shall the time between consecutive readings be less than 1 minute. Failure to allow the test specimen to stabilize at the equilibrium temperature as measured by the thermal barrier thermocouple will result in non-reproducible results.

7.3.8 Report

7.3.8.1 A report of test results should generally be in accordance with ASTM E575.

7.3.8.2 As a minimum, the information included in attachment B shall be included in the report format. (Reference Section 8.2).

7.4 System Performance Requirements

Composite thermal barrier systems must perform not only thermally but also equally well as a structural component of the total building system. For structural performance, refer to AAMA 505. In addition, they must perform satisfactorily in resisting air and water infiltration. The system performance limits should be set by the architect or engineer responsible for the project. FGIA has developed a series of minimum performance requirements and test methods to aid the design professional. A discussion of these tests and standards is given in the following paragraphs. More complete information is available in the documents which are listed in Section 9.0 References.

7.4.1 Structural

(AAMA Curtain Wall Guide Specifications, par 1.07.B)
This test is performed in accordance with ASTM E330/E330M, "Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference." Design limits for deflection at design load are held to 1/175 of the clear span for curtain wall, storefront and HC and AW windows. At a test pressure of 1.5 times the design load, permanent deformation is limited to 0.2% of the clear span for main curtain wall, storefront, entrance framing and AW windows and doors, 0.3% for HC and C windows and doors and 0.4% for R and LC windows and doors. Glass breakage, permanent damage to fasteners, anchors, hardware or actuating mechanisms is not permitted.

7.4.2 Water

(AAMA Curtain Wall Guide Specifications, par 1.07.D)
This test is performed in accordance with ASTM E331, "Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference." The appearance of uncontrolled water other than condensation on the indoor face of the wall is not allowed. Static test pressure is usually 20% of the architect specified design pressure for curtain wall, storefront, entrance framing and AW windows and 15% of the design pressure for R, LC, C and HC window, door and panel members. For curtain walls, a dynamic test for water penetration is also frequently run at the same test pressures. Penetration of a small amount of water is considered permissible, provided it is contained and drained back outside (or "controlled"), with no damage to the wall or adjacent structures.

7.4.3 Air

(AAMA Curtain Wall Guide Specifications, par 1.07.C)
This test is performed in accordance with ASTM E283/E283M, "Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Skylights, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen." The test pressure is specified by the architect with 1.57 psf usually being the minimum test pressure. Air

infiltration is limited to 0.3 L/s•m² (0.06 cfm/ft²) per square foot of projected wall area for fixed storefront and curtain wall glazing. AAMA/WDMA/CSA 101/I.S.2/A440, "North American Fenestration Standard/Specification for windows, doors, and skylights," provides air leakage limits for all other fenestration types. Air infiltration is measured after a tare reading for air leakage of other building components or the test chamber is deducted.

7.4.4 Thermal

(AAMA Curtain Wall Guide Specifications, par 1.07.E)

Thermal performance standards are especially important for thermally improved framing systems. Thermally broken systems offer a considerable reduction in the formation of harmful condensation on the interior of the glazing. A considerable reduction in heat flow or thermal transmittance is also a benefit provided by thermally broken systems. Both of these performance improvements may be relatively measured by AAMA 1503.

7.4.4.1 Condensation Resistance Factor (AAMA 1503)

The Condensation Resistance Factor (CRF) is a rating number, obtained under standard test conditions, which allows comparison within reasonable accuracy, of the condensation performance of windows, doors or glazed wall sections. CRF ratings are derived at standard test conditions of -18°C (0°F) on the cold side of the specimen, 21°C (70°F) on the warm side and a uniform air flow against the cold side of the specimen of 7m/s (15 MPH). Temperatures on the surface of the specimen are used to compute a CRF rating.

Since CRF is determined for a pre-specified configuration under controlled laboratory conditions, caution must be exercised in using CRF to predict field performance against the formation of condensation.

7.4.4.2 U-factor (AAMA 1503 and AAMA 507)

The Thermal Transmittance (U-factor) is the time rate of heat flow, per unit area, under steady state conditions, through a body for a unit temperature difference of air on either side of the body. The AAMA 1503 test method used to determine a U-factor is a modification of ASTM C1363, "Standard Test Method for the Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus." The test chamber conditions are the same as for the CRF procedure previously given. The calculation of U-factor is a function of inside and outside surface coefficients as determined by measured specimen surface temperatures and affected by air flow. There are many factors that can impact the actual U-factor of a glazing installation such as glass type and glass to frame ratios. These variables are taken into account for U-factors determined in accordance with AAMA 507, "Standard Practice for Determining the Thermal Performance Characteristics of Fenestration Systems in Commercial Buildings." In general it is up to the architect to determine how the job conditions relate to test conditions, particularly test size versus installed framing size.

7.5 Structural Design Method for Aluminum Beams with Composite Thermal Barriers

7.5.1 Overview of Sandwich Beams

Why do we need to treat thermal barrier beams differently than ordinary beams? This discussion addresses this question.

The key structural difference between an all-aluminum beam and a composite, thermal barrier beam is core (thermal barrier) shear deformation. Most of the behavior of an all-aluminum beam can be modeled using the traditional Bernoulli-Euler equation ($E\ I\ y'' = M$) for flexure, while ignoring shear strain. However, introduction of a relatively soft material for a part of the web (thermal barrier or core) results in a more complex behavior of the beam. Initially plane (flat) cross-sections of the beam do not remain so after loading, due to significant effects from shear deformation of the core. Core shear strain entails rectangular blocks of the core, with length parallel to the beam's span, distorting into parallelograms.

Beam deflection and aluminum stress both increase, due to the presence of a core which is "soft" compared to aluminum. On the other hand, the value of longitudinal shear flow (shear stress times core width) is less with a core than for an otherwise similar, all-aluminum beam.

There is another way to think of thermal barrier beam behavior, besides the concept of altering an all-aluminum beam so that it becomes more flexible and more highly stressed. One can consider the idea of joining two separate pieces of aluminum to create a beam which is stiffer and stronger than the un-joined pieces. As an example, two identical aluminum bars are placed, one on top of the other, so as to span between supports. (See Figure 29) A certain midspan load will cause the beam to sag 25 mm (1 in) (Case 'a'). In this set-up, the two bars are free to slide along each other so that the top of the lower bar is in compression and the bottom of the upper bar is in tension. Now assume (Case 'b') that the two bars are "glued" together so that any strains in the contacting bar surfaces are forced to be identical. The same load and span will now produce only 6 mm (1/4 in) deflection and half as much bending stress. These improvements come at a cost however, since the "glue" must resist a longitudinal shear flow which is equal to the maximum shear flow that exists within each bar in Case 'a'.

The behavior of a thermal barrier beam is, in a sense, between Case 'a' and Case 'b'. If the glue acquires a finite thickness and exhibits significant shear deformation, then one has a model of a composite thermal barrier beam. The core's shear stiffness engages the axial stiffness of each face. In addition, the core forces both faces to deflect the same amount, and so the individual bending stiffness of each face also assists in resisting the load.

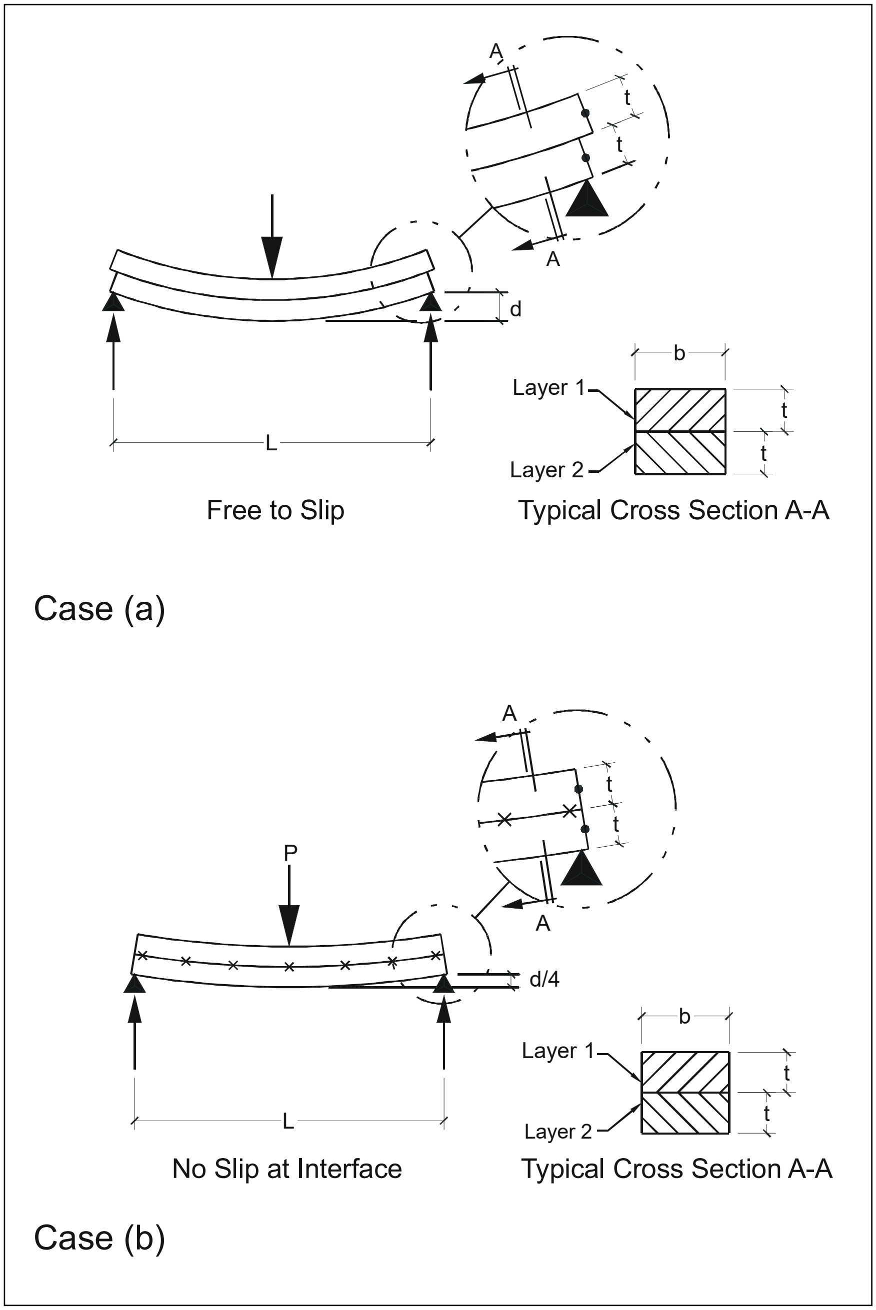


FIGURE 29: Thermal Barrier Beam Behavior using Joint Beams

7.5.2 Introduction to Method

Section 7.5.1 describes a design method for predicting the stiffness (effective moment of “inertia” [second area moment]), effective section modulus, and core shear for a simple span beam with a non-homogeneous cross-section, subject to midspan concentrated, uniform, triangular or trapezoidal load. All load types are symmetrical about the midspan of the beam. The model is a “sandwich” beam consisting of relatively stiff faces (e.g., aluminum) continuously joined to a much softer core material (e.g., an elastomer such as polyurethane, or a material such as glass-fiber reinforced nylon [polyamide]). The faces (also termed facing sections) may have significant bending stiffness in addition to axial stiffness. The core (thermal barrier) is assumed to resist only shear.

The method has been compared with over 60 tests (using concentrated load on beams with P & DB polyurethane cores) and found to predict trends in behavior and to produce reasonably consistent numerical results.

Refer to references [1], [2], [3] and [6] in Section 9.6 for details of the derivation of the final equations. Reference [4] pertains to development of a special finite element while reference [5] is an article about the design method. References [7] and [8] concern mathematics used in the design method, as well as the development of previous software. Reference [9] is a report of extensive testing and analysis of a certain type of composite thermal-barrier beams. References [10] and [11] present recent analytical developments, including a separate analysis of the linear portion of the flexural test results in [9], for thermal-barrier beams.

Note that Young's modulus ƚE of the "exterior" and "interior" metal components (facing sections, or simply faces) is assumed to be "large" compared to that of the core (thermal barrier). Thus only a very small error, on the safe side, is introduced in the analysis by considering the metal pieces to alone carry flexural (bending) stresses. For example, if the E of the core is 2,068 MPa (300,000 psi), it is only 3% of the aluminum modulus of 68,950 MPa (10,000,000 psi). Thus, a 12 mm (1/2 in) wide core is only 0.39 mm (0.015 in) wide in terms of an equivalent piece of aluminum. In most cases this is small compared to other section dimensions. This small difference could be addressed by including the core moment of "inertia" (times the core-to-aluminum modular ratio), but this has not been included in the method.

7.5.2.1 Load Due to Temperature Difference

A temperature difference between faces (and/or within a face) will cause bow (deflection), bending stresses and core shear stresses in thermal barrier beams that are composite. There are no closed-form equations in this document to predict this behavior. Finite element analysis (FEA) may, however, be used. With varying accuracy, two or three-dimensional (2-D or 3-D) general purpose, or 2-D special purpose FEA, software is capable of predicting a response to a temperature gradient. Refer to references [4] and [6] for information on special purpose FEA. Combined loading, consisting of wind and a given set of four temperatures (air side and core side of each face), can also be modeled with FEA.

7.5.3 Variables

This section presents the variables needed as input for the design method. Refer to Figures 30a and 30b for illustration of most of these quantities.

A — Shear area of aluminum, which equals total (average) web thickness (t_w) times net web height –h - g). See definitions for other variables.

A_c — Total cross section area of the thermal barrier which serves as the core, including any bite area (not simply metal to metal area). For example, the cumulative cross-sectional area of the polyamide strips would equal A_c.

a — Length of linearly increasing part of trapezoidal load.

a_1, a_2 — Areas of faces 1 and 2.

b — Average width of core (elastomer); $b = A_c/D_c$

b' — Clear opening between interlocks; usually the least width of the core.

c_{11}, c_{22}, D — Distances between centroidal axis and air side surface of each face, and between axes, respectively.

D_c — Cavity depth (maximum).

E — ~~Yo'ng's~~Young's modulus of aluminum faces; 68,950 MPa ($E = 10^7$ psi = 10^4 ksi).

E_c — ~~Yo'ng's~~Young's modulus of core.

g — Gap (clearance) between faces.

G_c — Shear modulus of uninstalled core material (thermal barrier).

G_{ce} — Effective shear modulus of assembled core (thermal barrier). [For expansion upon the definition see Section 7.5.3.1].

h — Overall depth of extrusion; $h = c_{11} + D + c_{22}$

h_1 , h_2 — Dimensions from ~~extrus'on's~~extrusion's center of gravity to air side of faces 1 and 2

I_{o1}, I_{o2} — Moments of "inertia" (second area moments) of faces 1 and 2.

k — Dimensionless ratio (a/L) for trapezoidal load.

L — Span, center-to-center of supports.

P — Concentrated load (force).

t_w — Thickness of strong axis web, or the total webs, of the aluminum extrusion. More generally, $t_w = A_w/(h-g)$ where A_w is the sum of individual web thicknesses (in each face) times height of the pertinent facing section.

w — Uniform load intensity (force/length).

w_o Maximum intensity of triangular and trapezoidal load (force/length).

