The Effect of Thermal Bridge in VIPs

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- A Real Life Demonstration with Shipping Boxes

Dr Yoash Carmi, R&D Senior Scientist, Avery Dennison Hanita

Executive Summary

Fiberglass cores are known to have two important advantages in comparison to cores made of fumed silica: they have a lower center of panel thermal conductivity, and they are substantially less expensive. Accordingly, many refrigerator manufacturers prefer fiberglass panels rather than fumed silica. Some fiberglass panels used in refrigerators are formed with Aluminum foil (Al foil) based envelopes to minimize gas permeation, which is important because the average pore size of fiberglass cores is about two orders of magnitude bigger than fumed silica powder, and fiberglass is thus far more sensitive to gas permeation.

The problem with Al foil based laminates is, of course, the heat bridge induced by the relatively thick Al foil. This thermal bridge effect can have a devastating impact on the insulation performance of the panels, and accordingly on the energy consumption of the refrigerators.

To manifest the impact of the thermal bridge a series of Dry Ice tests were performed to compare the actual heat flow into cold shipping boxes produced with VIPs formed from three different envelope materials: with metallized laminate on both sides of the envelope, Al foil based laminate on both sides of the envelope, and a Hybrid envelope, formed from metallized laminate on one side of the bag, and Al foil on the other. By changing the envelope of the VIPs forming the container, their impact on the thermal bridge could be quantitatively compared by the ratio of weight loss rates of the dry ice sublimation, measured with the different envelopes.

Dry ice weight loss (sublimation). 8" x 14" x 8.5" large boxes, three envelopes

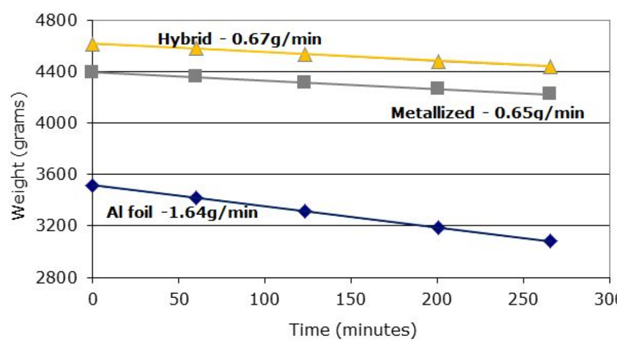

Fig. 2: Plot of the weight readings of the large boxes as a function of time. The slope values are proportional to the effective heat conductivity of the panels with the different types of envelopes.

Relative effective thermal conductivity of the six boxes compared to the boxes with metallized film V08621B

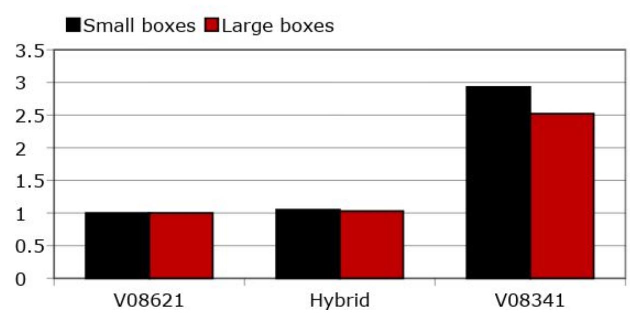

Fig. 5: Effective thermal conductivity of the small and large boxes compared to the boxes with the V08621B envelopes. In both cases, the Hybrid envelopes do not add extra edge leakage, while the Al foil envelopes more than double the effective thermal conductivity of the boxes, even more pronouncedly in the small box.

Conclusion

1. The thermal bridge effect caused by the use of Al foils in the VIP envelopes substantially

decreases the insulation performance of the panels, not only in theory or lab tests, but also in real life applications. This fact should be weighted very seriously when decisions are made on what type of envelopes should be used for refrigerator insulation.

2. The test results clearly show that what counts for the actual insulation performance of VIPs is not the center of panel thermal conductivity (λcop), but rather the effective thermal conductivity (λeff), which also includes the contribution of the thermal bridge. This contribution should not be ignored, and in many cases, it actually may be the dominant mechanism of heat conductivity.

