THERMAL RESISTANCE MEASUREMENT OF GLAZING SYSTEM EDGE-SEALS

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ABSTRACT

The existing design of glazing system edge-seals creates increased edge-glass heat transfer at the perimeter of sealed glazing units. This thermal short-circuit caused by edge-seal conduction results in added mechanical stress, condensation problems in cold climates and augments the building energy load. New edge-seal designs are being marketed but very few data are available regarding the thermal resistance of any of the various edge-seal configurations that are available. An experimental procedure has been devised whereby the thermal resistance of an edge-seal can be directly measured using a guarded heater plate apparatus. Results for nine edge-seal test samples are reported and discussed. A variety of conclusions and design guidelines are presented.

INTRODUCTION

A typical glazing assembly consists of two sheets of glass separated at their edges with a spacer bar, dessicant and some type of sealant. Advances in glazing system technology, primarily low-emissivity coatings and low conductivity fill gases, have substantially increased the thermal resistance of commercially available glazing systems. The resulting increase in centre-glass thermal resistance has highlighted the problems caused by the thermal short-circuit associated with edge-seal conduction. New and more innovative edge-seal designs are being developed as a result of this discrepancy.

In the present study, a guarded heater plate apparatus, which has been successfully adapted for the measurement of centre-glass U-values, was used for the direct measurement of heat transfer through a series of test samples constructed from spacer bars and sealant materials. Measured thermal resistance results are provided for nine edge-seal test samples. These experimental data provide a new perspective regarding the relative thermal performance levels to be expected from various edge-seal designs as well as an insight into the way in which edge-seals conduct thermal energy.

TEST PROCEDURE

Thermal resistance testing was carried out using a guarded heater-plate apparatus. This apparatus consists of two flat copper plates that can be maintained at different but constant temperatures. The test samples (each 12 x 12 inches (305x305 mm)) were placed between these plates but separated from the plates by neoprene mats. The steady-state heat transfer through each sample (driven by the temperature difference between the plates) was measured over the face of a guarded heater-plate (8 x 8 inches (203x203 mm)) embedded in the warmer copper plate. The measured heat transfer rate, plate-to-plate temperature difference and known thermal resistance of the neoprene mats was combined to give a measured thermal resistance of the test sample. A description of the test procedure as it is used for centre-glass U-value measurement can be found in reference (1). More details regarding the procedure for edge-seal thermal resistance measurement can be found in reference (2).

A sketch of a typical glazing unit edge-seal is shown in Figure 1. The construction consists of two glass sheets, a spacer bar and sealant(s). Table 1 presents a list of the spacer bar/sealant combinations for which edge-seal test samples were built and tested. Figure 2 shows how the more conventional edge-seal test samples containing aluminum or fibreglass spacer bars were constructed. A two part silicone was used in most cases because it could readily be gunned into the long narrow passages of the edge-seal test samples. The designs listed in Table 1 correspond closely to the spacer bar/sealant configuration shown in Figure 1 with the exception of samples 3, 5 and 6. The currugated strip spacer (sample number 3) is shown in Figure 3. This edge-seal consists of single corrugated aluminum strip (with the appearance of a continuous sine wave) embedded in butyl. The layout of samples incorporating foam spacers (samples 5 and 6) is shown in Figure 4. All of the edge-seals and edge-seal components are commercially available.

Each solid seal section was constructed and tested as shown in Figure 2. The spacer bars were arranged and back-filled with sealant in order to closely reproduce the construction that is typical of a commercially produced sealed glazing unit. Alternate seals were placed back-to-back to create a condition of symmetry and to allow the measured heat flux, q, measured over the area of a heater plate to be an accurate measure of the heat flux through each individual seal. In other words, planes of symmetry between each pair of seals could be considered to be adiabatic.