Consistent units are to be used throughout all equations.

7.5.3.1 Discussion on Shear Modulus G_c and Effective Shear Modulus G_{ce}

The Shear Modulus G_c supplied by manufacturers for uninstalled thermal barriers may be greater than the Effective Shear Modulus G_{ce} for installed thermal barriers.

The shear stiffness of the core (thermal barrier) is a function of both core geometry and material properties. Geometry includes the depth and width. The theory on which the equations are based treats the core as a rectangular block of depth D_c and width b. This approximates the core's actual shape, which includes interlocks or tapered flanges. The core's cross-sectional area is the product of its depth D_c and its *average* width b, both of which are used in the equations. Thus, the core's somewhat complex actual shape is represented by a simplified model, which is a rectangle.
Another approximation is that the theory assumes continuous longitudinal shear resistance between the core and facing sections. Variations from this idealization include the effects of mechanical indentations, or staking, at finite spacings. However, to the extent that a continuous longitudinal bond is present, the theoretical assumption is more closely realized. As to core material properties, there are two terms that pertain to the shear stiffness of the core (thermal barrier) material.

1) G_c is the shear modulus (units of force per unit area) of the uninstalled core material. Recall that shear stress equals shear modulus times shear strain (an angle change, as for example the increase or decrease from an initial 90° angle). Also, for linearly elastic behavior, $G_c = E_c / [2(1+v)]$ where E_c = Young's modulus for axial stiffness and v = Poisson's ratio. In addition, in some cases testing utilizing special procedures can be used to measure G_c directly.
2) Effective shear modulus G_{ce}. is the effective shear modulus value for installed thermal-barrier material that leads to a predicted deflection which matches the measured beam deflection for a particular load. Due to the approximation of the core's actual shape and due to details of the interface between the aluminum facing sections and the thermal barrier, the effective (installed) value of G_{ce} may not equal the uninstalled value.

   This becomes apparent when determining G_{ce} based on testing of a profile with a thermal barrier. Knowing the beam's properties, and deflection for a given midspan concentrated load, iteration of the governing equations can be used to find the value of G_{ce} which results in a predicted deflection that matches the measured deflection. It is often found that the iterated value is lower than the G_c of the uninstalled material.

7.5.3.2 Even if a test value of shear modulus G_c for the uninstalled core material alone is known, for core (thermal barrier) material specimens, it is necessary to obtain a design value (effective value) of G_{ce} by comparing test beam results to predictions of effective moment of "inertia" (I'_e) using various G_{ce} estimates. Refer to Section 7.2 for flexural test. This procedure results in a value of "effective" shear modulus G_{ce}, at least for a given core material, cavity, and profiles with the same general shape. One way of aiding this determination of G_{ce} is to plot the "predicted effective I" versus "span L" for several values of G_{ce}. By then plotting the *test* effective I at each of at least 2 spans, on the graph containing the predicted value, an approximate (design) value of G_{ce} can be determined.

Having determined an effective shear modulus, this modulus value may be used to design for other spans with that shape and with “similar” shapes. Here “similar” refers especially to composite beams with the same cavity, core material and method of resisting longitudinal shear. Deflection due to uniform, triangular or trapezoidal load may then also be calculated for various spans and “similar” shapes, using the G_{ce} value from the concentrated load tests.

The core material is assumed to be linearly elastic for the range of strain encountered in the core. As a starting point, (for urethanes), G_{ce} may be estimated to be between 0.33 E_c and 0.4 E_c, for constant temperature condition. Note that theoretically the value for G_c is at least equal to $E_c/3$ and at most equal to $E_c/2$. As the elastomer Young's (tension) modulus E_c increases, the shear modulus is usually expected to also increase. As shear modulus increases, the effective I of the beam would normally become less sensitive to variations in the value of elastomer shear modulus G_{ce}.

In order to address possible reduction in effective moment of “inertia” (I'_e) at temperatures higher than room temperature (e.g., warmest field conditions), it is recommended that I'_e for a test beam at the appropriate elevated temperatures be measured. If the I'_e is significantly lower than at room temperature, then the same iterative calculation process may be used to find the appropriate (reduced) “average” effective G_{ce} for that temperature distribution in the elastomer. The value of G_{ce} will be an average because the actual G_{ce} may, in general, vary with the core temperature. Core temperature varies through the depth of the core if the temperatures of the exterior and interior faces differ. Note that the use of more than one value of span length to get a best estimate of G_{ce} is recommended. If only one span length is used, and it results in a “large” span-to-moment of inertia ratio, the change in I'_e with various G_{ce} values may be relatively small.

For the types of beams considered in this document, the existing test and analytical data [3] have shown that unloaded overhangs do not significantly affect the behavior of simple span beams (with midspan concentrated load) for span/depth ratios of at least 20 and a shear modulus of at least 552 Mpa (80 ksi.) Shear modulus values less than 552 Mpa (80 ksi) and/or span-to-depth ratios less than about 20, may result in significant differences in stiffness of “overhang” versus “no overhang” beams. For such cases, other analytical methods (e.g., finite element analysis using available software) should be used. Refer to [3], [4] and [6]. “Overhang” refers to an extension, past the support, which is more than half the beam depth in length.

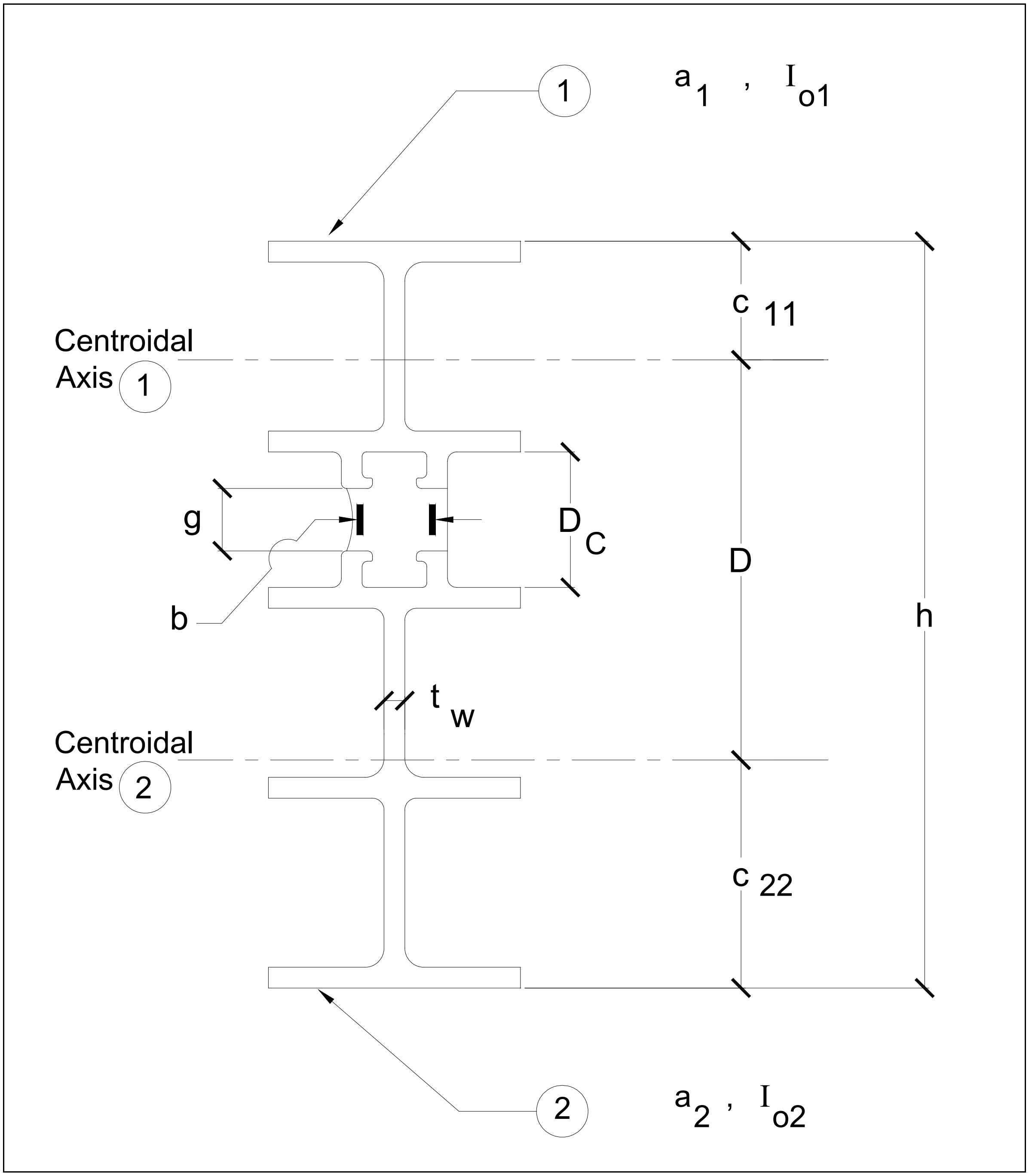


FIGURE 30a: Representative Drawing of Design Method Variables

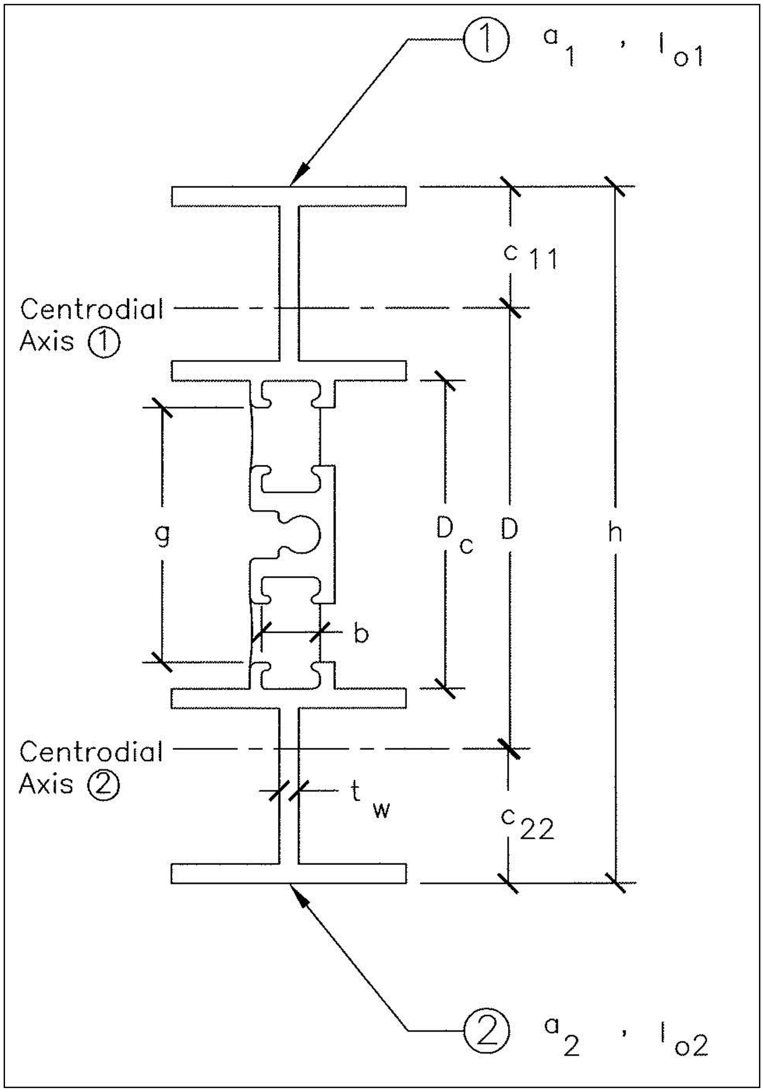


FIGURE 30b: Representative Drawing of Design Method Variables

7.5.4 Parameters, Basic Equations and Integration Constants

$I_c = \dfrac{a_1 a_2 D^2}{a_1 + a_2}$	for the case where both faces are same material (same E).	(1)
$I_o = I_{o1} + I_{o2}$	which is the lower bound on stiffness I'_e, assuming no composite action (i.e. slip is free to occur all along the core/aluminum interfaces).	(2)
$I = I_c + I_o$	which is the upper bound for values of I'_e. This value would only be realized exactly, for I'_e, if no shear deformation occurred in the core or faces.	(3)
I_c/I	Ratio which indicates how much of the flexural stiffness is due to area and separation of faces, rather than to the individual I values (I_{o1} and I_{o2}) of faces.	(4)
$G_p = \dfrac{I\, b\, D^2\, G_{ce}}{I_c\, D_c}$	Parameter which includes geometric and core material properties.	(5)
$c = \dfrac{G_p}{E\, I_o}$	for same E for both faces. [Note that most prior documents use C_y in lieu of c.]	(6)

The governing differential equation relating the deflected shape (y) to the beam's bending moment (M) and shear (V) is:

$$y'''' - cy'' = \frac{-cM}{EI} + \frac{V'}{EI_o} \qquad (7)$$

In this equation, the prime (') denotes differentiation with respect to x. See equation 24 in reference [2]. This fourth order equation requires the determination of four independent constants of integration that depend on the type of loading and boundary conditions. Related constants have been determined for a simply supported beam (without overhangs) for four types of symmetrical loading: midspan concentrated load, uniform, triangular and trapezoidal. (See Figure 31) The constants are combined with other terms in the final equation for the deflected shape.