3. The Hybrid envelopes added very little to the thermal bridge effect. Hybrid bags allow substantially reduced gas and moisture permeation in comparison to metallized films and therefore can be the optimal solution for fiberglass VIPs in refrigerator applications.

4. The metallized film used to construct one-half of the bags should have ultra-high barrier to moisture vapor as well as to oxygen and nitrogen molecules, otherwise, the degradation rate of the panel will not meet industry requirements. In elevated temperature applications, the hybrid bags can also be very useful with the Al foil side of the bags facing the high-temperature side.

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- A Real Life Demonstration with Shipping Boxes

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Introduction

Fiberglass cores are known to have two important advantages in comparison to cores made of fumed silica: they have lower center of panel thermal conductivity, and they are substantially less expensive. Accordingly, many refrigerator manufacturers prefer fiberglass panels rather than fumed silica. Some fiberglass panels used in refrigerators are formed with Aluminum foil based envelopes to minimize gas permeation, which is important because the average pore size of fiberglass cores is about two orders of magnitude bigger than fumed silica powder, and fiberglass is thus far more sensitive to gas permeation.

The problem with Al foil based laminates is, of course, the heat bridge induced by the relatively thick Al foil. This thermal bridge effect can have a devastating impact on the insulation performance of the panels, and accordingly on the energy consumption of the refrigerators.

Some years ago, the thermal bridge effect of VIPs for Al foil based laminates and for metallized laminates was measured very accurately by a group from the EMPA institute (1). The main conclusion of this important work was that the size of the thermal bridge effect depends strongly on the thickness of the barrier Al layers/foils in the envelope laminates, with a severe impact in many cases on the effective insulation performance of the panels.

These results serve as the benchmark for the VIP industry for estimating the decrease in the insulation performance of a VIP due to the thermal bridge. Avery Dennison Hanita has drawn up a very friendly Excel tool (2) that allows quantitative calculation of the size of the thermal bridge effect as a function of the dimension of the panels and the structure of the envelope laminate. The predictions of this thermal bridge calculator were tested experimentally by comparing the heat flow into cold shipping boxes produced with VIPs with metallized laminate, Al foil based laminate, and a Hybrid envelope formed from metallized laminate on one side of the bag, and Al foil on the other.

A very high correlation was demonstrated between the predictions of the thermal bridge calculator and the test results of this real-life testing, confirming that the thermal bridge effect has a substantial negative impact on the insulation performance of VIPs in real life applications when Al foil based laminates are used. Another very interesting result of the test was that using the hybrid solution has a negligible impact on thermal bridge, compared to using metallized laminates on both sides of the envelope.

Test Description: The Dry Ice Test

The goals of the test were a) to accurately measure the insulation performance of vacuum insulation panels in real life applications, taking into account the contribution of the thermal bridge, and b) to provide a quantitative comparison between the insulation performance of different envelopes.The dry ice test is a well-established, simple and very accurate way to measure the heat flow rate into a thermally insulated container. At atmospheric pressure, dry ice sublimes directly from the solid phase to the gas phase at temperature of -78.5C. After sublimation, the gaseous CO_2 leaves the container. In the test, a block of solid carbon dioxide (dry ice) was placed inside the container in a controlled-atmosphere room for steady state conditions to be reached within a few hours. Over time, the dry ice continuously sublimes and most of the gas leaves the container. As a result, the weight of the container reduces in a rate proportional to the overall heat flow rate into the container. By weighing the container, the insulation performance of the walls can be determined in just a few hours. By changing the envelope of the VIPs forming the container, their impact on the thermal bridge can be quantitatively compared by the ratio of weight loss rates measured with the different envelopes.

Test Procedure

The American Aerogel Company (3) performed the test by producing six different boxes, each made up of six panels. The core material used in the test was a 25.4mm thick block of Aerogel. Two sizes of boxes were tested, small, with panel dimensions of 8”X6”X8.5”, and large, 8”X14”X8.5”. All of the panels in each box were made up with the same envelope, with three different types of Avery Dennison Hanita envelopes:

1. V08621B - Metallized films (tri-laminate) on both sides of the envelope.
2. V08341P - Al foil based (6.3µ thick Al foil,) on both sides of the envelope
3. Hybrid - V08341P (Al foil) forming one side of the envelope and V08621B (metallized film) the other.