RESULTS

The measured quantities of prime importance from the edge-seal experiments were the plate-to-plate temperature difference, ΔT_{pp}, and the heat flux between the plates, q. The ratio of these two values provides the thermal resistance of the neoprene/glass/seal assembly. The thermal resistance of the seals alone, R_{seal}, can be found by subtracting the resistance of the neoprene mats ($2R_n$) and the sheets of glass ($2t_g/k_g$). This representation of thermal resistance, expressed by equation 1, is a direct measure of resistance to heat transfer provided by the edge-seal on a "per unit area" basis.

$$R_{seal} = (\Delta T_{pp}/q) - 2R_n - 2(t_g/k_g) \qquad (1)$$

k_g = glass conductivity (0.96 W/mC)
t_g = glass thickness

In order to provide a more useful representation of the results, the thermal measurement quantities were recast into the form of a thermal conductance on a "per unit length of seal" basis, k_{lin}. This linear conductance is defined by equation 2.

$$Q = qA = L \cdot k_{lin}(T_1 - T_2) \qquad (2)$$

Q = heat loss through seal
L = length of seal
A = area of seal in contact with glass = $L \cdot w$
w = width of a single seal (see Figure 2)
$T_1 - T_2$ = temperature drop through seal material

Equations 1 and 2 can be rearanged to give:

$$k_{lin} = w/((\Delta T_{pp}/q) - 2R_n - 2(t_g/k_g)) = w/R_{seal} \qquad (3)$$

Table 2 presents a summary of the measured results for the nine edge-seal test sections. In each case the measured values of ΔT_{pp}, q, t_g and w are shown along with the resulting values of R_{seal} and k_{lin}. The linear conductance results of Table 2 are presented graphically in Figure 5.

One note of caution is in order. While testing units with very low thermal resistance (e.g., units 1 and 2) the majority of the thermal resistance measured between the copper plates was due to the neoprene mats. The accuracy of the measured thermal resistance of the seal is less than in the experiments where thinner mats were incorporated or where the seals provided more thermal resistance. It is safe to say that the single seal (unit 1) provided more thermal resistance than the double seal (unit 2), but to say it had 19% more thermal resistance would be unfounded. The important observation is that the thermal resistance between the two sets of seals (with and without the conventional aluminum spacer bar) differed by a significant factor. This difference could make the difference between having or not having to deal with condensation running down windows in the winter time. The results of other experiments where thinner neoprene mats were used (R_n=0.009 m^2C/W; see Table 2) are much less likely to be in error because of the thermal resistance of the mats.

DISCUSSION

The data shown in Figure 5 demonstrate that the seals tested possess a wide range of k_{lin}; a factor of 12 exists between the lowest and the highest. These seals can readily be split into two groups on the basis of their thermal performance. The more conventional single and double seals (units 1,2 and 9) provide little thermal resistance while the edge-seals incorporating corrugated metal, fibreglass or foam spacers provide considerably more thermal resistance. The greatest thermal resistance was measured across the foam edge-seal with hot-melt butyl sealant.

The edge-seal thermal resistance results reveal that the single seal configurations provided more thermal resistance than similar dual seal configurations in the two cases where direct comparisons could be made. Compare the k_{lin} results for unit 1 versus units 2 and 9 which all had aluminum spacer bars and silicone edge sealant or examine the results for unit 7 versus unit 8 which both had fibreglass spacer bars and silicone edge sealant. The thermal resistance of edge-seals with aluminum spacer bars seems to be sensitive to the placement of sealant between the spacer and the glass. It might be reasoned that a large portion of the thermal resistance was due to the material in place between the aluminum bar and the glass. Further reasoning indicates that some of the thermal resistance present in the single seal configuration resulted from a contact resistance between the spacer and the glass and that this resistance was reduced or eliminated by the presence of the primary sealant in the dual seal design. The results for single and dual seal edge-seals with fibreglass spacers (units 7 and 8) support this line of reasoning. In this case, the majority of the thermal resistance exists in the spacer bar and k_{lin} was insensitive to the presence of primary sealant between the spacer and the glass.

The thermal performance of the edge-seal that incorporates the foam spacer is highly sensitive to the choice of edge sealant that is used. Compare k_{lin} for units 5 and 6 where the use of silicone sealant instead of hot-melt butyl approximately doubled the linear conductance of the edge-seal. Clearly, the majority of the heat transfer occurs through the sealant rather than the spacer (as opposed to edge-seals with aluminum spacers where the reverse was seen to be true). The thermal conductivity figures shown in reference 2 support this assertion in that the conductivity of silicone was found to be three times higher than the conductivity of the foam. It can be reasoned that the thermal resistance of edge-seals incorporating the fibreglass spacer would also be sensitive to the conductivity of the edge sealant but to a lesser extent because the fibreglass edge seal design includes a slightly smaller portion of sealant (about 30% sealant versus 50% for the foam design). It is likely that if a fibreglass edge-seal with hot-melt butyl sealant had been tested it would have had significantly more thermal resistance than the samples that were tested with silicone edge sealant (units 4, 7 and 8). On the other hand, the use of hot-melt butyl instead of silicone would likely have had little impact on the performance of the units with aluminum spacer bars.