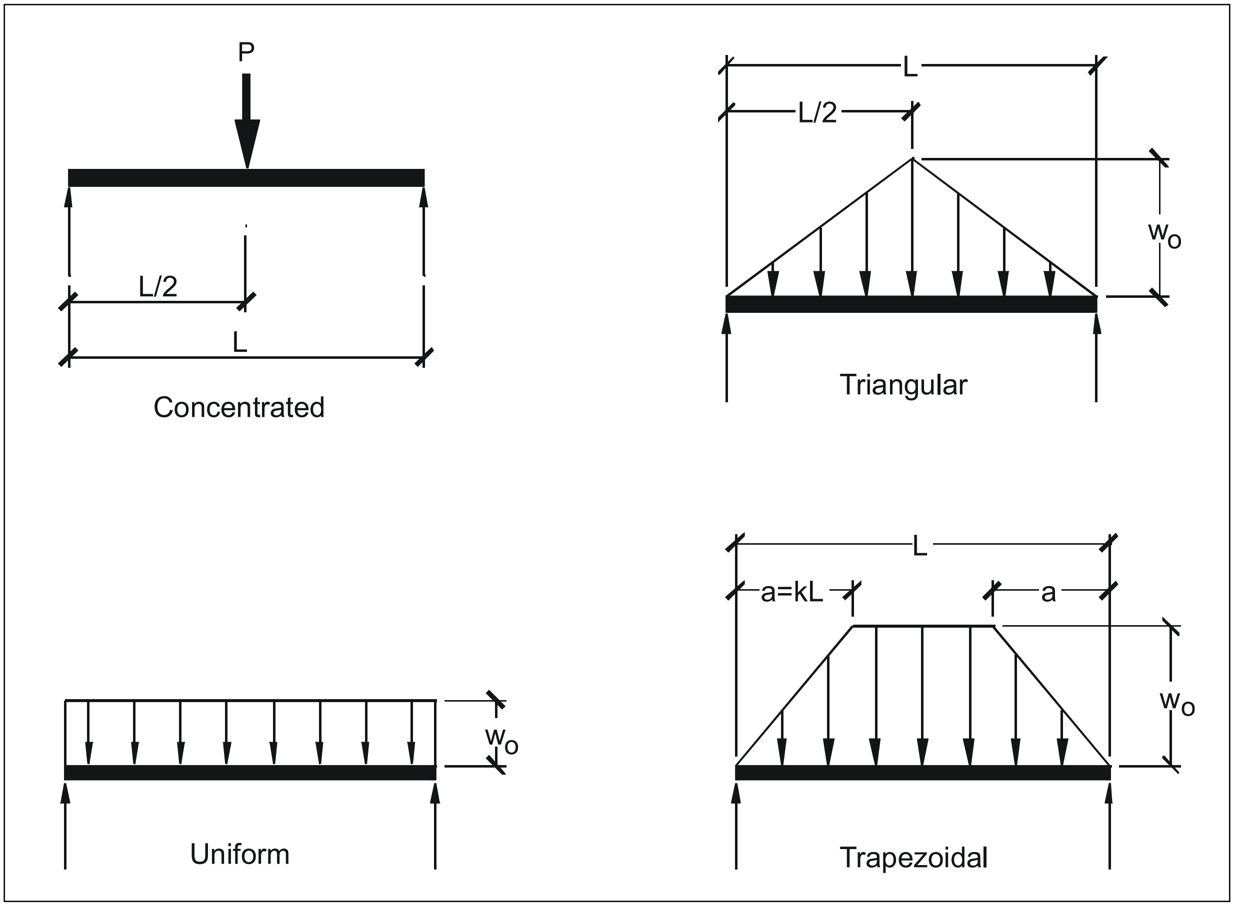


FIGURE 31: Symmetrical Loadings

$$y = D_5x^5 + D_4x^4 + D_3x^3 + D_2x^2 + D_1x + D_0 + F_1e^p + \frac{F_2}{e^p} \tag{8}$$

Equivalently:

$$y = \sum_{n=o}^{5} D_n x^n + F_1 e^p + \frac{F_2}{e^p} \tag{8.a}$$

This equation reaches a maximum at x = L/2. Note that p = x√c. The expressions for the constants D_0 to D_5 are given in Tables 2 and 3 for each of the four load types. The constants D_0 to D_5 for trapezoidal load apply to the region a ≤ x ≤ L – a. For trapezoidal load in the linearly increasing load region (0 ≤ x ≤ a), the equation for deflection y is:

$$y = \sum_{n=0}^{5} E_n x^n + G_1 e^p + G_2 / e^p \tag{8.b}$$

Constant	Loading	
	Midspan Concentrated	Uniform
D_0	0	$\frac{w\ E\ I_o\ I_c}{(G_p)^2\ I}$
D_1	$\frac{-P\ I_c}{2\ G_p\ I} - \frac{PL^2}{16\ E\ I}$	$\frac{-(wL)\ I_c}{2\ G_p\ I} - \frac{wL^3}{24\ E\ I}$
D_2	0	$\frac{w\ I_c}{2\ G_p\ I}$
D_3	$\frac{P}{12\ E\ I}$	$\frac{w\ L}{12\ E\ I}$
D_4	0	$\frac{-w}{24\ EI}$
D_5	0	0

TABLE 2: Constants $D_0 \rightarrow D_5$

Constant	Loading
	Triangular (Sym.)
D_0	0
D_1	$\left[\frac{-w_o\ L}{4}+\frac{2\ w_o}{L\ c}\right]\left(\frac{I_c}{G_p\ I}\right)-\frac{5\ w_o\ L^3}{192\ E\ I}$
D_2	0
D_3	$\frac{w_o\ I_c}{3\ L\ G_p\ I}+\frac{w_o\ L}{24\ E\ I}$
D_4	0
D_5	$\frac{-w_o}{60\ L\ E\ I}$
	Trapezoidal Load ($a \le x \le L - a$)
D_0	$\frac{w_o I_c}{c G_p I}+\frac{w_o a^2 I_c}{6 G_p I}-\frac{w_o a^4}{120 EI}$
D_1	$\frac{-w_o L I_c}{2 G_p I}+\frac{w_o L a^2}{12 EI}-\frac{w_o L^3}{24 EI}$
D_2	$\frac{w_o I_c}{2 G_p I}-\frac{w_o a^2}{12 EI}$
D_3	$\frac{w_o L}{12 EI}$
D_4	$-\frac{w_o}{24 EI}$
D_5	0
	Trapezoidal ($0 \le x \le a$)
E_0	0
E_1	$\frac{w_o I_c}{c a G_p I}-\frac{w_o I_c (L-a)}{2 G_p I}+\frac{w_o\left(-a^3+2La^2-L^3\right)}{24 EI}$
E_2	0
E_3	$\frac{w_o I_c}{6 a G_p I}+\frac{w_o (L-a)}{12 EI}$
E_4	0
E_5	$\frac{-w_o}{120 a EI}$

TABLE 3: Constants $D_0 \rightarrow D_5$

The expressions for F_1 and F_2, and for G_1 and G_2, are given in Table 4. The expressions for both concentrated and uniform load have been simplified compared to the expressions given in previous documents.

Load Type	Complementary Constants*	
	F_1	F_2
Concentrated	$\frac{PI_c}{2G_pI\sqrt{c}\left(e^r+e^{-r}\right)}$	$-F_1$
Uniform	$\frac{-w_oI_ce^{-r}}{cG_pI\left(e^r+e^{-r}\right)}$	F_1e^{2r}
Triangular	$\frac{-2w_oI_c}{c^{1.5}G_pLI\left(e^r+e^{-r}\right)}$	$-F_1$
Trapezoidal ** ($a \le x \le L - a$)	$\frac{-w_oI_c\left(e^q-e^{-q}\right)e^{-r}}{2c^{1.5}G_paI\left(e^r+e^{-r}\right)}$	F_1e^{2r}
	G_1	G_2
Trapezoidal ** ($0 \le x \le a$)	$F_1-\frac{w_oI_ce^{-q}}{2c^{1.5}G_paI}$	$-G_1$

TABLE 4: Expressions for Concentrated and Uniform Loads

* $r = L\sqrt{c}/2$

** $q = a\sqrt{c}$

Note that e is the base of the natural logarithms.

The expressions for F_1 and F_2 in Table 4 have been found to be suitable for computation with the precision normally available on personal computers, and for the application considered in this publication.

Equations (9 to 12) for effective moment of "inertia" (second area moment), without effects of shear deformation in the faces follow. Note that y = maximum deflection.

Concentrated Load: $$I_e=\frac{PL^3}{48Ey} \tag{9}$$

Uniform Load: $$I_e=\frac{wL^4}{76.8Ey}=\frac{(wL)L^3}{76.8Ey} \tag{10}$$

Triangular Load: $$I_e=\frac{w_oL^4}{120Ey} \tag{11}$$

Trapezoidal Load: $$I_e = \frac{w_o L^4 \left(25 - 40k^2 + 16k^4\right)}{1920 E y}$$ (12)

Note that since y is a function of many variables, so is I_e. In particular, I_e is a function of L (span), G_{ce} (effective shear modulus of the core) and type of load (e.g., concentrated, uniform, triangular or trapezoidal).

7.5.5 Correction for Shear Deformation in Aluminum Faces

The preceding expressions for an effective I can be made more accurate by accounting for shear deformation of the "web(s)" of the metal components (facing sections). The following procedure is semi-empirical and has been found to significantly improve predicted values, particularly at shorter spans, as compared to test values. Note that the equations for concentrated and uniform I'_e are slightly different than given in prior documents. The current expressions are improvements [8] which result in only small changes (increases for the example problem).

Assume maximum deflection d (due to the four load types considered) of "solid aluminum" beams can be represented by:

$$d = \frac{P^* L^3}{B}\left(\frac{1}{EI_e}\right) + \frac{P^* L}{S}\left(\frac{F}{AG}\right)$$ (13)

Here the first term accounts for bending and the second term is for shear effects on the web(s). See Table 5 for values of B, S and P* for the four load types.

Load Type	B	S	P*
Concentrated	48	4	P = applied load
Uniform	76.8	8	w L = W = total
Triangular	120	12	$w_o L$
Trapezoidal (k = a/L)	$\frac{1920}{\left(5-4k^2\right)^2}$	$\frac{24}{3-4k^2}$	$w_o L$

TABLE 5: Values of B, S and P for the Four Load Types

Note that uniform and triangular loads are limiting cases of trapezoidal load (k = 0 and k = 0.5, respectively).

G is the aluminum shear modulus = 0.375 E, and A is the sum of the areas of the "web" elements. Let I'_e include shear deformation effects on the aluminum web(s), so that:

$$d = \frac{P^* L^3}{BEI'_e}$$ (14)

If F (form factor) is assumed equal to 1, which is approximately correct for "I" beams and appropriate values of B and S are used for each type of loading, then the following expressions result for an all aluminum beam:

Concentrated: $$I'_e = \frac{I_e}{1 + \left[32(I_e)/(L^2 A)\right]} \qquad (15)$$

Uniform: $$I'_e = \frac{I_e L^2 A}{L^2 A + 25.6 I_e} = \frac{I_e}{1 + \left[25.6(I_e)/(L^2 A)\right]} \qquad (16)$$

Triangular: $$I'_e = \frac{I_e}{1 + \left[(26\tfrac{2}{3})(I_e)/(L^2 A)\right]} \qquad (17)$$

Trapezoidal: $$I'_e = \frac{I_e}{\left[1 + \dfrac{25.6(I_e)\left(1 - \dfrac{4k^2}{3}\right)}{(1 - 1.6k^2 + 0.64k^4)L^2 A}\right]} \qquad (18)$$

Note that for very large values of L, the value of I'_e is essentially I_e. In the case of small span/depth ratios (e.g., less than 10 to 1), even this refinement of the basic approach will not account for all aspects of the structural behavior. In these cases equation (15) has been found to predict too large a value of I'_e compared to test. If attempts are being made to optimally design a short span with a ratio less than 10 to 1, a test should be conducted.

7.5.6 Bending Stress Equations

Stress in face 1 (at distance c_{11} from centroidal axis 1) is:

$$f_{11} = \frac{-(M - EI_o y'')}{a_1 D} - Ec_{11} y'' \qquad (19)$$

and in face 2 (at distance c_{22} from centroidal axis 2) is: (20)

$$f_{22} = \frac{M - EI_o y''}{a_2 D} + Ec_{22} y''$$

Refer to Table 6 for the expression for maximum moment for the appropriate load type. If the stress at a location other than midspan is desired, use the more general expression in the next column.

Load Type	max. M	M *	*Domain
Concentrated	PL/4	Px/2	$0 \le x \le 0.5$ L
Uniform	$wL^2/8$	wx(L – x)/2	$0 \le x \le 0.5$ L
Triangular	$w_oL^2/12$	$w_o x\left(\frac{L}{4} - \frac{x^2}{3L}\right)$	$0 \le x \le 0.5$ L
Trapezoidal		$w_o(-a^2 + 3Lx - 3x^2)/6$	$a \le x \le 0.5$ L

	$w_o L^2 \left(1 - \frac{4}{3}k^2\right)/8$	$w_o x(3a[L - a] - x^2)/(6a)$	$0 \le x \le a$

TABLE 6: Expression for Maximum Moment

$y'' = d^2y/dx^2 = 20 D_5 x^3 + 12 D_4 x^2 + 6 D_3 x + 2 D_2 + c [F_1 e^p + F_2/ e^p]$ (21)

Note that $p = x\sqrt{c}$

In equation (21) for y'', substitute $x = L/2$ and the expressions for D_5 to D_2, and F_1 and F_2, for the particular load case. Next substitute the resulting value for y'' in equations (19) and (20) for f_{11} and f_{22}, to obtain maximum compressive and tensile stresses. Note that no web crippling criteria have been developed for regions subject to concentrated load.

Similar to the approach used for stiffness, an "effective section modulus" (S_e) may be calculated for each face for a given load type, span and core shear modulus, for a particular section. One value (S_{e1}) will be for face 1 and another (S_{e2}) for face 2. (22)

$S_{e1} = M / f_{11}$

$S_{e2} = M / f_{22}$ (23)

7.5.7 Shear Stress Equations

An approximate expression for shear resisted by the core is: (24)

$V_c = V - E I_o y'''$

See Table 7 for the expression for maximum shear, which occurs at the ends ($x = 0$ and $x = L$), for the desired load type. Shear at other locations is given in the next column.

Load Type	max. V	V *	*Domain
Concentrated	$\frac{P}{2}$	$\frac{P}{2}$	$0 \le x \le 0.5L$
Uniform	$wL/2$	$w\left(\frac{L}{2} - x\right)$	$0 \le x \le 0.5L$
Triangular	$w_oL/4$	$\frac{w_oL}{4} - \frac{w_ox^2}{L}$	$0 \le x \le 0.5L$
Trapezoidal	--	$w_o(L - 2x)/2$	$a \le x \le 0.5L$
	$w_o L(1 - k)/2$	$w_o(La - a^2 - x^2)/(2a)$	$0 \le x \le a$

TABLE 7: Expression for Maximum Shear

For non-trapezoidal loads ($0 \le x \le L$) and for trapezoidal ($a \le x \le L - a$): (25)

$y''' = d^3y/dx^3 = 60\ D_5\ x^2 + 24\ D_4\ x + 6\ D_3 + c^{1.5}\ [F_1e^p - F_2/e^p]$

As before, $p = x\sqrt{c}$. Maximum V for all four load types considered occurs at x = 0, and at x = L. (25.a)

Thus, at x = 0, for all load types except trapezoidal:

$y''' = 6D_3 + c^{1.5}(F_1 - F_2)$

For trapezoidal load (for $0 \le x \le a$):

$y''' = 60\ E_5\ x^2 + 6\ E_3 + c^{1.5}\ [G_1e^p - G_2\ /\ e^p]$ (26)

For trapezoidal load at x = 0: (26.a)

$y''' = 6E_3 + c^{1.5}\ [G_1 - G_2]$

The fraction of total shear carried by the core is:

(27)

$$R = \frac{V_c}{V}$$

This dimensionless ratio R is independent of load magnitude, but is a function of load type, span and core shear modulus, for a given beam section.

The shear flow (force per unit length) is approximated by: (28)

$q_c = \frac{V_c}{D} = \frac{RV}{D}$

Where D is the distance between centroidal axes of the two faces. This shear flow value may be compared to an allowable value derived from longitudinal shear tests (see Section 7.3) for the given cavity, elastomer, and method (adhesion and/or mechanical indentations) of resisting slip longitudinally.