All boxes were filled with a few kilograms of dry ice and placed in a controlled temperature room for 16 hours to reach steady-state conditions. After that, the weight of each box was measured four times in the next four and a half hours.

The table and graph below summarize the weight changes of the three 8” x 6” x 8.5” boxes with three different envelopes, caused by the sublimation of the packed dry ice loads. As expected, it can be seen that due to the impact of the thermal bridge, the heat flow into the box made with Al foil based laminates was 2.8 times faster than into the box with metallized laminate. Using the Hybrid solution had a minor impact on the thermal bridge effect.

Dry ice weight loss (sublimation). 8" x 6" x 8.5"small boxes, three envelopes

Time (minutes)	Al foil based (grams)	Metallized (grams)	Hybrid (grams)
	V08341P	V08621B	V08621B/ V08341P
0	3295	3930	3865
60	3230	3905	3840
123	3150	3880	3815
201	3060	3850	3780
266	2985	3820	3750
Total weight change	-310g	-110g	-114g

Table 1: Weight changes due to sublimation of dry ice. Small boxes (8”X6”X8.5”)

Dry ice weight loss (sublimation). 8" x 6" x 8.5" small boxes, three envelopes

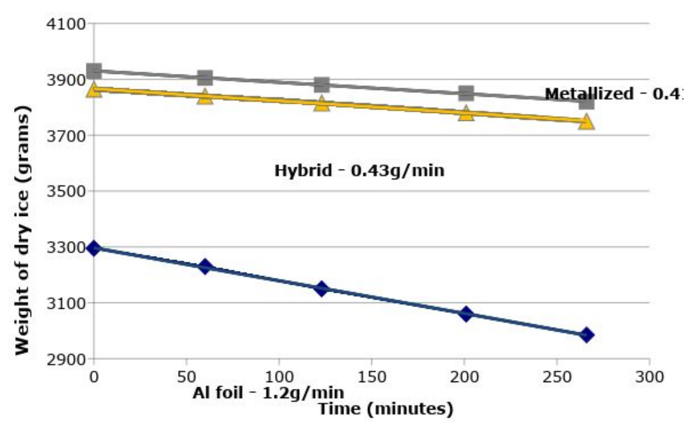

Fig. 1: Plot of the weight readings of the small boxes as a function of time. The slope values are proportional to the effective heat conductivity of the panels with the different types of envelopes.

Table 2 and Fig.2 summarize the test results with the large boxes (8” x 14” x 8.5”):

Dry ice weight loss (sublimation). 8" x 14" x 8.5" large boxes, three envelopes

Time (minutes)	Al foil based (grams)	Metallized (grams)	Hybrid (grams)
	V08341P	V08621B	V08621B / V08341P
0	3515	4390	4615
60	3420	4355	4580
123	3315	4315	4536
201	3185	4260	4480
266	3080	4220	4440
Total weight change	-435g	-170g	-175g

Table 2: Weight changes due to sublimation of dry ice. Large boxes (8"X14"X8.5")

Dry ice weight loss (sublimation). 8" x 14" x 8.5" large boxes, three envelopes

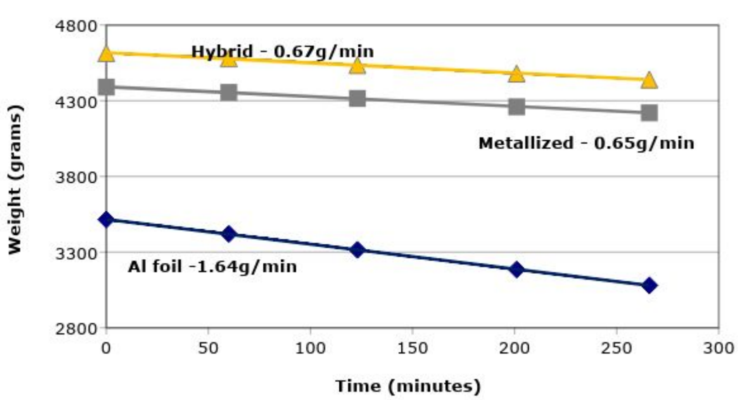

Fig. 2: Plot of the weight readings of the large boxes as a function of time. The slope values are proportional to the effective heat conductivity of the panels with the different types of envelopes.

