STRUCTURAL VACUUM INSULATION PANELS

Musgrave D., President
Thermal Visions, Inc., 83 Stonehenge Dr., Granville, Ohio 43023, U.S.A.
Phone: 1-740-973-3671, Fax 1-740-587-4025
dwight.musgrave@thermalvisions.com

Theme 2: VIP Innovations – Product Development

Key Words: vacuum insulation, structural panel, stress- skin panel

ABSTRACT

Two of the challenges for vacuum insulation acceptance are the durability of the vacuum panels and providing the required product value to warrant the use in the application. The barrier film maintains the vacuum but can typically be damaged or punctured. In many past symposium presentations, damage to the barrier film has been discussed and some potential solutions proposed. Smith et al. presented a paper "Applications of Vacuum Insulation Panels in Extreme Environments" at the 7th International Vacuum Insulation Symposium (2005), which showed that manipulation of the barrier film can result in failure or locally increased diffusion. At the 8th International Vacuum Insulation Symposium (2007) Teniers presented "Ultra High Barrier VIP Laminates-New Solutions to Tougher Requirements" which discussed among other things the flexing of barriers. These papers and others discuss the "normal" or incidental abuse of the barrier. There are emerging applications, such as use in construction or transportation, where the vacuum panels can be exposed to a sever environment and requires extreme protection. This paper presents one approach to handle this abusive environment.

The other challenge is to provide greater value. The typical way to accomplish this is to provide higher thermal performance or lower cost. However an alternative or additional approach is to have the product provide additional function. This paper presents the use of the vacuum panel as the core of a "stress-skin panel". Extra value is provided by the structural stiffness of the "structural vacuum panel". Both experimental and computer Finite Element Analysis is used to show the structural performance of the proposed "structural vacuum panel" and some of the cost of the vacuum panel can be credited to the structural performance obtained. Depending on the exact design situation, the structural and thermal performance that the vacuum panel provides can make the vacuum panel a much better value.

1. INTRODUCTION

Vacuum insulation panel durability and value have been a challenge for many applications. This is particularly true of many potential high sales volume applications such as construction and transportation. Providing protection to the panel only makes the cost to benefit (value) a more difficult sell. This paper suggests an approach to improve the value proposition by adding structural function to the benefits of a protected vacuum insulation panel.

2. VACUUM PANEL PROTECTION

Since the barrier film maintains the vacuum and failure of the barrier film would result in a major decrease in thermal performance, it is important that the vacuum panel is handled and maintained in an environment that is safe for the barrier film. In many past symposium presentations, damage to the barrier film has been discussed and some potential solutions proposed. Smith et al. presented a paper “Applications of Vacuum Insulation Panels in Extreme Environments” at the 7th International Vacuum Insulation Symposium (2005), which showed that manipulation of the barrier film can result in failure or locally increased diffusion. At the 8th International Vacuum Insulation Symposium (2007) Teniers presented “Ultra High Barrier VIP Laminates-New Solutions to Tougher Requirements” which discussed among other things the flexing of barriers. These papers and others discuss the “normal” or incidental abuse of the barrier such as folding the seal flaps of vacuum panels.

There are emerging applications, such as use in construction or transportation, where the vacuum panels can be exposed to a sever environment and requires extreme protection. Use of exterior sheets of strong material that are applied to the vacuum panel surfaces was proposed decades ago. However, this adds to the already expensive vacuum insulation cost. One material particularly of interest is the use of composite sheets, such as fiberglass reinforced plastics. A common example of this kind of material is the hull of recreational boats. An advantage of composites is the material can be designed (reinforcement percentage, type, and orientation and matrix resin) to meet the particular requirements. It can be designed to handle virtually any abusive environment. If needed the composite skin could be designed to stop a steel jacked 9 mm bullet or worse. Thus the required protection is possible and the remaining issue has to do with cost implications.