It is instructive to consider the homogeneous edge-seal configuration shown in Figure 6. In this case the cross-section of the edge-seal has the dimensions w and t; the latter being equal to the pane spacing. An edge-seal test sample for this construction would simply contain a uniform slab of the seal material. The heat flux expected through the test section can be shown to be:

$$q = (k/t)\cdot(T_1 - T_2) \tag{4}$$

k = thermal conductivity of seal material
t = seal thickness or pane spacing
$T_1 - T_2$ = temperature drop through seal material*

Substitution of this result into Equation (1) yields:

$$k_{lin} = k\cdot(w/t) \tag{5}$$

Thus, for an edge-seal made of a homogeneous material the linear conductance can be estimated knowing only the thermal conductivity of the seal material and the aspect ratio of the seal (i.e., w/t).

Examine the homogeneous edge-seals shown in Figure 7a. One seal is twice the size of the other but they would have the same linear conductance. The seals shown in Figure 7b differ only in that the one on the right provides twice as much pane spacing. It also has half the linear conductance of the seal on the left.

Consider the corrugated strip edge-seal (test sample no. 3). The aspect ratio of this seal is approximately equal to 1/2 (w/t = 7.43/14.1). Assume it is known that the thermal conductivity of the butyl used in this seal is k=0.2 W/m·K. If this seal were built without the internal aluminum strip then a linear conductance value of k_{lin}=0.1 W/m·K would be expected according to Equation 5. In this case the measured value of k_{lin}=0.41 W/m·K suggests that there is potential for significant improvement if a metal with lower conductivity or thinner cross-section (or both) were substituted.

If an edge-seal were constructed simply by bonding a metal strip or foil to the outer edges of two sheets of glass its linear conductance could be estimated using Equation 5. Say a particular metal has been chosen for this application and a specific linear conductance is required. It is possible to determine the maximum thickness of the metal strip by rearanging Equation 5. This is shown in Equation 6.

$$w = t\cdot(k_{lin}/k) \tag{6}$$

For example, say the desired edge-seal conductance is k_{lin}=0.5 W/m·C and the pane spacing is to be t=12.7 mm. The calculated thicknesses for copper, aluminum and stainless steel edge-seals (k=400, 237 and 17 W/m·C, respectively) are w=0.016, 0.027 and 0.374 mm, respectively.

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* Each seal/glass interface is assumed to be isothermal for the purpose of simplifying the calculation procedure. Although this is not strictly be true it is expected to be a good approximation (especially in the case of seals with high thermal resistance) because of the very high conductivity of the copper plates, the reasonably high conductivity of the glass and because the neoprene sheets are thin.

CONCLUSIONS

The guarded heater plate measurements of the solid edge-seal test samples have provided a direct measure of the edge-seal thermal resistance. The seals tested can be grouped into two sets. Seals providing low thermal resistance were the single and double seals with conventional aluminum spacer bars. Seals with high thermal resistance incorporated corrugated metal, fiberglass or foam spacers. The difference in thermal resistance between these two groups of seals was significant. The presence of a primary sealant in the dual seal design appears to lower the edge-seal thermal resistance - more for the edge-seals with aluminum spacers and very slightly for the fibreglass spacers. The conductivity of sealant used with the higher thermal resistance spacer bars (fibreglass and foam) has a strong bearing on the thermal resistance of the complete edge-seal.

REFERENCES

(1) Wright, J.L.; Sullivan, H.F., "Glazing System U-value Measurement Using a Guarded Heater Plate Apparatus." ASHRAE Transactions, (1988), Vol. 94, Pt. 2.

(2) Wright, J.L.; Sullivan, H.F., "Thermal Resistance Measurement of Glazing System Edge-Seals and Seal Materials Using a Guarded Heater Plate Apparatus." ASHRAE summer meeting, Vancouver, (1989), VA-89-11-3.

