Structural Vacuum Insulation Panels

Dwight S. Musgrave
Thermal Visions, Inc.
83 Stonehenge Dr., Granville, Ohio 43023, USA
dwight.musgrave@thermalvisions.com

Introduction

- Some VIP applications are a particular challenge due to the required durability and value
  - Construction
  - Transportation
    - Both can be very hazardous to VIP
  - Adding protective layers to VIP increases the cost to benefit
  - Suggested is an approach to increase value while providing protection

Vacuum Panel Protection

- Many previous presentations through the years have discussed damage to barriers
  - Typical damage was caused by flexing the film to fold over seal flaps and other normal abuse of the barrier
- Emerging applications such as construction puts VIP in a very hostile environment
  - Protective sheets of strong material have been suggested
    - Adds to the already high VIP cost
  - Fiberglass reinforced plastic
    - (Such as used in hulls of recreational boats)
    - Reinforcement type, %, orientation, and selection of the matrix resin can be designed to meet the requirements
  - Virtually any level of protection can be provided

Vacuum Insulation Value

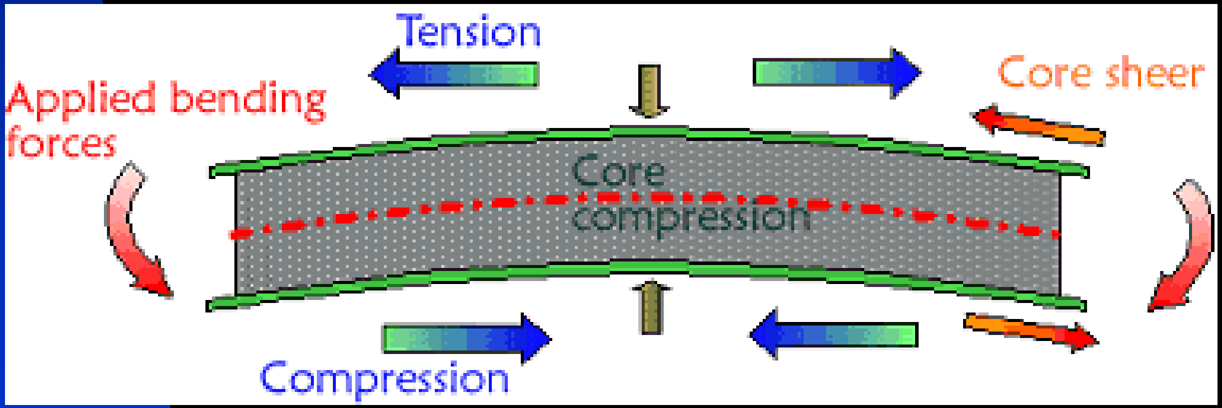
- A few select specialty applications
  - Benefits so great VIP was always a great value
- Many, particularly high volume, applications
  - The benefits were desired but the cost far too high
  - Typical approach to provide better value
    - Increase performance
    - Reduce cost
  - Even with increased cost of energy and greater environmental awareness – still hard sell

Vacuum Insulation Value

- An additional approach to increase value
  - Find additional benefits from vacuum insulation
    - One such benefit is for VIP to provide structure as well as thermal performance
  - VIP used as core of a stress-skin structural panel
    - Provides exceptional protection of the VIP
    - Provides the VIP thermal performance
      - Very high thermal performance in very small thickness
    - Can be used as part of a structural wall or floor, etc. of buildings or transportation vehicles
    - Possibly even the structural walls of refrigerators, freezers, walk-in coolers, etc.

What is a Stress-Skin Panel?

- Stress-skin panel (sandwich panel)
  - Basic structural component for the composites industry for over 50 years
  - Concept
    - Strong thin face sheets bonded to a thicker usually lighter core
  - Usually used in bending load applications



What is a Stress-Skin Panel?

- Stress-skin panel compared to an “I” beam
  - The panel skins represent the flanges of an “I” beam and carry most of the load
  - Core similar to the web of an “I” beam
    - Separates the skins and transfers load between the skins by shear stresses
  - “I” beams are used to be lighter and more material efficient in providing load caring ability at a given deflection
  - Stress-skin panels accomplish the same objective
  - The core of a stress-skin panel
    - Usually same length and width as the skins
    - Structurally much weaker and usually lighter
  - Care in design of the stress-skin panel is required
    - Core and adhesive (used to bind the skins and core) must be able to carry the required shear stress

What is a Stress-Skin Panel?