3. VACUUM INSULATION VALUE

Even a decade ago there were a few select applications where the benefits of vacuum insulation were so large that vacuum insulation was a very good value. However there were many applications, particularly high sales volume applications, where the benefits were desired but the cost was far too high. Over the years the typical performance has increased, costs have come down some, energy cost have risen, and desire to be environmentally conscious has increased. The value proposition for many applications is still a difficult sell. Adding protective skins when required only makes the proposition more difficult. This author has found through many years of product design that often the best approach is to try to find ways to have the product add additional value. The primary focus of this paper is on how to get additional value from vacuum insulation by using the vacuum insulation to provide an additional function providing load carrying ability as well as thermal insulation ability. The vacuum insulation could be the core of a structural stress-skin panel design.

4. WHAT IS A STRESS-SKIN PANEL?

A stress-skin panel, sometimes called a sandwich panel, has been a basic component of the composites industry for over 50 years. The concept is to use relatively strong thin face sheets bonded to thicker, light weight core materials to produce strong light highly durable structures. The core is “sandwiched” between the two thin strong skins. This type of structure is used extensively in the aerospace industry as well as many other less exotic applications. Stress-skin panels are typically used in a panel bending load situations but could be used on column compression applications. However, buckling of the skins from separation from the core would have to be studied. For this paper, we will focus on only the bending load situation, see Figure 1 below.

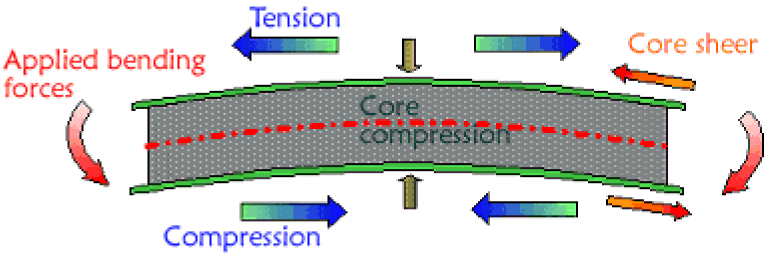


Figure 1: Stress-skin panel bending

A stress-skin panel is often compared to an “I” beam structure. The panel skins represent the flanges of the “I” beam and they carry most of the load in bending. The core of the stress-skin panel is similar to the web of the “I” beam. It separates the strong skins and like the web of an “I” beam the core must transfer the stresses in the top and bottom skin by the shear stresses in the core. The purpose of an “I” beam is to lessen the weight and material required to support a given load and/or provide the desired stiffens (deflection) under the load. The stress-skin panel provides the same function as the “I” beam. Typically the core is as wide and long as the stress-skins but the core is much weaker and usually lighter than the skins. Care in the design of the stress-skin panel is required to make sure the shear carrying ability of the core and adhesive often used to bond the core to the skins is not exceeded.

The skins can be almost any material such as steel, aluminum, or composites. If the skins are composite sheets, it can cover the full range of composites from common fiberglass reinforced polyester thermo-set resin to carbon fiber in an epoxy resin. Some extremely high grade composites are almost 3 times the modulus (stiffness) of steel.

Typical core materials are in four basic categories: blown foam, syntactic foam, honeycomb, and wood. Latter in the paper we will compare vacuum insulation as a core material to some of these common core materials in both performance and cost. Therefore some of the common core materials should be discussed in a little more detail.

4.1 Blown foams

Blown foams can be open or closed cell foams and the most common blown foams used as cores are closed cell urethanes or polyvinyl chlorides (PVC). The foam densities range from about 16 to 300 kg/m^3 (1 to 18 lb/ft^3). Typical urethane foam commercially available is the Dow TRYMER™ foams. These are produced in large “buns” and are cut by a horizontal ban saw to the desired thickness. Typical conductivity of the TRYMER™ foams is 0.027 to 0.029 W/m ^{o}C.

4.2 Syntactic foams

Syntactic foams are blends of resins and hollow particles. The hollow particles can be micro or macro spheres made of glass, ceramic, plastic, and other materials. Typical syntactic foams have superior mechanical properties than blown foams but also are much higher weight with typical densities in the 480 to 1040 kg/m^3 (30 to 60 lb/ft^3). They are used typically in high shear applications.