Note that an upper bound value of q_c may be calculated by the formula:

(28.a)

$$q_c = \frac{VQ}{I} = \frac{Va_n\left(h_n - c_{nn}\right)}{I}$$

This formula for shear flow is less accurate, but conservative. It results in almost the same values, as equation (28), for high values of core shear modulus and span. In cases where the composite centroidal axis passes through the clear space (gap) between faces, n equals 1 for all subscripts (or it may be set to 2 for all subscripts). In other cases, n corresponds to the face which does not contain the composite centroidal axis. Refer to Figure 32 in the example for an illustration of h_1 and h_2.

The approximate maximum core shear stress, at maximum V_c, is:

(29)

$$f_{vc} = \frac{V_c}{b'D}$$

Where b' equals the minimum core width (which normally occurs between the aluminum interlocks).

7.5.8 Example

To illustrate use of the equations, consider the following values (based on measurements, not the nominal die drawing dimensions) for an AAMA test extrusion. Note that CAD software may be used to calculate section properties of faces 1 and 2. This example is given in IP units only.

In this example G_{ce} = 80 ksi at room temperature, and G_{ce} = 20 ksi at an elevated temperature. This second G_{ce} value was determined at a mid-cavity temperature of about 105°F with “exterior” aluminum maximum temperature about 160°F, “interior” aluminum ≥ 80°F, and room air about 70°F.

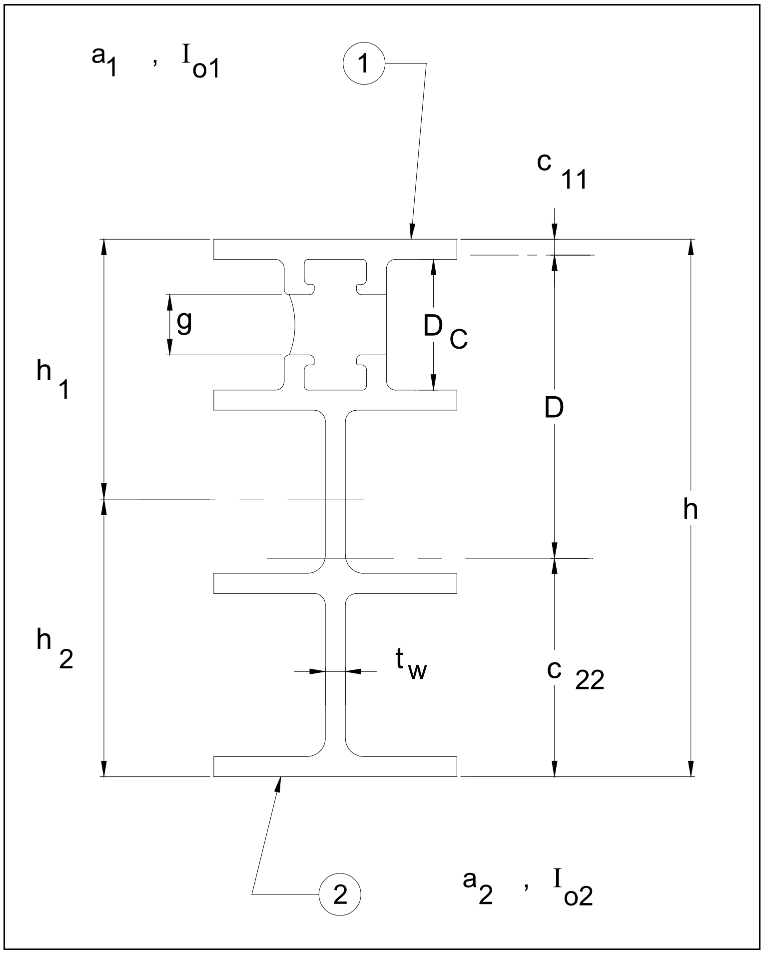


FIGURE 32: Example Die Drawing with Dimensions

a_1 = 0.2377 in^2 I_{01} = 0.00188 in^4 c_{11} = 0.1059 in.

a_2 = 0.8222 in^2 I_{02} = 0.6374 in^4 c_{22} = 1.2763 in.

D = 1.9046 in.

D_c = 0.807 in. which is the maximum depth of the polyurethane.

T_w = 0.107 in.

A = 0.3121 in^2 = t_w (h-g) = 0.107 in. (3.287 in. – 0.370 in.) = web area

A_c = 0.355 in^2 = 0.56 in. (0.37) + 2(0.062 in.) (0.25) + 0.156 in. (0.375 in.) = core area

g = 0.370 in. clear (gap)

b = 0.440 in. which is the “average width” = A_c/D_c = 0.355in^2/0.807 in.

E = 10,000,000 psi = 10,000 ksi = Young’s modulus of aluminum

G_{ce} = (See tables for values considered)

L = (See table) = span

P = 100 pounds; concentrated load at midspan

w = 100 pounds divided by span L; uniform load

Substituting in equations (1) to (4) for the various parameters:

$I_c = 0.6689\ in^4$

$I_o = 0.6393\ in^4$

$I = 1.3082\ in^4$

$I_c / I = 0.5113$

Note that $I = I_c + I_o$ is the upper bound value of moment of "inertia" (second area moment) which would only be attained if there were no shear deformations of the core or faces and no slip occurred. $I_o = I_{o1} + I_{o2}$ is the lower bound, which would apply if the faces were free to slip along the core.

Effective Moment of Inertia:

Calculate deflection y from Eq. (8), and I_e from Eq. (9) and (10). First use expressions from Table 2 for D_5 to D_0 for concentrated and uniform load, and expressions from Table 4 for F_1 and F_2. Now calculate y (at x = L/2) and I_e, at this maximum value of y. Next compute I'_e, using Eq. (15) and (16) respectively. Values are presented in Table 8 for several spans. Refer to Figure 33 for a plot of I'_e for spans of 36 in. (3 feet) to 96 in. (8 feet), for G_{ce} = 80 ksi and 20 ksi.

Effective Section Modulus:

Refer to Eq. (19) to (23), and appropriate expressions for maximum moment in Table 6, to calculate values of effective section moduli S_{e1} and S_{e2}. Values are given in Table 9.

For comparison note that if the core were replaced by a thin aluminum bridge, the section modulus values (using distances h_1 and h_2 to the centroidal axis of the entire section) would be approximately:

S_1

$= 1.3082\ in^4/1.5845\ in. = I/h_1$

$= 0.8256\ in^3$ TOP ("exterior", face 1)

S_2

$= 1.3082\ in^4/1.7035\ in. = I/h_2$

$= 0.7679\ in^3$ BOTTOM ("interior", face 2)

In other words the noted values are the usual section modulus values from ordinary beam theory. These two values may be compared to the effective section moduli (that include the effect of the polyurethane core, span and load type) in Table 9.

Span L (in)	Elastomer Effective Shear Modulus G_{ce} (ksi)	Concentrated Load			Uniform Load	
		I'_e/I_e	Predicted I'_e (in^4)	Effec I by test (in^4)	I'_e/I_e	Predicted I'_e (in^4)
48	20	0.9566	0.9765	1.02	0.9647	0.9924
	80	0.9494	1.1381	1.08	0.9587	1.1574

72	20	0.9779	1.1128	1.10	0.9822	1.1266
	80	0.9758	1.2231	1.23	0.9805	1.2348
96	20	0.9868	1.1830	--	0.9893	1.1943
	80	0.9860	1.2578	--	0.9887	1.2654

TABLE 8: Effective Moment of Inertia

Span L (in)	Effective Shear Modulus G_{ce} (ksi)	Concentrated Load		Uniform Load	
		S_{e1} (TOP) (in^3)	S_{e2} (BOTTOM) (in^3)	S_{e1} (TOP) (in^3)	S_{e2} (BOTTOM) (in^3)
48	20	1.221	0.640	1.049	0.679
	80	0.988	0.698	0.880	0.740
72	20	1.056	0.677	0.924	0.721
	80	0.927	0.720	0.849	0.755
96	20	0.988	0.698	0.880	0.740
	80	0.900	0.731	0.839	0.761

TABLE 9: Effective Section Moduli (for midspan stress)

Span L (in)	Effective Shear Modulus G_{ce} (ksi)	Concentrated			Uniform		
		$R = V_c/V$	P = 100 lbs		$R = V_c/V$	W = 100 lbs = wL	
			V_c (lbs)	$V_c/D = q_c$ * (lbs/in)		V_c (lbs)	$V_c/D = q_c$ (lbs/in)
48	20	0.439	21.9	11.5	0.320	16.0	8.4
	80	0.506	25.3	13.3	0.414	20.7	10.9
72	20	0.492	24.6	12.9	0.382	19.1	10.0
	80	0.511	25.5	13.4	0.447	22.3	11.7
96	20	0.506	25.3	13.3	0.414	20.7	10.9
	80	0.511	25.5	13.4	0.463	23.1	12.2

TABLE 10: Core Shear (Maximum; refer to Section 7.5.7)

*Note that VQ/I = 13.43 lbs/in, per equation (28.a), for P = 100 lbs.

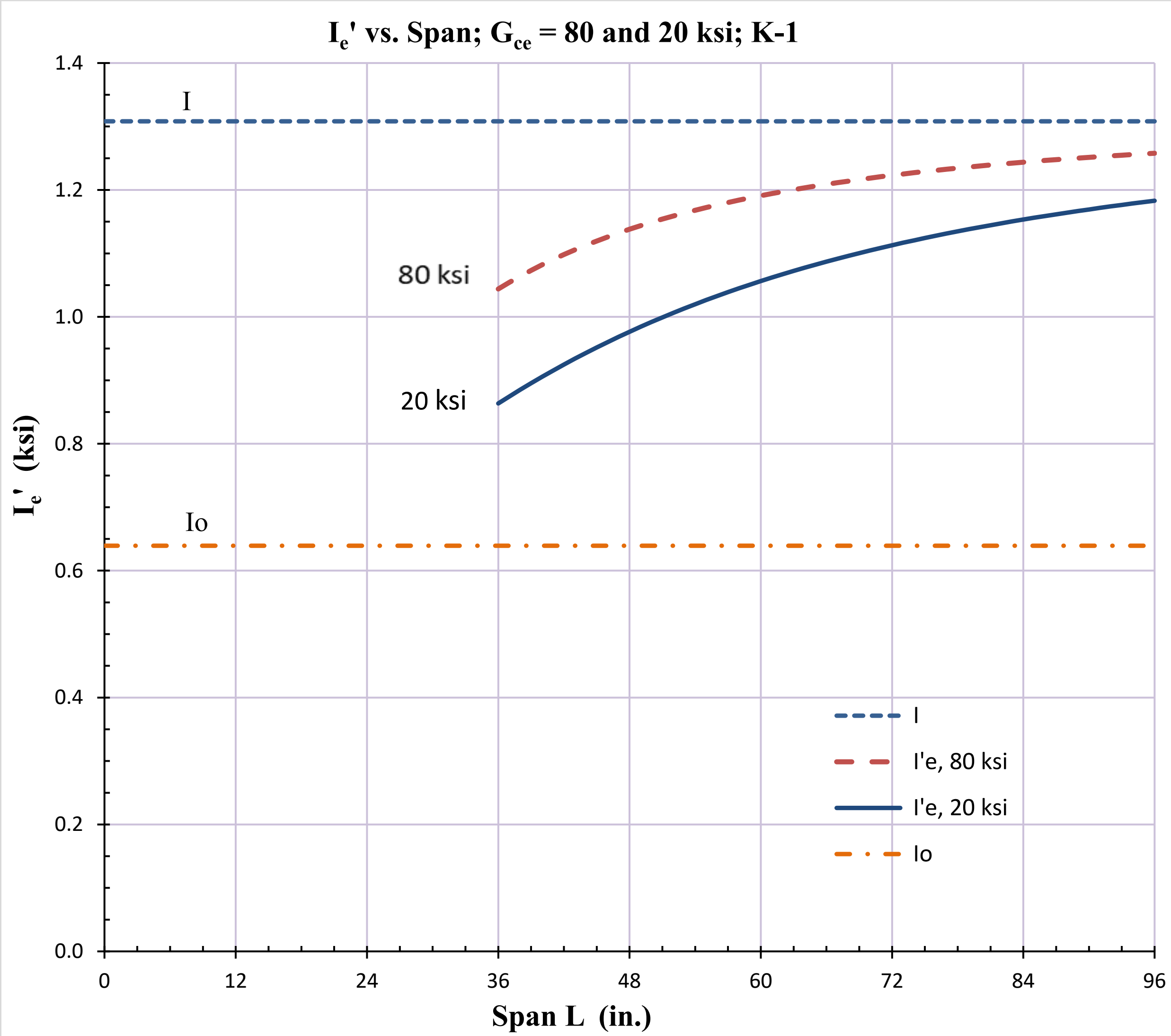


FIGURE 33: Predicted Correction for Shear Deformation

NOTE 8: In Figure 33, I'_e is based on measured dimensions, for a midspan concentrated load and no overhangs. Refer to the profile cross-section in Figure 32 and selected I'_e values in Table 8. In Figure 33, $I = I_o + I_c = 1.3082 \text{ in}^4$ and $I_o = I_{o1} + I_{o2} = 0.6393 \text{ in}^4$. For G_{ce} = 80 ksi, the profile with its urethane core was at room temperature. For G_{ce} = 20 ksi, the core had an average temperature of 40.5° C (105° F). The profile had a maximum temperature of 71.1° C (160° F) and a minimum of 26.7° C (80° F).

Using the governing equations, a plot of deflection as a function of effective G_{ce} can be made for a particular profile, span and midspan load. Refer to Figure 35 for an example using AAMA test profile K-1 (see Figure 34) with a 400 lb load and a 4 ft span. The vertical dashed lines indicate the lower and upper limits of about 0.074 in. and 0.148 in., respectively. The lower limit occurs with an infinitely stiff core and the upper deflection limit occurs with G_{ce} equal to zero (no composite behavior). The small dark squares are the plotted points for the curve. As G_{ce} decreases, the deflection increases at an increasing rate.

Figure 36 shows this relation more generally, for the same profile, as beam stiffness (K) versus G_{ce}. Here K equals load (P) divided by deflection (y). For example, K = 4,880 lbs/in = 400 lbs / 0.082 in.. This corresponds to G_{ce} = 67.6 ksi. Because stiffness (K) is inversely related to deflection (y), as G_{ce} decreases, stiffness decreases (deflection increases) at an increasing rate.

Figure 37 is a plot of K versus G_{ce}, for a 6 ft span of K-1. This span is more flexible than the 4 ft span and core shear effects contribute a smaller percentage of the total deflection. The range of K is smaller than for a 4 ft span and K is less sensitive to changes in G_{ce}.

These plots are examples only. Other profiles and thermal barriers (materials, shapes and sizes) will have plots that differ in the details. However, the general trends in behavior are expected to be similar.