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Table 1
List of Edge-Seal Test Samples

Sample no.	Spacer Bar	Secondary Sealant	Primary Sealant	Pane Spacing in(mm)
1	Aluminum	Silicone (g)+		0.516(13.1)
2	Aluminum	Silicone (g)	PIB*	0.551(14.0)
3	Corrugated Strip	Butyl	Butyl	0.555(14.1)
4	Fibreglass	Silicone (b)+	Silicone (b)	0.500(12.7)
5	Foam!	Hot-Melt Butyl		0.516(13.1)
6	Foam!	Silicone (g)		0.508(12.9)
7	Fibreglass	Silicone (g)		0.496(12.6)
8	Fibreglass	Silicone (g)	PIB	0.504(12.8)
9	Aluminum	Silicone (g)	PIB	0.512(13.0)

\+ The silicone sealant used is disignated as either (g) or (b) depending upon whether its colour was grey or black.

* PIB is an abbreviation of Polyisobutylene.

! This edge-seal consists of approximately 50% foam spacer and 50% sealant.

Table 2
Summary of Results for Edge-Seal Test Units

		ΔT_{pp} (C)	q (W/m²)	t_g (mm)	w (mm)	R_n (m²C/W)	R_{seal} (m²C/W)	k_{lin} (W/mC)
1	Aluminum SS*	18.70	372.2	3.96	12.8	0.017	0.008	1.6
2	Aluminum DS*	18.78	383.9	3.96	12.9	0.017	0.007	1.9
3	Corrug'd Strip	18.90	324.8	2.90	7.43	0.017	0.018	0.41
4	F'glass	19.18	192.2	2.84	16.3	0.017	0.060	0.27
5	Foam/ Hot-Melt Butyl	18.98	187.9	4.75	12.3	0.009	0.073	0.17
6	Foam/ Silicone	18.69	302.15	3.91	12.7	0.009	0.036	0.36
7	F'glass SS	18.95	272.5	3.91	12.7	0.009	0.043	0.29
8	F'Glass DS	18.96	277.9	3.91	12.7	0.009	0.042	0.30
9	Alum DS	18.41	574.3	3.91	12.6	0.009	0.006	2.1

* SS and DS are abbreviations of single seal and dual seal.