4.3 Honeycomb

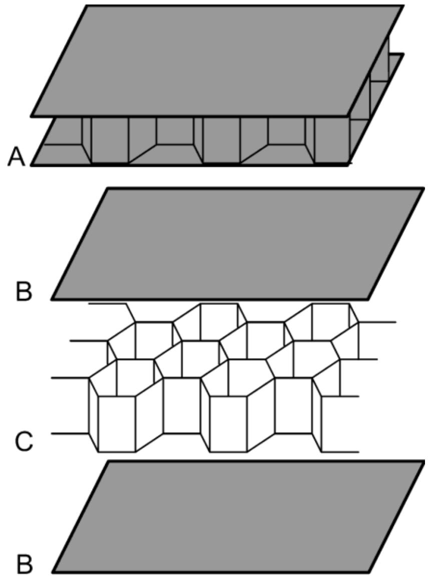


Figure 2: Honeycomb panel and its components

Honeycomb, see Figure 2 above, cores can be made from a broad range of materials such as paper, aluminum, steel, fiberglass, plastics, and ceramics. The designer can design the optimum core by selecting the material, overall honeycomb dimensions, wall thickness, etc. This type of core offers typically the highest strength to weight ratio. However this type of core is expensive compared to most other core materials. Typical densities are 16 to 240 kg/m³ (1 to 15 lb/ft³).

4.4 Wood Cores

The most common wood core is end grain balsa. The core is very light weight and can give good mechanical properties but the properties in the cross grain directions are far inferior. Also since this core is based on a material grown in nature, the properties can vary significantly making it hard to design to the maximum potential of the material. Often the minimum mechanical performance values must be used. Typical densities are 96 to 144 kg/m³ (6 to 9 lb/ft³). Moisture degradation of the core can be an issue if not protected.

5. VACUUM INSULATION AS A CORE MATERIAL

Vacuum insulation can be produced by using many different materials. This paper focuses on vacuum insulation that has a fiberglass core in about the 192 kg/m³ (12 lb/ft³) range because this is what the author knows best from experience. However, the approach and techniques described could be used to evaluate vacuum insulation produced with other materials.

Making a stress-skin panel with vacuum insulation as the core requires first selecting the adhesive to bond the vacuum panel, actually the exterior barrier surface, to the stress-skin sheets. The adhesive must not damage the barrier either chemically or by creating sharp edges of adhesive that might puncture the barrier. The adhesive should be a thermoset adhesive. A thermoplastic adhesive would creep over time. The adhesive is an important part of the structure since all shear loads carried by the core must be transferred by the adhesive to the core.

The load transfer in the vacuum panel must be from the barrier to and through the core structure. The load transfers from the barrier to the core by the friction between the barrier and the core since in most cases the barrier is not bonded to the core. The atmospheric pressure provides the force perpendicular to the barrier to create a high frictional bond between the barrier and the core. The actual level of frictional bond is dependent on the materials and morphology of the interior barrier and the core. In the case of a fiberglass core and typical barrier, glass has a very high coefficient of friction and the morphology of the fiberglass assists in producing an exceptional frictional bond.

The load must then be transferred within the core. In the case of fiberglass, there are two things that provide exceptional ability to transfer the load. Glass to glass has a very high coefficient of friction. Also, the fiberglass is not completely parallel straight fibers. The fibers intertwine with each other to some extent, see Figure 3 below.