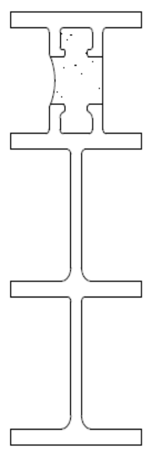


FIGURE 34 Test Profile K-1

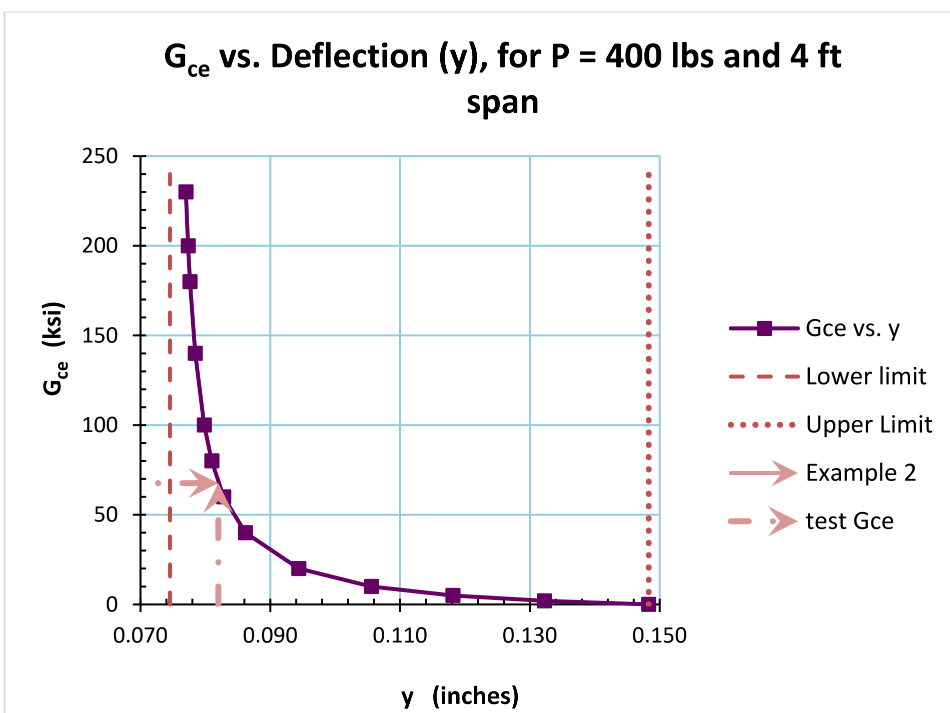


FIGURE 35 Effective G_{ce} vs. deflection (y) for 4 ft span, with P = 400 lbs

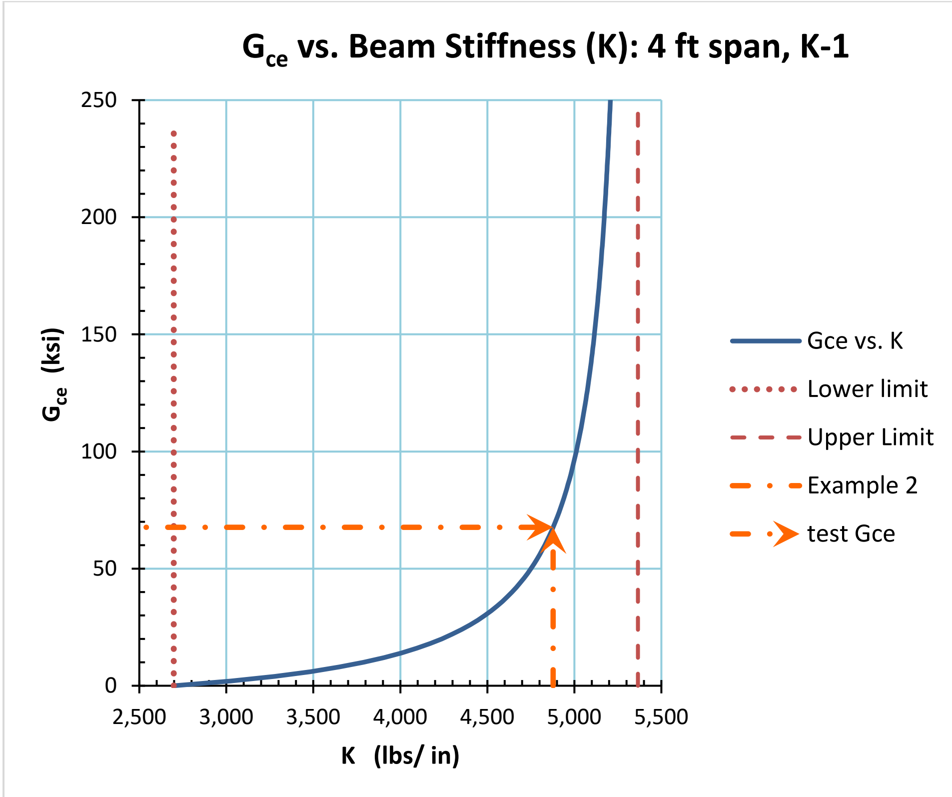


FIGURE 36: Effective G_{ce} vs. stiffness (K = P / y) for 4 ft span

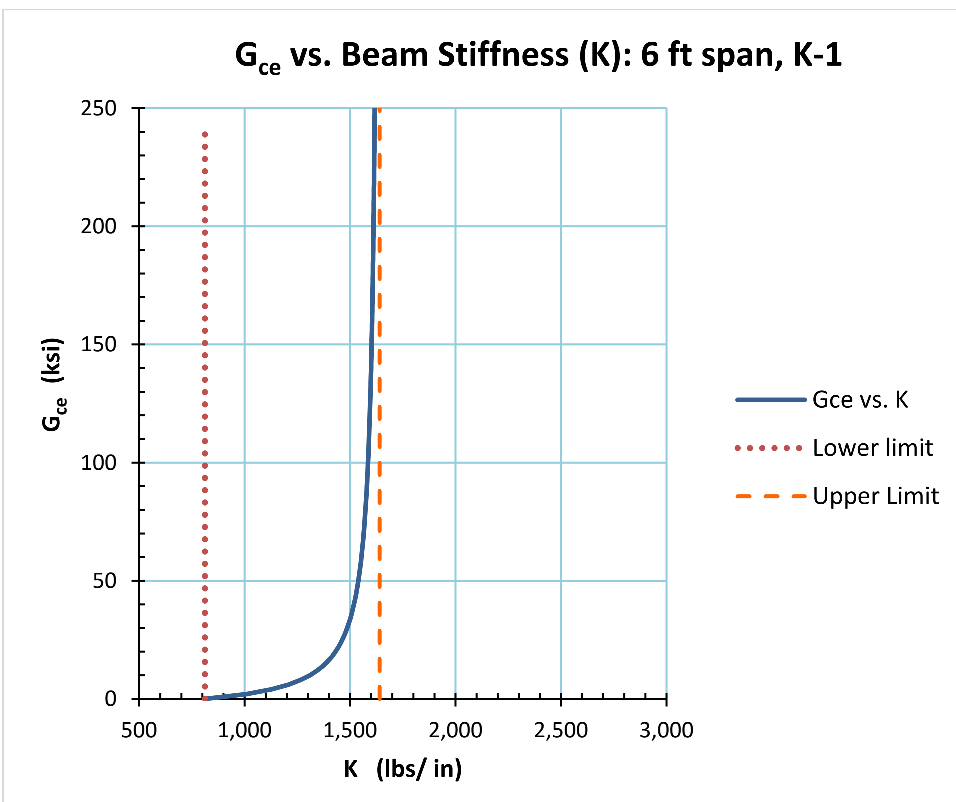
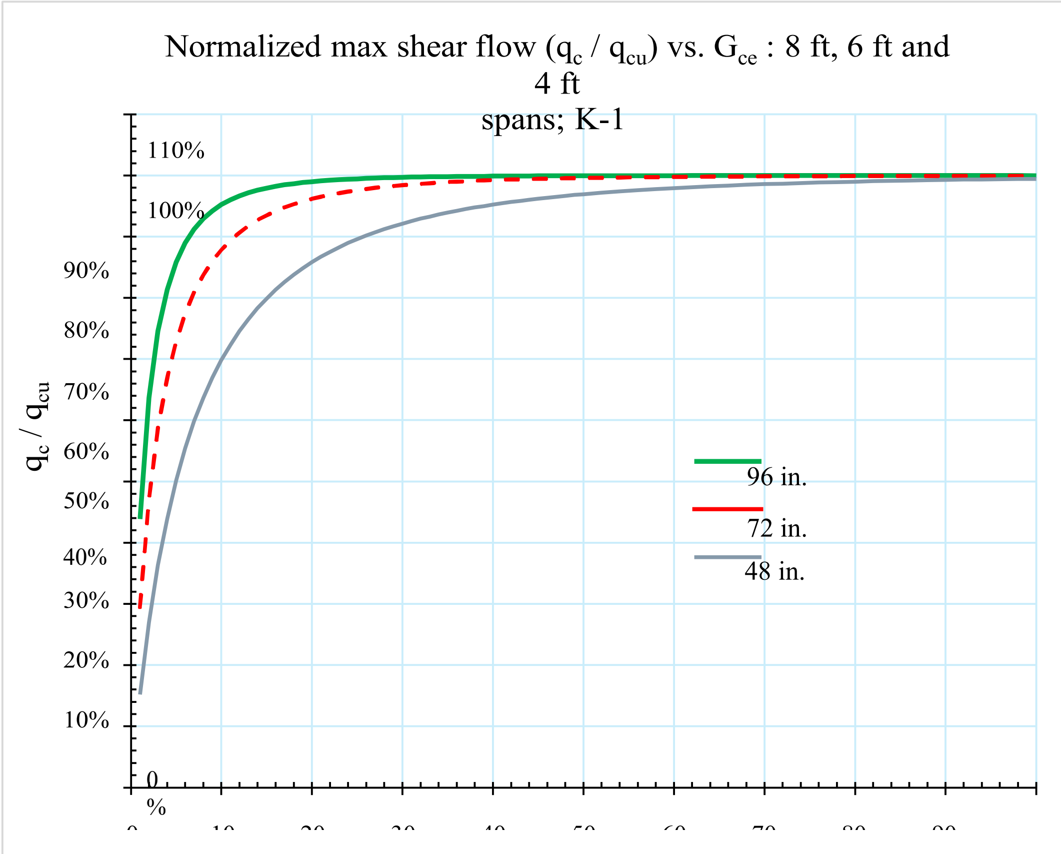


FIGURE 37: Effective G_{ce} vs. stiffness (K = P / y) for 6 ft span

TIR-A8-16 includes a calculation tool for the structural design method set forth in Section 7.5 for aluminum beams with composite thermal barries. This makes the method practical for quick, simple and suitably accurate evaluation of composite properties for many shapes and sizes of extrusions.

7.5.9 Longitudinal shear flow (examples)

Considering the example profile K-1, a study was made of the effect of Gce on maximum longitudinal shear flow. Refer to Section 7.5.7 for Equation 27 for the shear ratio $R = V_c / V$ and Equation 28 for shear flow $q_c = V_c / D$. The upper bound on qc, which will be designated as qcu, is given by equation (28.a). The ratio $(q_c / q_{cu}) = (RV / D) / (VQ / I) = (R / D) / (Q / I)$, which is independent of the total shear (V = P / 2, per Table 7). For a midspan concentrated load on a simply supported beam, without overhangs, the maximum core shear and shear flow occur at the supports.
See Figure 38 for plots of the normalized maximum shear flow (qc / qcu) versus G_{ce}, for three span lengths (96 in., 72 in. and 48 in.). Refer also to Table 10 for values of qc, for an example loading, for two G_{ce} values and these three spans. The plotted range of G_{ce} values is 1 ksi to 100 ksi. Notice that as G_{ce} increases so does the normalized shear flow. Also note that the shortest span exhibits the greatest sensitivity to G_{ce}. This figure presents examples only, as other profiles and conditions will differ in detail. However, the overall trends are expected to be similar.



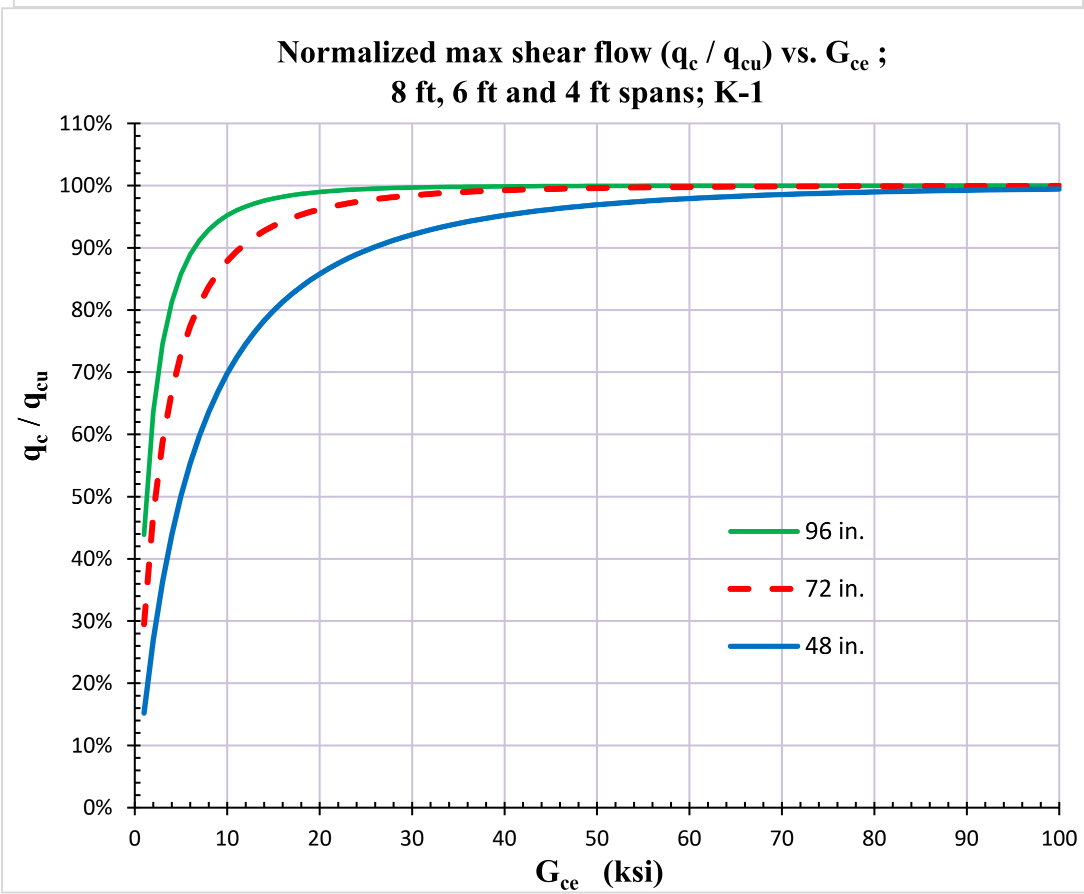


FIGURE 38: Shear Flow vs. G_{ce}

Dead Load Support: Considerations

Dead load due to glazed infill (e.g., glass lites) is commonly resisted by horizontal framing members. One support method for the infill utilizes an aluminum bridge beneath each setting block. The bridge spans across the thermal barrier and between facing sections (faces) and thus transfers the infill's weight to the faces. This method, which depends on adequate bridge design, minimizes or avoids dependence on the local bending strength and stiffness (in the vicinity of each setting block) of the thermal barrier. Of course, the aluminum faces must also be designed for bending about a horizontal axis (strength and stiffness) so that the member can span between mullions.