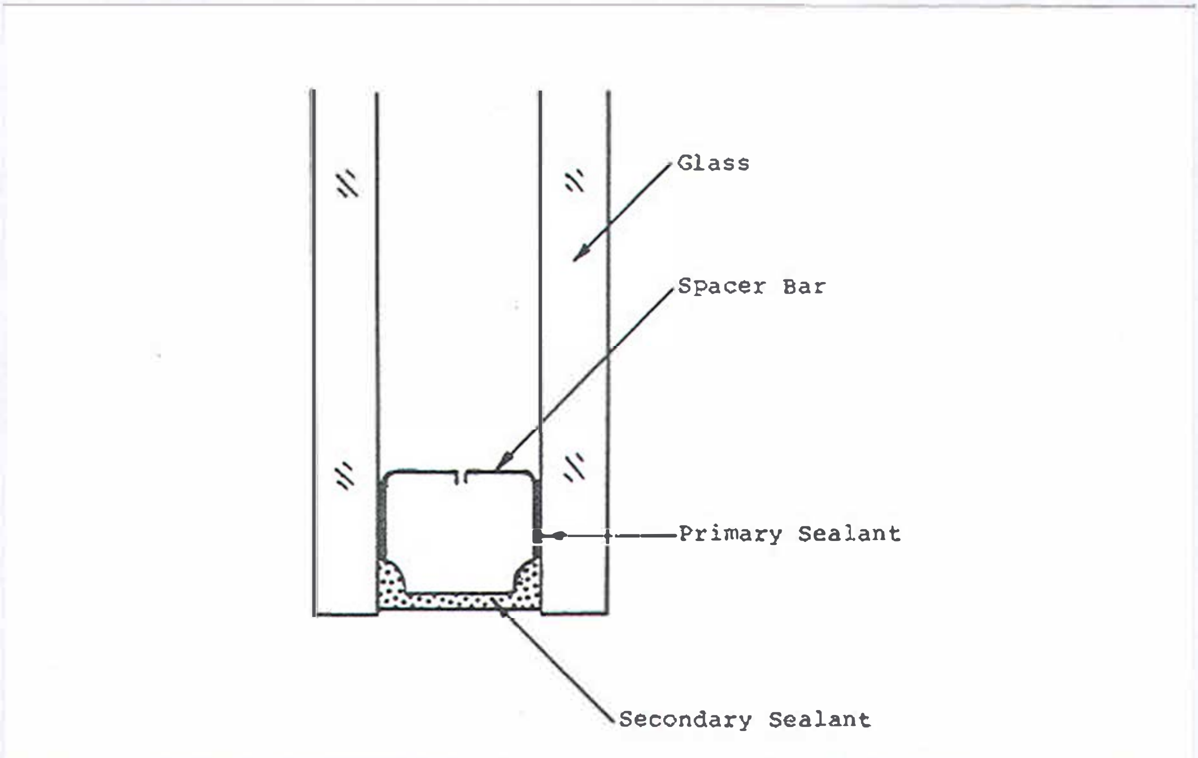

Figure 1: Typical Edge-Seal Design

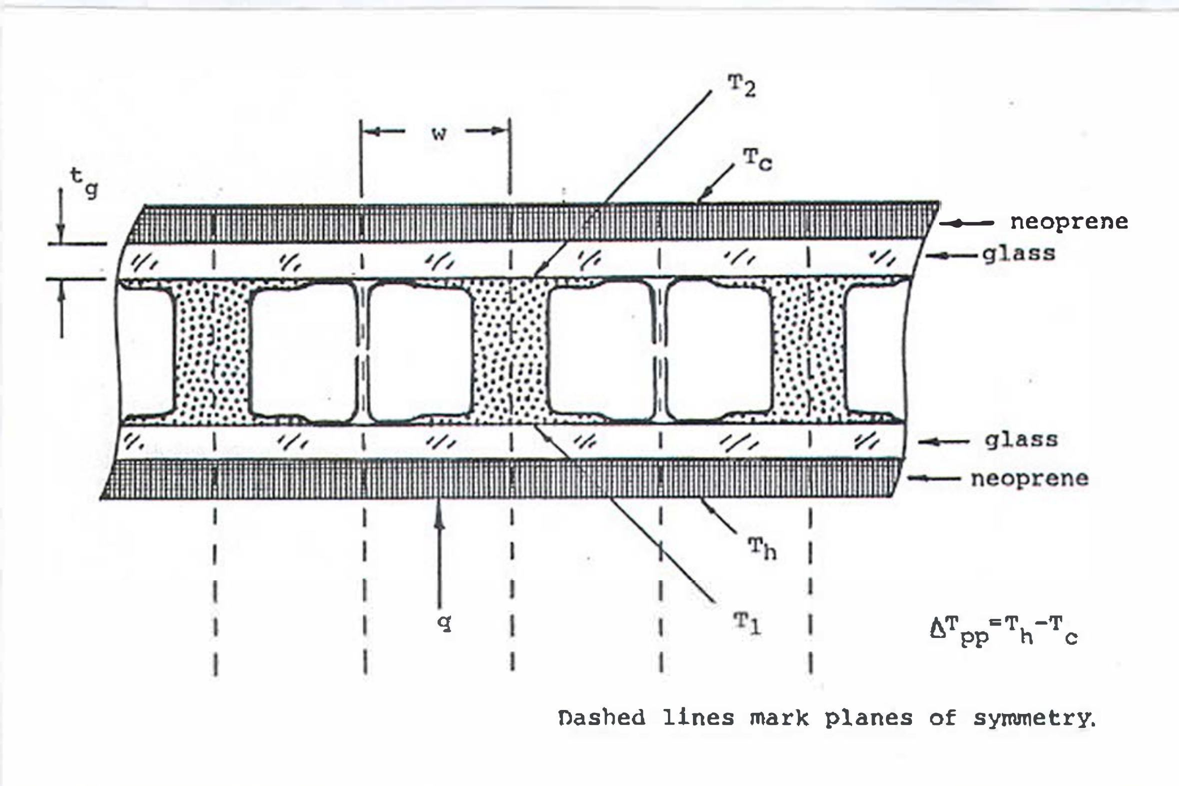

Figure 2: Cross-Section of Edge-Seal Test Sample

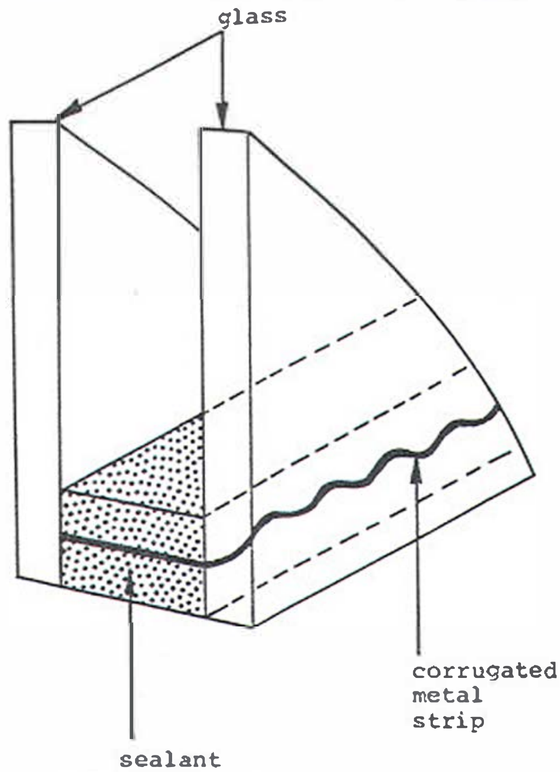

Figure 3: The Corrugated Strip Edge-Seal Design