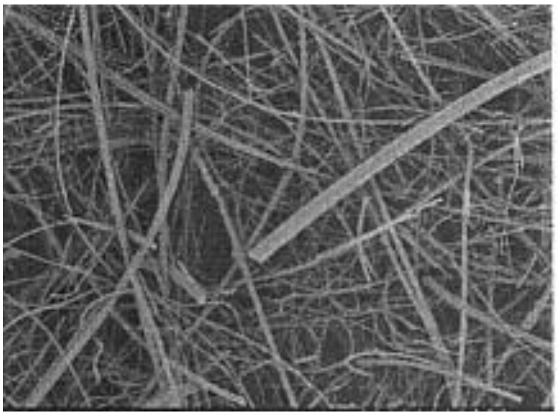


Figure 3: Photo micrograph of fiberglass at 500 magnification

5.1 Failure Mechanisms

As mentioned above, the load transfer is dependent on the frictional bond. This frictional bond is almost completely dependent on the difference in air pressure between the interior and exterior of the vacuum panel. If the vacuum is lost, the frictional bond will be drastically reduced and the shear load ability of the vacuum insulation panel will be almost negligible. Catastrophic failure occurs. Thus both structurally and thermally it is imperative that the vacuum be maintained. However, the stress skins can provide substantial protection to the barrier. Also good design can be used to assure both thermally and structurally failure of one panel does not have a large impact on the entire structure.

There is also one general failure mechanism for most stress-skin panels. Stress-skin panels generally do not perform well where the load is very local such as a fork truck tire load. Usually the failure is a compression failure of the core material. Some point or local loads can be handled by spreading the load. This can be done by applying a structural member between the local load and the stress-skin panel. An example is, attachment points often have spreader (thick) plates attached to the stress-skin at the location of a point load.

6. TESTING TO DETERMINE THE VACUUM PANEL SHEAR MODULUS

To design stress-skin panels based on vacuum panel cores, it is necessary to determine the effective shear modulus. It is called the effective modulus since it involves the adhesive, barrier film, and core material (everything except the skins of the stress-skin panel). There are several ways the effective modulus can be determined but the easiest is to build stress-skin panels, simply support the ends, and provide a load in the center of the span.

The stress-skin panels were composed of a 16.51 mm (0.65 inch) thick vacuum panel (fiberglass core at about 192 kg/m^3 (12 lb/ft^3) density), a thermoset adhesive, and two composite skins. The composite skins were commodity composite sheet (30% random glass reinforcement in a polyester thermoset resin) that was 2.54 mm (0.1 inch) thick.

The deflection versus load was recorded. The easiest way to back calculate the effective shear modulus of the vacuum panel stress-skin core was by performing a computer Finite Element Analysis (FEA) of the test situation and having know all properties except the vacuum panel stress-skin core shear modulus it could be adjusted to match the actual test data. This same model could then be used to investigate any configuration of stress-skin panel desired. This model was then used to compare stress-skin panels composed of several different core materials.

The shear modulus of the vacuum panel tested was 13.1MPa (1900psi). Many applications for stress-skin panels have deflection as the performance criteria and are not close to the panel failure load. Thus, this initial study did not take the testing to failure.

7. COMPARISON TO COMMON STRESS-SKIN PANEL CORES

Some common stress-skin panel cores were compared to the vacuum panel core in shear modulus, thermal performance, and cost. It is assumed that the application must have some thermal performance criteria to consider vacuum insulation. To illustrate the impact of the shear modulus, an example panel that has a core thickness of 25.4 mm and 2.54 mm thick stress skins was computer modeled for each material. Figure 4, below, shows the computer model loads and constraints. The right edge of the bottom skin was fixed (it could not move). The left edge of the bottom skin was fixed in the "Y" direction (it could not move up or down). The entire flat surface of the top skin was uniformly loaded (the arrow is just a graphic to indicate loading) at 5000 N.