Effect of Box Size on the Sublimation Rate

The box size has two contradicting effects on the overall heat flow rate into the box. For a specific temperature difference, the heat flow is proportional to the surface area of the box walls, so the sublimation rate of the dry ice inside large box will be higher than the rate of a smaller box with an identical type of VIP. The effect of box size on the sublimation rate can be eliminated when comparing boxes of different sizes by dividing the sublimation rate of the large box by the ratio of the surface area of the walls of the two boxes. The surface area ratio between the two box sizes used in the test was 1.8.

The box size also affects the sublimation rate due to the dependence of the relative importance of the thermal bridge on the panel size. In general, the thermal bridge is more effective for smaller panels, therefore it acts in the opposite direction to increase the effective thermal conductivity of panels in smaller boxes as compared to larger boxes.

Summary of Results

The table below summarizes the rates of weight loss of all boxes. Because weight loss is proportional to the heat flow rate, the values in the tables provide an indication of the average effective thermal conductivity (bulk plus edges) of the panels.

Envelope 4	Small boxes	Large boxes	Large boxes normalized
V08621B	0.41g/min	0.65	0.36g/min
Hybrid	0.43g/min	0.67	0.37g/min
V08341P	1.2g/min	1.64	0.91g/min
Hybrid compared to V08621B	1.05	1.03	1.03
V08341P compared to V08621B	2.93	2.52	2.52

Table 3 Weight loss due to sublimation of the 6 boxes tested. The right column presents the calculated weight loss of the large boxes after omitting the surface area effect on the heat flow rate.

The last two rows at the bottom of Table 3 manifest the impact of the thermal bridge: negligible for the hybrid envelopes, and very large for Al foil based laminates. As expected, the comparison between the values for the normalized large box to the values relating to the small box teaches us that the thermal bridge effect is less pronounced for larger panels.

Further graphic presentations of the test results

Heat flow rates of small boxes with the 3 different envelopes:

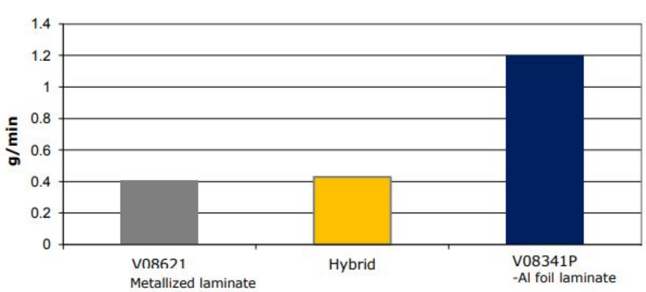

Fig.3 The heat flow rates into small boxes with three different envelopes. The effective thermal conductivity of the Al foil envelope was 2.9 higher than the metallized or the Hybrid envelopes.

Dry ice weight losses of the six boxes (g/min)

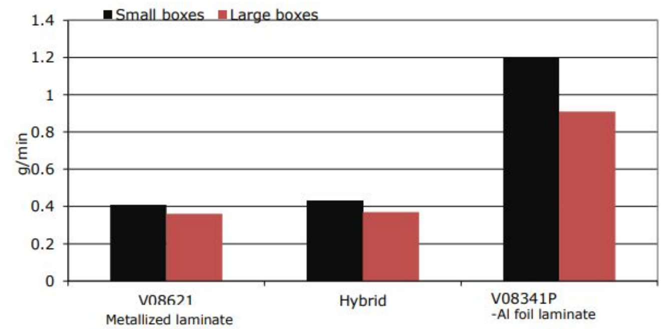

Fig.4: Heat flow rates of the small boxes together with the normalized heat flow rates (eliminating the surface area effect) of the large boxes. The values of the small boxes are higher due to the smaller panels' greater thermal bridge.