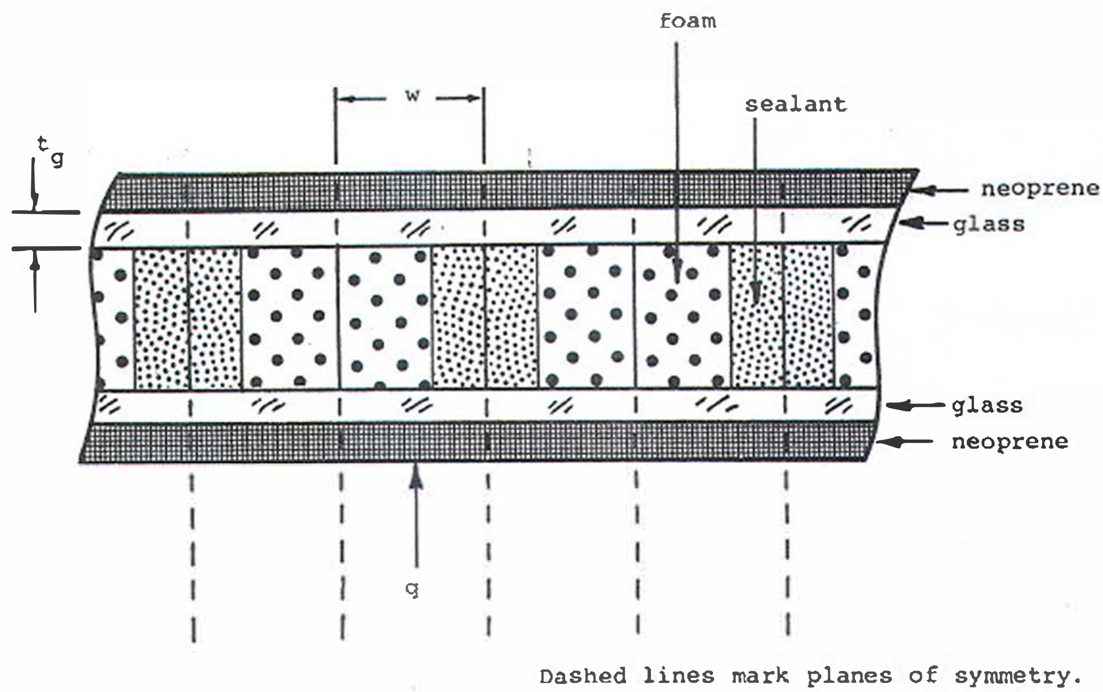

Figure 4: Cross-Section of Edge-Seal Test Sample with Foam Spacer

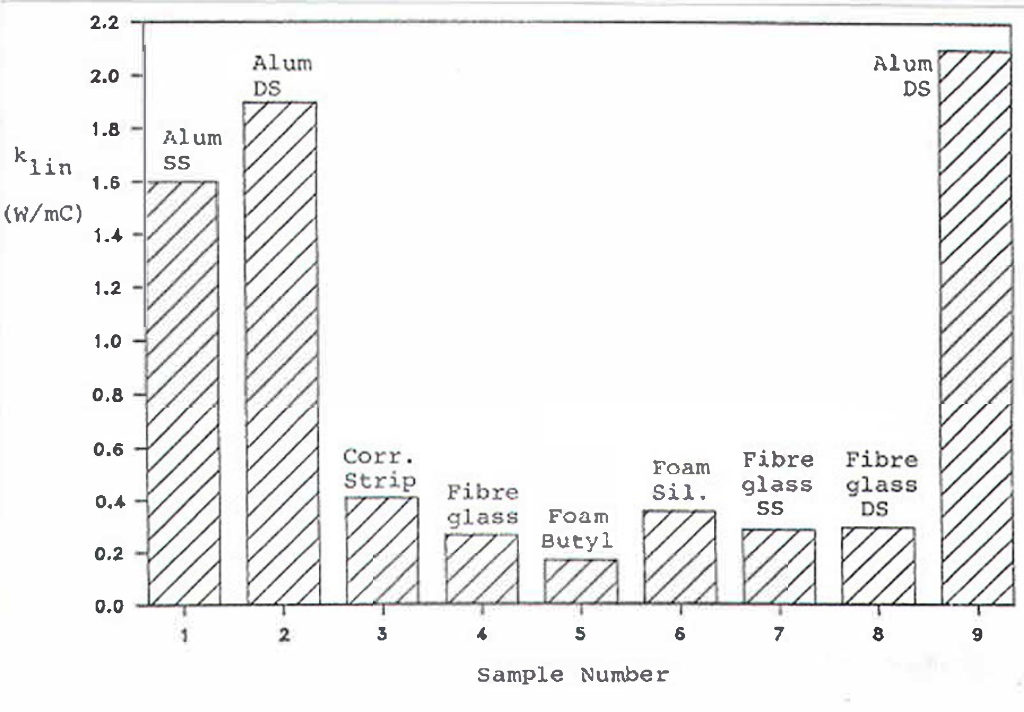

Figure 5: Measured Linear Conductance Results

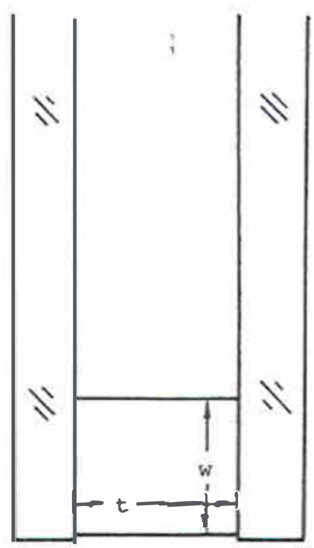

Figure 6: Homogeneous Edge-Seal Dimensions