There is also another method, one which does not utilize a bridge, and which must be evaluated carefully for adequacy before using. This method does rely on the thermal barrier's local strength and local stiffness to adequately transfer the infill weight to the faces. Because dead weight is sustained over a long time (years and decades) and over a range of temperatures, suitable testing and analysis of the proposed horizontal profile, with the installed thermal barrier, are needed. Thus, the following items need to be considered:

- Creep effect. Thermal barrier materials vary in their response to sustained load. Refer to Section 6.7.4 for examples and commentary on creep. The long-term strain due to a particular stress level may be significantly larger than that caused by that same stress held for a short period (e.g., a few minutes). Therefore, the short-term deflection, due to local bending of the thermal barrier and adjoining aluminum, might be small enough to maintain adequate clearance between a glass lite's edge and the aluminum faces. However, that same load imposed on the setting blocks for a few months or a few years might result in additional deflection such that a glass edge contacts a face. Potentially that contact could result in sufficient bearing stress to break the glass.

Also, a thermal-barrier material's flexural rupture stress might depend on the load duration.

- Temperature effect. Properties of thermal-barrier materials may also vary over the range of temperatures that they could reach in service after infill installation. Therefore, for example, a thermal-barrier material with a specific cross-section might have adequate creep resistance at room temperature but not at a realistic in-service elevated temperature attained and held for long cumulative period (e.g., many hot days). In general, a thermal barrier design (a selected material with a particular cross-section) must be determined to have sufficient strength and stiffness, for the pertinent temperature range and load duration, to adequately resist local stresses and limit the deflection due to dead load.

Thermal-barrier material manufacturers can be requested to supply properties (e.g., tensile) related to creep and temperature. This information would assist in analytically evaluating a proposed design. However, it may still be necessary to test profiles with installed thermal barriers for creep and temperature effects on their ability to adequately support a given dead load.
Analytical methods for assessing the effects (local stresses and local deflection) due to dead load include simplified but conservative approximations of the faces and thermal barrier. More accurate results can be attained using sufficiently detailed models and finite element analysis (FEA).

Example case

To illustrate the potential for problems in supporting glass weight, an example of a failure is briefly presented. The failure occurred several months after the installation of a relatively large insulating glass unit (an IGU about 11 ft high) in a punched window opening in the west masonry wall of a remodeled historic building in the Midwest. The exterior lite, which was tempered, shattered unexpectedly during the construction project. No obvious cause was immediately apparent. Investigation found that no chairs had been used to support the setting blocks and that there was no local blocking (beneath the setting blocks) between the sill profile's web and the masonry. Neither chairs nor local blocking were included in the design. At each setting block, the web of the sill member (aluminum faces with a P&DB urethane thermal barrier) was depressed such that the depression's depth was approximately equal to the setting block's thickness. The depressions had allowed the glass edge to contact the aluminum face.

The sill member was supported for vertical load by the bearing wall. The bottom edges of the profile's faces (specifically the flanges) were continuously supported. Thus, the IGU weight resulted in local bending of both the thermal barrier and aluminum web; the composite web spanned horizontally (perpendicular to the glass plane) for the profile's depth between flanges. Post-failure calculations indicated a relatively high local bending stress in the thermal barrier, which was consistent with creep being the highly probable cause of the failure.

7.6 See Figures 39 through 42 for plots of calculated quantities (deflection, shear flow and moments) for the unsymmetrical profile K-1. Refer to Figure ~~3~~34 in the body of this document. These plots are for the case of a midspan concentrated load of 400 lbs on a 6 ft (= 72 in) simply supported span, with no overhangs. The effective shear modulus (G_{ce}) is 50 ksi. FEA software (TB-FEM) was used, with 1 in. long elements.

Figure 39 is a deflection plot. The software does not include the effect of the faces' shear deformation, which is small (0.0062 in.) for this span. Figure 40 depicts shear flow. The drop-off is apparent — especially for x greater than about 20 in. — as the distance from midspan decreases. This is the local-zone effect, in which the degree of sandwich beam behavior decreases to zero at the concentrated load. The faces' bending and shear stiffnesses, as well as the need for slope continuity of the deflection curve, in this region cause the faces to resist an increasing share of the shear.

Figure 41 is an enlarged plot showing only the beam's left half and the three bending moments that comprise the overall bending moment response: moment in face #1 and #2, plus the moment due to coupling (via the core's shear stiffness) of the faces' axial forces. The moment in the shallow face #1 is very small (12 in-lbs maximum). The non-linear portions of the other two moment curves are apparent: for face #2's moment, note the increasingly steep slope as the distance to the load decreases; for the moment due to the coupled axial forces, observe that the slope decreases as the distance to the load becomes smaller. The short, straight dotted blue line, from 30 in. ≤ x ≤ 36 in., is projected from the origin and indicates where a linear response would plot. The local decrease, relative to the linear plot, in the coupled axial-forces moment (as local shear flow decreases) is offset by a corresponding relative increase in the moment in face #2.

Figure 42 depicts the entire span as well as the sum of the individual moments that comprise the beam's total bending resistance.

NOTE ~~7~~9: *The local effect on the constituents of the overall bending moment for a deeper profile (the full AAMA test profile), used as a 14 ft long beam with two continuous spans and loading due to restrained thermal bow, was shown in a plot in a departmental paper by K. Wolf and D.R. Sherman, at UW-Milwaukee in the 1990s. Dr. Wolf is the creator of the TB-FEM software.*