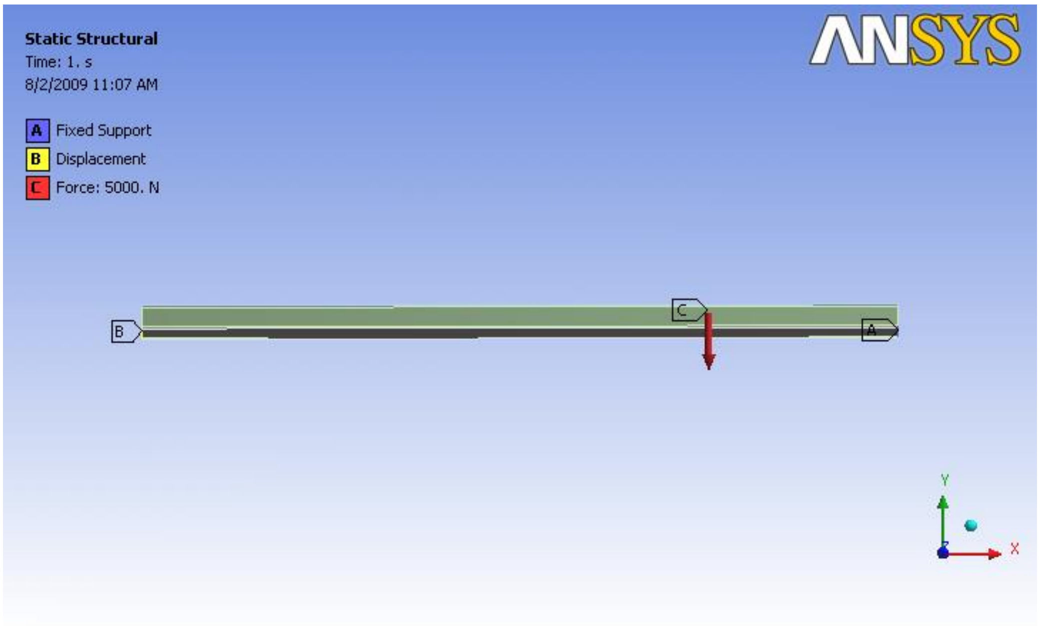
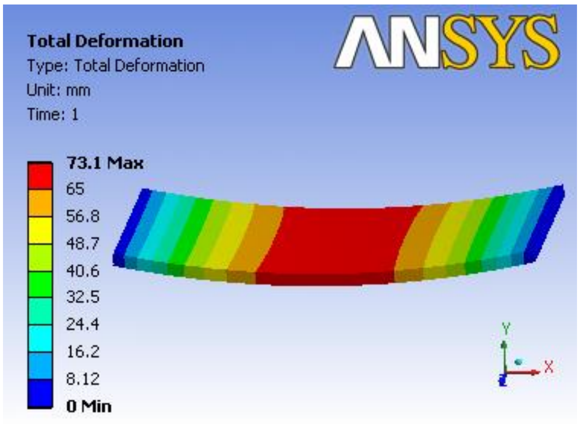
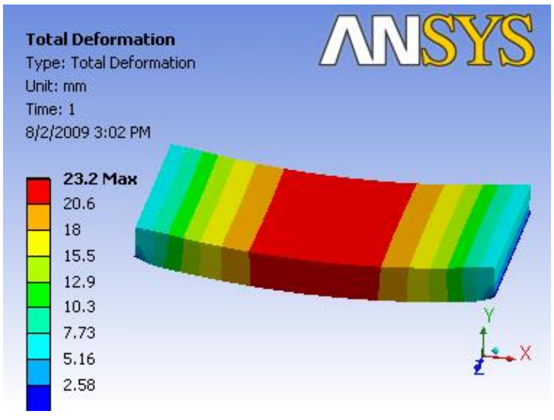


Figure 4: Model loads and constraints

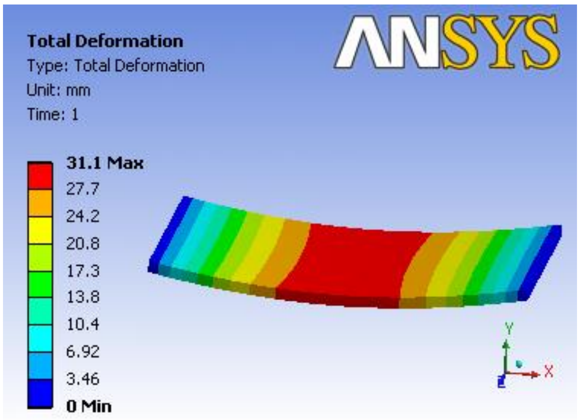
The deflection results for each of the different cores are shown in Figure 5 below. The 32 kg/m³ (2 lb/ft³) foam is used primarily for insulation and structural performance is of less importance. Therefore it is most often used at about 100 mm in thickness. Therefore this foam was studied at two different thicknesses.