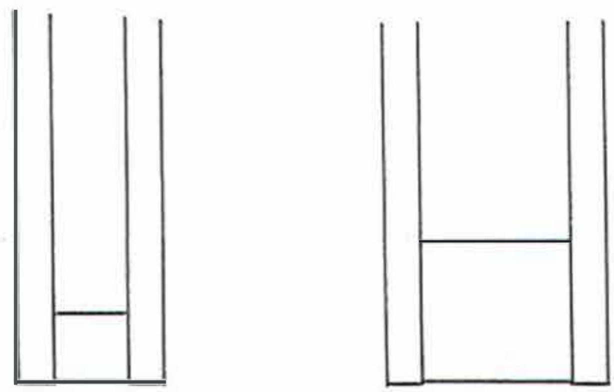

Figure 7a: Examples of Homogeneous Edge-Seal Configurations, Equal Linear Conductance Values

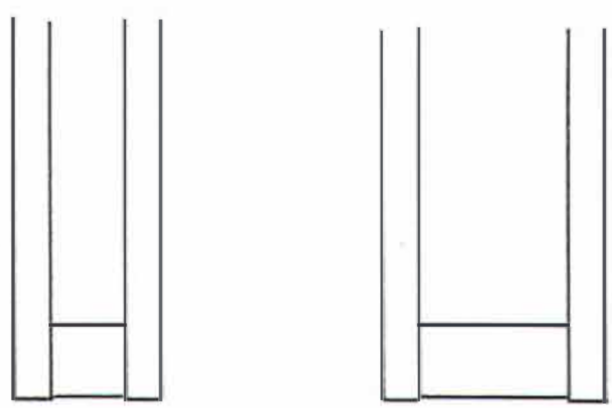

Figure 7b: Examples of Homogeneous Edge-Seal Configurations, Unequal Linear Conductance Values