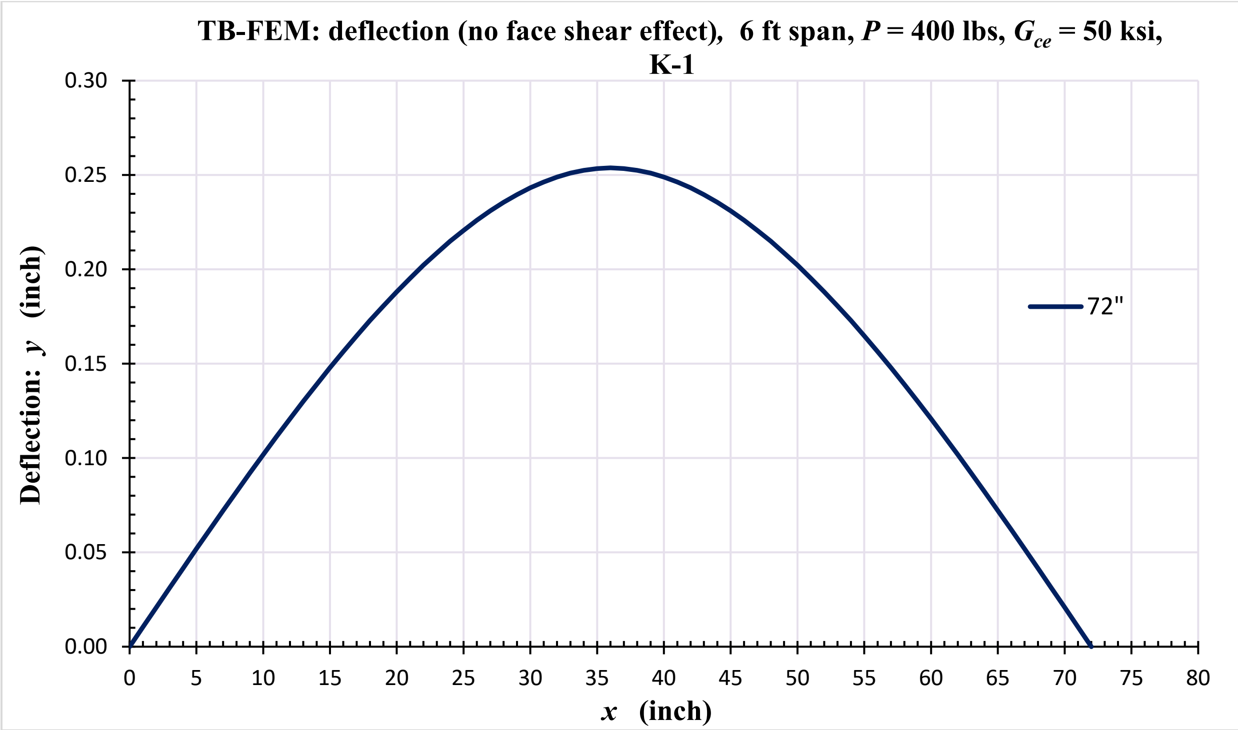


FIGURE 39: Deflection

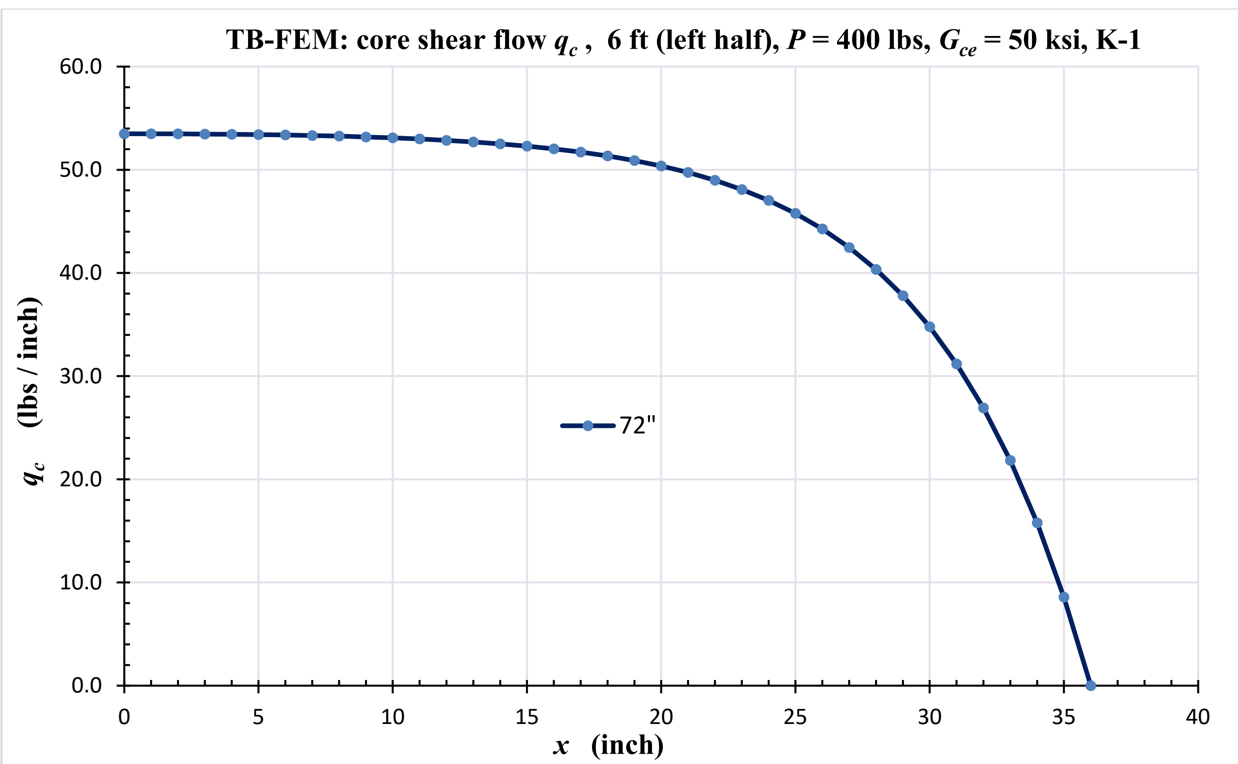


FIGURE 40: Shear Flow

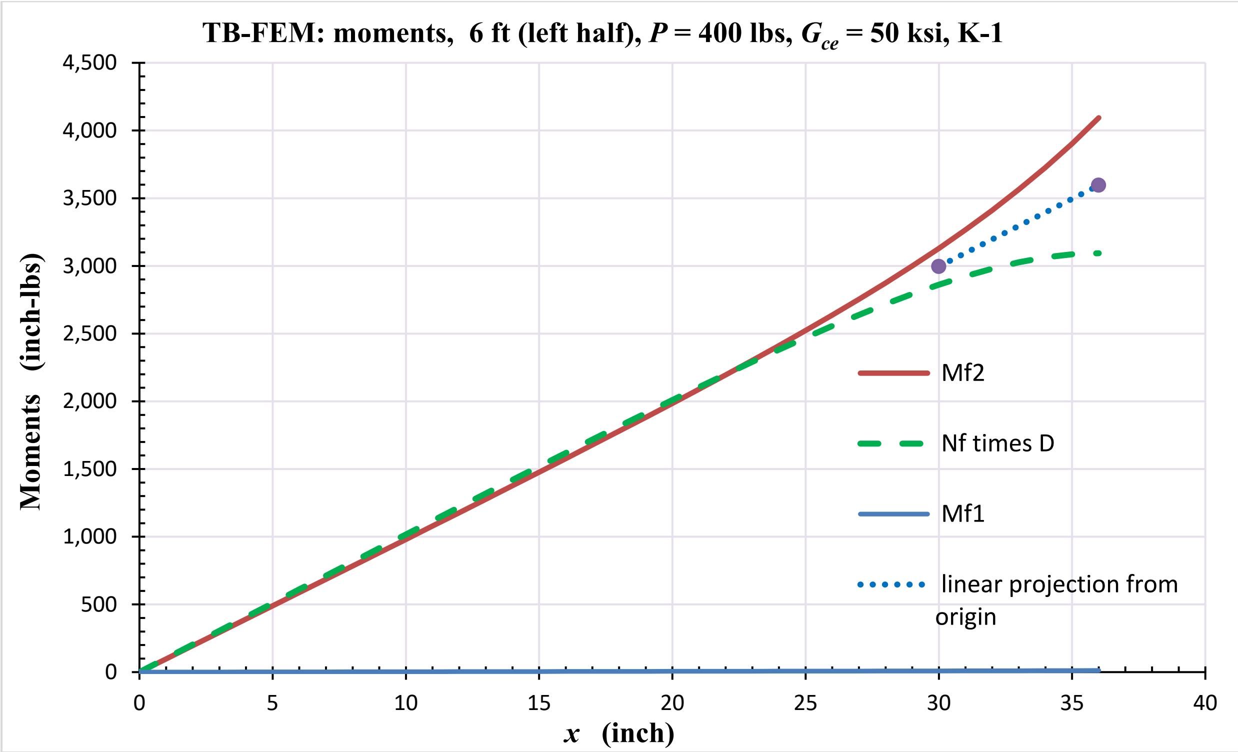


FIGURE 41: Bending Moments: Face 1, Face 2 and Coupled Axial Forces

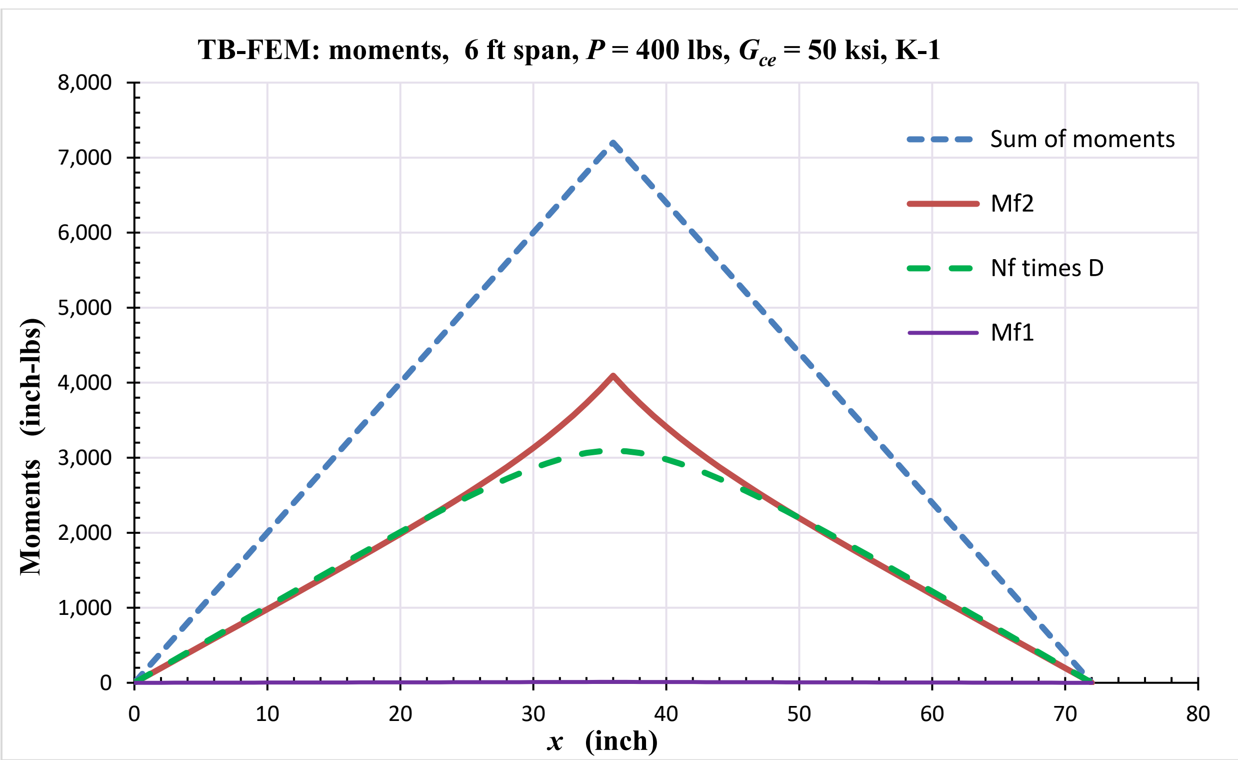


FIGURE 42: Bending Moments: Sum, Face 1, Face 2 and Coupled Axial Forces

7.7 Glossary of Terms

All definitions for this document were taken from the 2024 FGIA Glossary.

8.0 ATTACHMENTS

8.1 Canadian Research Council Temperature Study

CBD-47. Extreme Temperatures at the Outer Surfaces of Buildings
Originally published November 1963.
D.G. Stephenson

It is sometimes taken for granted that the variation in the outer surface temperature of a wall or roof will never exceed the range of the outside air temperature. This ignores the influence of radiation and seriously under estimates the maximum temperatures that building materials must withstand. This Digest discusses the effect on outside surface temperature of solar radiation, long-wave radiation, surface colour, the position and colour of adjacent surfaces, temperature of the air inside and outside the building, and the thermal properties of materials used to form a building envelope.

The most direct way of determining the temperatures that actually occur in buildings is to measure them. This approach is quite impractical, however, when the purpose is to find the extreme temperatures that any wall or roof surface may experience; this would require a long series of observations on structures with every combination of wall and roof construction, surface colour, orientation and location. Instead, the heat exchange at the outside surface of a wall or roof can be analysed and the factors that influence the surface temperature can be studied separately. With these data it is possible to predict the temperatures that will obtain under any specified circumstances.

Thermal Radiation

All objects continuously emit radiation and absorb some of the radiation from other bodies that is incident on them. Emission and absorption of radiation play a large part in the energy exchange at the outer surface of a building.

The wave-lengths of the thermal radiation depend on the temperature of the emitting surface - the higher the temperature the shorter the wave-length at which the maximum energy occurs. The absolute temperature of the outer layers of the sun's atmosphere is about twenty times as great as the temperature of the surface of the earth and terrestrial objects such as buildings. The energy in solar radiation is concentrated, therefore, at much shorter wave-lengths than occur in the radiation from low-temperature bodies. Thus solar radiation is generally referred to as "shortwave" and radiation from terrestrial objects as 'long-wave."

The rate of energy emission from unit area of a surface depends on the fourth power of the absolute temperature of the surface and on the nature of the surface, which is characterized by the value of the emissivity. The value of the emissivity also indicates the propensity of the surface to absorb radiation of the same wave-length as that it emits. The absorptivity of a surface for short-wave radiation, a, is not, in general, equal to its absorptivity for long-wave radiation. The change in absorptivity with wave-length can sometimes be exploited to reduce the maximum temperatures that occur at the surface of bodies exposed to the sun. This is discussed later under the effects of colour.

Heat Balance at a Surface

At every instant the total heat leaving a surface must be equal to the total heat approaching the surface. Figure 1 shows the various components of the heat flow toward and away from an opaque surface. For the surface of a building exposed to solar radiation the various heat flows will be in the directions shown in the figure. The temperature of the surface is always at the value where the heat gains and losses balance. If the solar radiation incident on a surface increases, the surface temperature rises, causing conduction, convection and long-wave radiation to increase just enough to offset the increased rate of energy absorption.

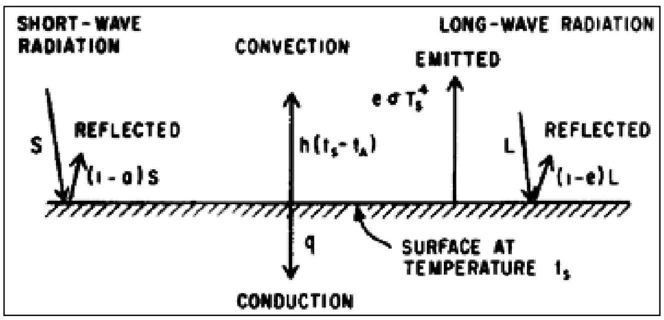


Figure 1. Components of heat balance at an opaque surface.

Calculation of the surface temperature and heat flux can be greatly simplified through the use of the sol-air temperature concept. The S. A. T. is the fictitious temperature of the outside air that would produce by convection alone the same rate of heat exchange at the surface as actually occurs by convection and long and short-wave radiation combined. Thus
$q = h\,(S.A.T. - t_s)$;
combining this definition of S. A. T. with the energy balance at the surface gives

$$S.A.T. = t_A + \frac{aS}{h} + \frac{eL}{h} - \frac{E\sigma T_s^4}{h}$$

The temperature of the outside surface of a wall or roof with negligible heat storage capacity can be determined by the graphical method described in CBD 36, using S. A. T. as the outside temperature and *h* as the outside surface conductance. Figure 2 gives the magnitudes of the different components of S. A. T. and shows how the roof conductance and inside temperature affect the outside surface temperature. The values used for this example are appropriate for a dark coloured, flat roof in the region between 40 and 50 degrees north latitude, at a time when the surface temperature would be a maximum. The indicated surface temperature of 190°F represents the highest temperature a dark roof with an unobstructed view of the sky is likely to attain in any part of Canada.

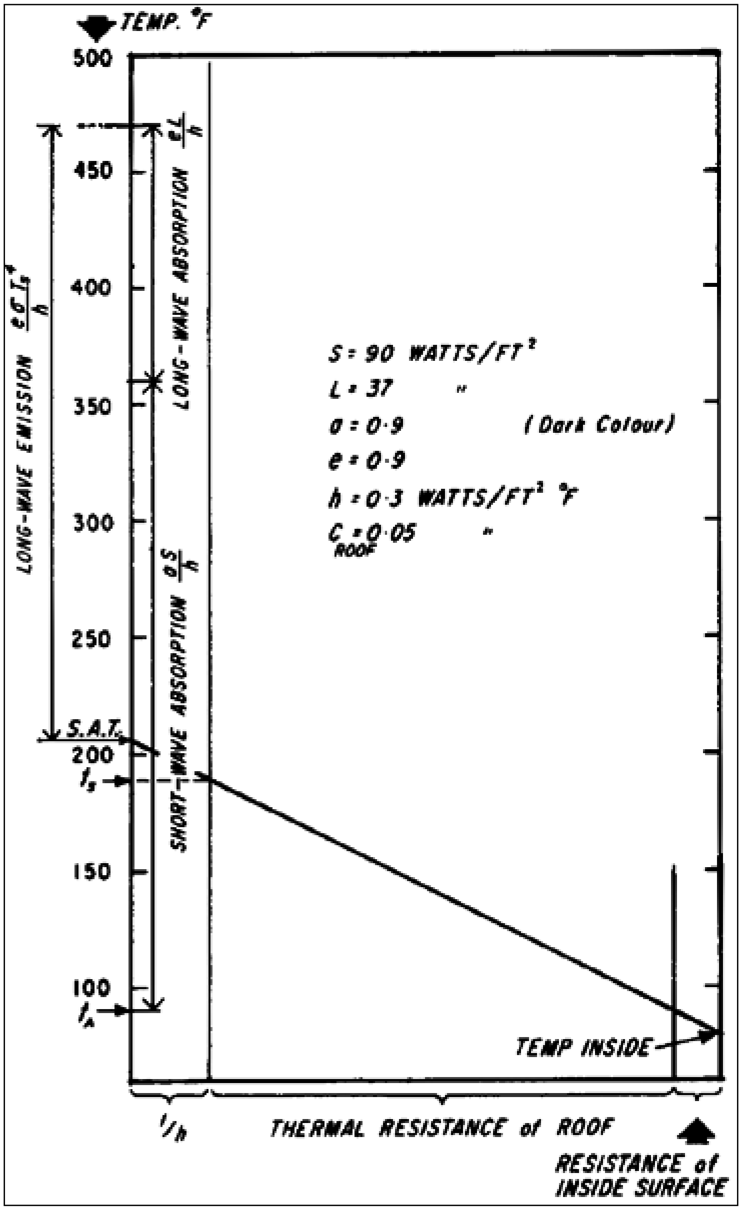


Figure 2: Summer temperature for dark roof with unobstructed view of sky.

The short-wave irradiation S may include reflected radiation from adjacent surfaces, depending on their colour, proximity and the irradiation they receive, as well as the radiation that comes directly from the sun and sky. The value of the long-wave radiation, *L*, is likewise dependent on the surrounding surfaces that can be seen from the surface in question. For example, the roof of a low building situated directly south of a much higher building will receive a considerable amount of reflected sunlight, plus some fraction of the long-wave radiation emitted by the wall of the higher building. The maximum temperature of a dark horizontal roof situated close to the south wall of a very high building could be as high as 230°F.

Vertical Surfaces

The annual maximum insolation is nearly the same for all walls facing not more than 90 degrees from south, regardless of latitude. The hour and date of the maximum depend, however, on the wall orientation and latitude. Walls facing east and west receive their greatest irradiation in the middle of the summer about 4 hours before and after noon, respectively, whereas those facing south receive their maximum at noon about the middle of November. Walls facing east and west will have higher surface temperatures than walls facing south, other things being equal, because their maximum irradiation coincides with the maximum ambient air temperature.

Walls always receive some reflected shortwave radiation from their surroundings. They also receive more long-wave irradiation than flat roofs because at least half their field of view is below the horizon where the intensity of long-wave irradiation is always greater than that from the sky. Thus the total radiation incident on a vertical surface is just about the same as that shown in Figure 2 for a flat roof. A surface temperature of 190°F, therefore, is the maximum a dark coloured wall is likely to attain.

Effect of Heat Storage

It is commonly recognized that the surface of a thick masonry wall does not become as hot during a clear summer day as the outer layer of a light curtain wall section, if both walls have the same exposure. The difference lies in the heat storage capacity of the walls.

When the radiation incident on a wall or roof surface suddenly changes, as when a cloud moves away from in front of the sun, the S. A. T. increases abruptly, but the temperature of the exposed surface does not reach a new equilibrium value until some time later. The time required depends on the value of the surface conductance and the heat storage capacity of the wall or roof. Lightweight walls reach equilibrium in a fraction of an hour; very heavy walls require more than a day. The temperatures indicated by the straight line on Figure 2 are the equilibrium values. Even on a cloudless day the S. A. T. is never constant, because solar radiation continuously changes from sunrise to sunset. Around midday, when the solar radiation on a horizontal surface is maximum, the S. A. T. changes very little in a period, of an hour so that the surface of a lightweight roof could reach the maximum temperature of 190°F shown in Figure 2. The maximum surface temperature for a massive slab with the same total thermal resistance would be somewhat lower. The precise calculation of surface temperature, allowing for heat storage capacity, is quite involved and a detailed discussion is beyond the scope of this Digest. It is perfectly correct to say, however, that the temperatures at various points throughout a building enclosure will never exceed the values that would obtain at equilibrium with the maximum S. A. T. Thus the straight line on Figure 2 represents the upper limits for the temperatures everywhere through the roof.

The Effect of Surface Colour

The fraction of the solar irradiation absorbed by a surface depends primarily on its colour. A white surface absorbs about 40 per cent, whereas dark green, brown and black surfaces absorb about 90 per cent. Figure 2 shows the extent to which the S. A. T. for a surface depends on the magnitude of the absorbed short-wave radiation. If the roof considered in Figure 2 had a white instead of black surface (i.e. a = 0.4 instead of 0.9) the surface temperature would be 130°F instead of 190°F. The difference between the maximum temperatures of black and white vertical surfaces is about 50 F degrees compared with 60 F degrees for horizontal surfaces.

The aptness of these calculated values has been corroborated by measurements made on a building in Ottawa. The opaque parts of the wall were lightweight panels, black on one side and white on the other. They were originally installed with the black side out, but as an experiment two panels in the middle of a south-west wall were reversed so that the white surface was outside. During one summer the observed maximum temperature of the outer black surface was 175°F, while that of the adjacent white panel was 130°F.

Unpainted metal surfaces that are not heavily oxidized reflect about the same fraction of incident short-wave radiation as a white painted surface, but their emissivity is only one quarter the value for a painted surface. Consequently, the radiation emitted by an unpainted metal surface is much less than that for a painted surface and its surface temperature is higher, therefore, than that for a similarly exposed white painted surface. It is for just this reason that most airlines have the upper half of the fuselages of their aircraft painted white and the under surfaces unpainted. An aircraft parked in the sun is significantly cooler when painted this way than if it is completely unpainted or completely painted.