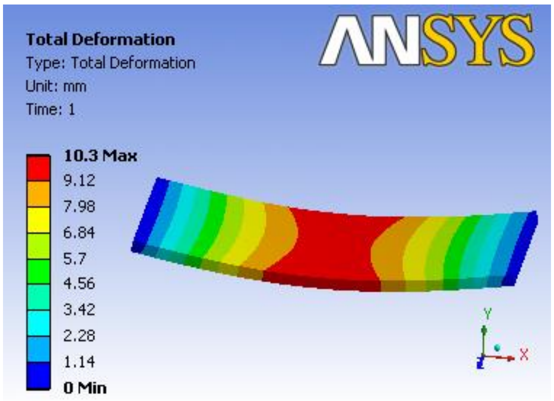
25 mm core of 32 kg/m³ urethane foam



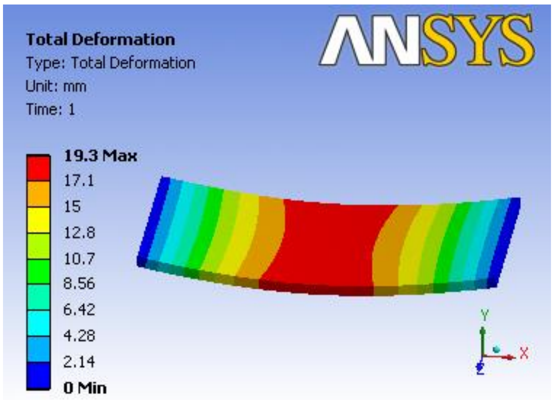
100 mm core of 32 kg/m³ urethane foam



25 mm core of 96 kg/m³ urethane foam



25 mm core of 150 kg/m³ end grain balsa



25 mm core of 192 kg/m³ VIP (fiberglass)

Figure 5: Deflection plots of various core materials

Table 1 below, shows the various core materials, shear modulus, resulting stress-skin panel deflection, approximate cost of the core, and the thermal performance of the panel.

Table 1: Property Comparison of Various Stress-Skin Panel Cores

	32 kg/m³ Urethane Foam 25 mm Thick Panel	32 kg/m³ Urethane Foam 100 mm Thick Panel	96 kg/m³ Urethane Foam 25 mm Thick Panel	150 kg/m³ End Grain Balsa 25 mm Thick Panel	192 kg/m³ VIP (fiberglass) 25 mm Thick Panel
Shear Modulus in MPa	1.79	1.79	5.52	157.2	13.1
Max. Deflection in mm	73.1	23.2	31.1	10.3	19.3
% of VIP Deflection	379%	120%	161%	53%	100%
Approx. Cost of the Core/m² at Indicated Thickness					
U.S. Dollars	13.50	54.00	36.00	71.70	65.00 to 110.00
British Pound	8.08	32.32	21.55	42.91	38.90 to 65.80
Euro	9.47	37.89	25.26	50.31	45.60 to 77.20
% of Avg. VIP Panel Cost	15%	62%	41%	82%	100%
Panel Thermal Resistance in m²K/W	0.93	3.72	0.88	0.51	8.80
% of VIP Thermal Resistance	11%	42%	10%	6%	100%

8. CONCLUSIONS

The objective was to obtain additional value from the vacuum insulation panel by providing structural as well as thermal performance. In applications where both thermal and structural bending stiffness are desired, the vacuum panel can structurally out perform both the 32 kg/m³ and 96 kg/m³ urethane foam cores commonly used for the core of stress-skin panels requiring both thermal and structural performance. By replacing the stress-skin panel core with the vacuum insulation panel, some of the cost of the vacuum panel can be credited to the structural performance obtained. Depending on the exact design situation, the structural and thermal performance that the vacuum panel provides can make the vacuum panel a much better value.

BIBLIOGRAPHY

SMITH, D., RODERICK, K., AND GLOVER, B. Applications of Vacuum Insulation Panels in Extreme Environments, 7th International Vacuum Insulation Symposium, 2005.

TENIERS, C., Ultra High Barrier VIP Laminates-New Solutions to Tough Requirements, 8th International Vacuum Insulation Symposium, 2007