Relative effective thermal conductivity of the six boxes compared to the boxes with metallized film V08621B

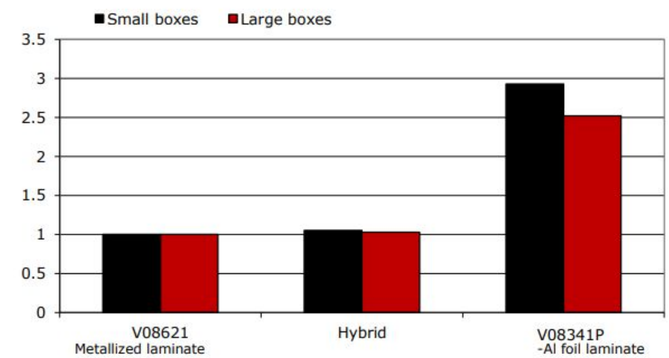

Fig. 5: Effective thermal conductivity of the small and large boxes compared to the boxes with the V08621B envelopes. In both cases, the Hybrid envelopes do not add extra edge leakage, while the Al foil envelopes more than double the effective thermal conductivity of the boxes, even more pronouncedly in the small box.

Relative R value of Al foil and Hybrid envelopes compared to V08621B

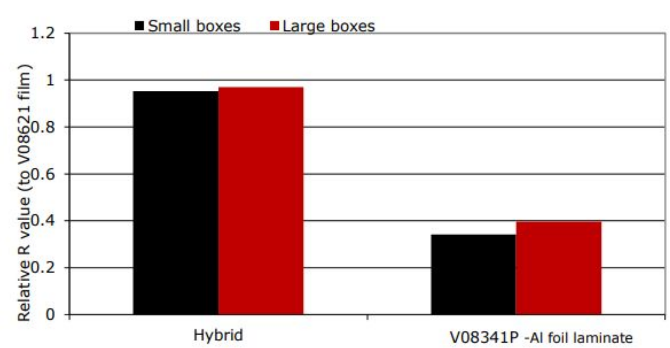

Fig.6: Relative R values of the small and large boxes with Hybrid and V08341P envelopes compared to boxes with V08621B metallized laminate envelopes.

Conclusions

The dry ice sublimation test clearly confirmed the following expected facts:

1. The thermal bridge effect caused by the use of Al foils in the VIP envelopes substantially decreases the insulation performance of the panels, not only in theory or lab tests, but also in real life applications. This fact should be weighted very seriously when decisions are made on what type of envelopes should be used for refrigerator insulation.

2. The test results clearly show that what counts for the actual insulation performance of VIPs is not the center of panel thermal conductivity (λcop), but rather the effective thermal conductivity (λeff), which also includes the contribution of the thermal bridge. This contribution should not be ignored, and in many cases it actually may be the dominant mechanism of heat conductivity.

3. The Hybrid envelopes added very little to the thermal bridge effect. Hybrid bags allow substantially reduced gas and moisture permeation in comparison to metallized films, and therefore can be the optimal solution for fiberglass VIPs in refrigerator applications.

4. The metallized film used to construct one half of the bags should have ultra-high barrier to moisture vapor as well as to oxygen and nitrogen molecules, otherwise the degradation rate of the panel will not meet industry requirements. In elevated temperature applications, the hybrid bags can also be very useful with the Al foil side of the bags facing the high temperature side.

References

(1) EMPA –"Effective thermal conductivity of vacuum insulation panels" 2004, K.Ghazi-Wakili, R. Bundi and B. Binder, Laboratory for Applied Physics in Building, Swiss Federal Laboratories for Materials Testing and Research (EMPA),CH-8600 Duebendorf, Switzerland.

(2) Hanita Coatings "Thermal Bridge Calculator" – Dr Yoash Carmi, 2011

(3) American Aerogel Company, 460 Buffalo Rd., Suite 200A, Rochester, NY 14611 www.americanaerogel.com info@americanaerogel.com