Low Temperature Extremes

The foregoing discussion has been concerned only with the annual maximum S. A. T. and the resultant maximum surface temperature. A building designer also needs to know the minimum temperature that can occur so that he can allow for thermal expansion effects and condensation within the wall or roof. Minimum surface temperature occurs when there is no solar radiation, the ambient air temperature is at a minimum, there is no wind and the sky is clear. Under these conditions the S. A. T. is well below ambient air temperature and the surface of an insulating roof may be about 10 degrees cooler than ambient air temperature. In this case the energy leaving the surface in the form of long-wave radiation is equal to the sum of the heat conducted through the material backing the surface, the convection from the outside air to the surface and the fraction of the long-wave radiation from the sky that is absorbed by the surface. The frost that forms on the windshield of a car left out on a clear calm night is a good demonstration that surfaces exposed to a clear sky do, in fact, fall well below the temperature of the air. As walls receive more long-wave irradiation than flat roofs, they have a minimum outer surface temperature only slightly below the minimum air temperature. The colour of the outer surface has no appreciable effect on minimum surface temperature because all paints have nearly the same value of emissivity. Painted surfaces will always have lower minimum temperatures, however, than similarly exposed unpainted metal.

Conclusion

The maximum temperature of the outer surface of any building depends mainly on its colour and orientation. The colour and proximity of neighbouring surfaces also have a significant effect on surface temperature. Analysis has shown that dark roof surfaces may reach temperatures of the order of 230°F in summer and fall a few degrees below the minimum air temperature in winter. It is important, therefore, to be sure that any proposed roofing system with a dark surface can operate satisfactorily at temperatures varying between -50 and 230°F. If a light coloured surface is used to reduce the maximum temperature it is important to be sure that the surface will retain a low value of short-wave absorptivity over its entire service life.

The maximum temperature for a wall surface is between 140 and 190°, depending on colour and proximity to reflecting surfaces. If external shading devices are used they should have a dark surface that will absorb the radiation incident on them rather than reflect it onto adjacent wall or window surfaces. It is important, however, not to darken the colour of an outer surface until it has been established that its new shade will not cause the temperature of the wall materials to exceed their allowable values.

8.2 Test Report Forms

ATTACHMENT A

AAMA TEST METHOD FOR FLEXURAL LOADING OF COMPOSITE BEAM SECTIONS

MFG Name/Address:______________________________ Test Date ____________

____

____

Extrusion Identification #:______________________
Extrusion Description: ______________________________

____

Ambient Temperature: ______________________ Exterior Surface Temperature: ______________
Thermal Barrier Temperature: ______________ Interior Surface Temperature: ______________
Thermal Barrier Material Description: ______________

Sketch showing specimen orientation with respect to the point of load application and thermal barrier cavity location.

Specimen Length (L)	L/175	Applied Load (P)	Measured Deflection (Δ)	Permanent Deformation % of L	Calculated Moment (I)

Average Calculated I mm^4 (in^4):______________
Comments: ______________________________

____

____

Extrusion Die Drawing Attached for reference.

I certify that this test was conducted in accordance with AAMA Test Method For Flexural Loading of Composite Sections:

By: ______________________________
Company/Position: ______________________________

ATTACHMENT B

AAMA TEST METHOD FOR TENSILE, SHEAR AND ECCENTRIC LOADING
OF COMPOSITE BEAM SECTIONS

MFG Name/Address: ____ Test Date ______________

____

____

Extrusion Identification #:________________________

Extrusion Description: ____

____

Ambient Temperature:__________________________ Exterior Surface Temperature: ____________________

Thermal Barrier Temperature: ____________________ Interior Surface Temperature: _____________________

Thermal Barrier Material Description: _______________

Sketch showing specimen orientation with respect to the point of load application and thermal barrier cavity location.

Specimen Length (L)	Applied Load (P)	Off Set of Load from Thermal Barrier Centerline (d)	Measured Deflection (Δ)	Failure Load (P)

Average Failure Load N (lbf): _____________________

Comments:____

____

____

Extrusion Die Drawing Attached for reference.

I certify that this test was conducted in accordance with AAMA Test Method For Tensile, Shear and Eccentric Loading of Composite Sections:

By: ____

Company/Position: ____

8.3 Test Fixtures

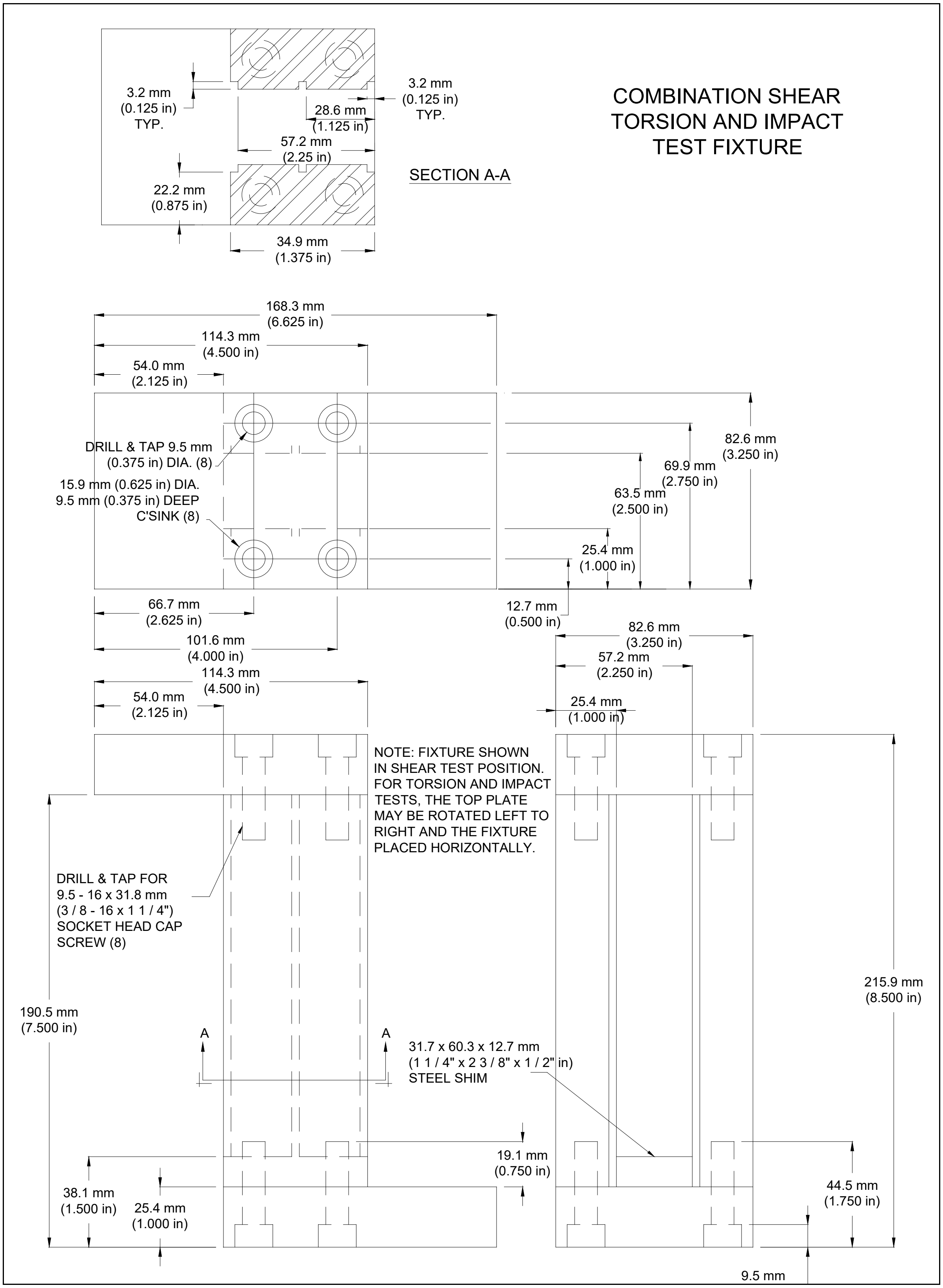


FIGURE 43: Combination Shear Torsion and Impact Test Fixture Schematic

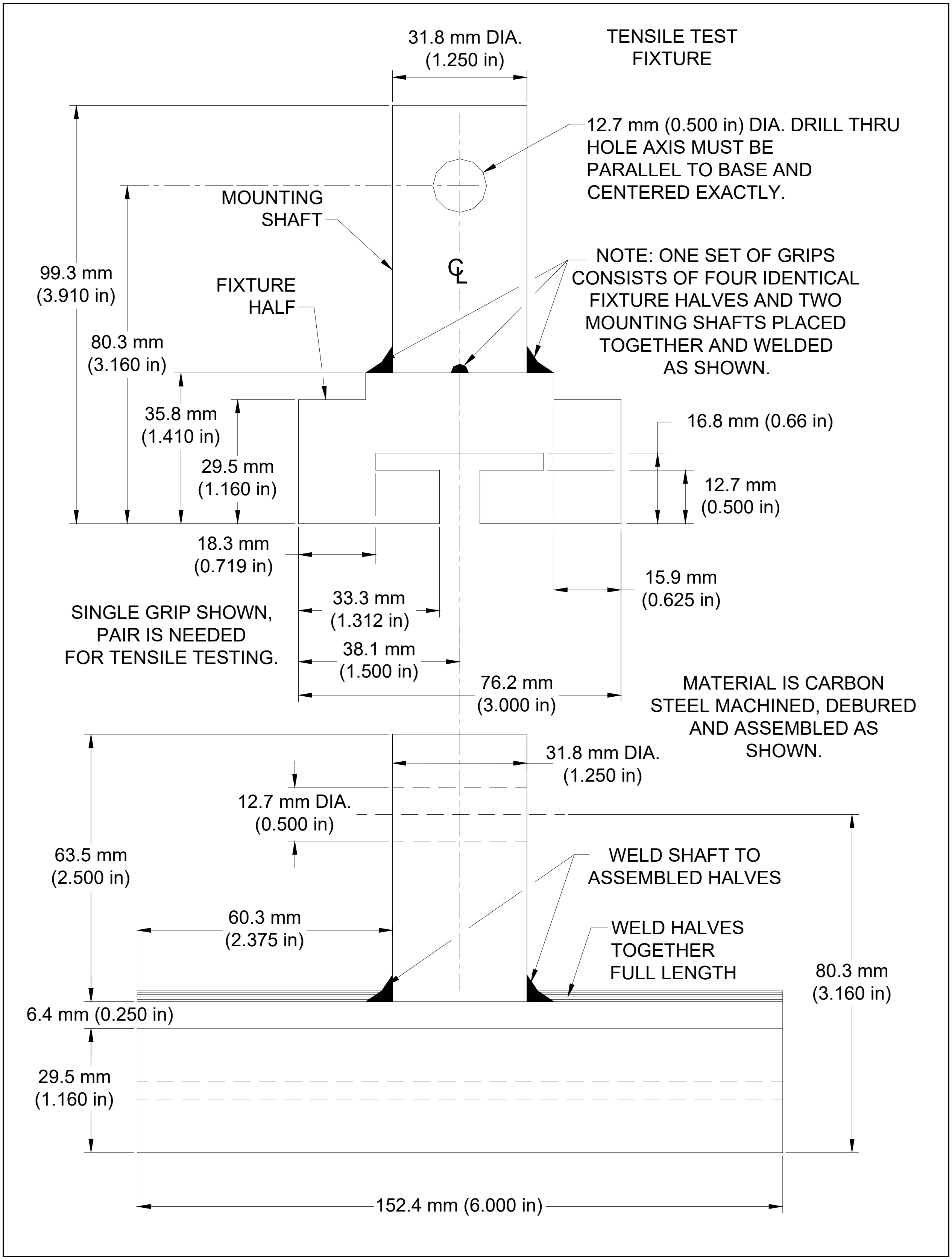


FIGURE 44: Tensile Test Fixture Schematic

9.0 REFERENCES

9.1 References to the standards listed shall be to the edition indicated. Any undated reference to a code or standard appearing in this section shall be interpreted as to referring to the latest edition of that code or standard.

9.2 The Aluminum Association

ADM-2020, Aluminum Design Manual

9.3 AAMA, Fenestration and Glazing Industry Alliance (FGIA)

AAMA/WDMA/CSA 101/I.S.2/A440-22, North American Fenestration Standard/Specification for windows, doors, and skylights

AAMA 505-17, Dry Shrinkage and Composite Performance Thermal Cycling Test Procedure

AAMA 507-15, Standard Practice for Determining the Thermal Performance Characteristics of Fenestration Systems in Commercial Buildings

AAMA 1503-09, Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Sections

AAMA QAG-1-09, Quality Assurance Processing & Monitoring Guide for Poured and Debridged Polyurethane Thermal Barriers

AAMA SFM-1-14, Aluminum Storefront and Entrance Manual

9.4 American Society of Civil Engineers (ASCE)

ASCE/SEI 7-22, Minimum Design Loads and Associated Criteria for Building and Other Structures

9.5 ASTM International (ASTM)

ASTM C177-19e1, Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus

ASTM C518-21, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus

ASTM C1363-24, Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus

ASTM D256-24, Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics

ASTM D638-22, Standard Test Method for Tensile Properties of Plastics

ASTM D648-18, Standard Test Method for Deflection Temperature of Plastics Under Flexural Load in the Edgewise Position

ASTM D695-23, Standard Test Method for Compressive Properties of Rigid Plastics

ASTM D696-24, Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between -30°C and +30°C with a Vitreous Silica Dilatometer

ASTM D790-17, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials

ASTM D792-20, Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

ASTM D2240-15(2021), Standard Test Method for Rubber Property—Durometer Hardness

ASTM D2849-69(1980), Methods of Testing Urethane Foam Polyol Raw Materials

ASTM E283/E283M-19, Standard Test Method for Determining Rate of Air Leakage Through Exterior Windows, Skylights, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen

ASTM E330/E330M-14(2021), Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference

ASTM E331-00(2023), Standard Test Method for Water Penetration of Exterior Windows, Skylights, Doors, and Curtain Walls by Uniform Static Air Pressure Difference

ASTM E529-04(2018), Standard Guide for Conducting Flexural Tests on Beams and Girders for Building Construction

ASTM E575-05(2018), Standard Practice for Reporting Data from Structural Tests of Building Constructions, Elements, Connections, and Assemblies

9.6 Other Applicable References

1. J.A. Hartsock, (1969), “Design of Foam-Filled Structures,” Technomic Publishing Co., Stamford, CT.

2. J.A. Hartsock and K.P. Chong, (1976), “Analysis of Sandwich Panels with Formed Faces,” Journal of the Structural Division, ASCE, Volume 102, ST4, April; Article 12058; pp. 803-819.

3. J.C. LaBelle, (1990), "Structural Behavior of Aluminum/Elastomer Sandwich Beams". A thesis in partial fulfillment of the requirements for Doctor of Engineering at the University of Wisconsin-Milwaukee.

4. K. Wolf and D.R. Sherman, (1991), "Application of a Finite Element for Sandwich Beams". Department of Civil Engineering and Mechanics, University of Wisconsin-Milwaukee.

5. J.C. LaBelle, (1992), "New Structural Design (Method) Developed for Poured and Debridged Thermal Barrier Framing," Glass Digest, Ashlee Publishing, New York, NY, V. 71, n. 8, August, pp. 92-95.

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James C. LaBelle, P.E., Doc.E. and
Mal Davies, BA (Honors 1st class: Math/ Physics)