- Skins can be any strong material
  - Steel, aluminum, wood, composite, etc.
  - If composite
    - Common fiberglass reinforced polyester thermoset resin
    - Very high performance composites – carbon fiber reinforcement in epoxy resin
      - Possible to be 3 times the modulus of steel
  - Four typical core material categories
    - Blown foams
    - Syntactic foams
    - Honeycomb
    - Wood

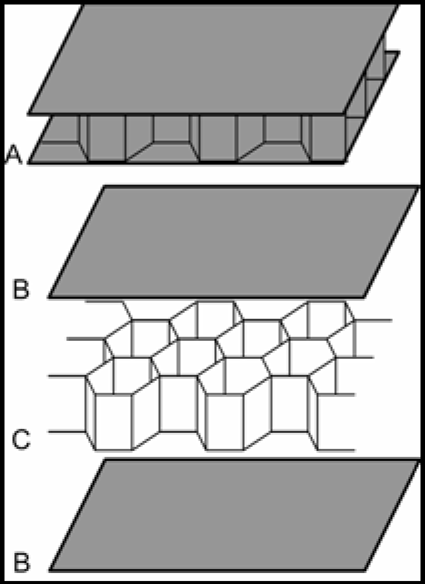
Blown Foams

- Open or closed cell foams
- Most common foams
  - Closed cell urethanes or polyvinyl chlorides (PVC)
  - Densities range from 16 to 300 kg/m^3
  - Typical urethane foam
    - Dow TRYMER™ foam
      - Produced in large “buns” and cut to desired thickness and length and width
      - Conductivity 0.027 to 0.029 W/mºC

Syntactic Foams

- Blends of resin and hollow particles
  - Hollow micro or macro spheres
    - Glass
    - Ceramic
    - Plastic
    - Other materials
    - Densities relatively high 480 to 1040 kg/m^3
- Used for high shear applications

Honeycomb Core



- Broad range of materials
  - Steel, aluminum, fiberglass reinforced plastic, plastic, ceramics, etc.
- Design freedom in cell size, wall thickness, etc. to optimize the core
- Highest strength to weight ratio
- Usually expensive compared to other cores
- Densities 16 to 240 kg/m^3

Wood Cores

- Most Common – End Grain Balsa
  - Very light weight
  - Good mechanical properties in grain direction
  - Cross grain directions are far inferior properties
  - Material grown in nature
    - Properties can vary significantly
    - Must be a conservative design due to variability
  - Densities 96 to 144 kg/m^3
  - Moisture degradation can be an issue if not properly protected

Vacuum Insulation as a Core Material

- There are many core materials for vacuum insulation
- Focus on fiberglass core in the 192 kg/m^3 range
  - Approach and techniques described could apply to other core materials
- Selection of adhesive
  - Bonds stress-skin exterior sheets to barrier film
    - Must not cause damage – chemically or sharp edges
    - Must be a thermo-set adhesive so it does not creep with time
    - Must be able to transfer all the shear loads

Vacuum Insulation as a Core Material

- Load transfer from the barrier to the VIP core material
  - Barrier usually not bonded to core
  - Load transfer is by friction
  - Atmospheric pressure creates the perpendicular force to create a high “Frictional Bond”
    - Level of “Frictional Bond”
      - Materials and morphology of the interior of barrier film and core
- Glass in the fiberglass has a very high coefficient of friction
- Morphology of the fiberglass core assists in creating a “Frictional Bond”

Vacuum Insulation as a Core Material

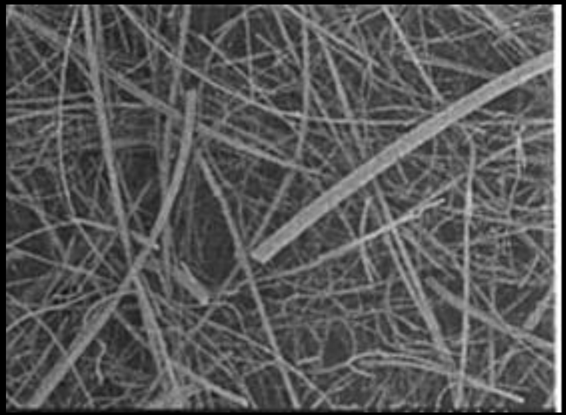


Photo micrograph of fiberglass at 500 magnification

- Glass to glass has a very high coefficient of friction
- Not parallel straight fibers
  - Fibers are bent and intertwine

VIP as Stress-Skin Core Failure Mechanisms

- “Frictional Bond”
  - Dependent on the pressure differential between the interior and exterior of the VIP
  - If vacuum is lost
    - “Frictional Bond” drastically reduced
    - Shear load transfer ability negligible
      - Catastrophic failure
    - Thermally and structurally it is imperative that the vacuum not be lost
- The skins of the stress-skin panel must protect the vacuum panel

VIP as Stress-Skin Core Failure Mechanisms

- Good design can assure that failure of one panel does not have a large impact thermally or structurally on the entire structure
- One general failure mechanism for most stress-skin panels
  - Local loads (loads over a small area)
    - Fork truck tire, attachment points, etc.
    - Compression failure of the core
    - Structural spreader plates between the load and stress-skin panel sometimes can be used
      - Spreads load over much larger area to eliminate compression failure

Testing to Determine VIP Shear Modulus

- To design stress-skin panels using VIP as the core, the “effective” shear modulus of the VIP panel is required
  - “Effective” modulus because it is the result of the adhesive, barrier, and core of the VIP
  - Actual stress-skin VIP panels created
    - Tested under bending load
    - Load versus deflection determined
    - 16.5 mm thick vacuum panel
    - 192 kg/m^3 fiberglass core
    - Composite skins
      - 30% random glass reinforcement
      - Thermoset polyester resin
      - 2.5 mm thick

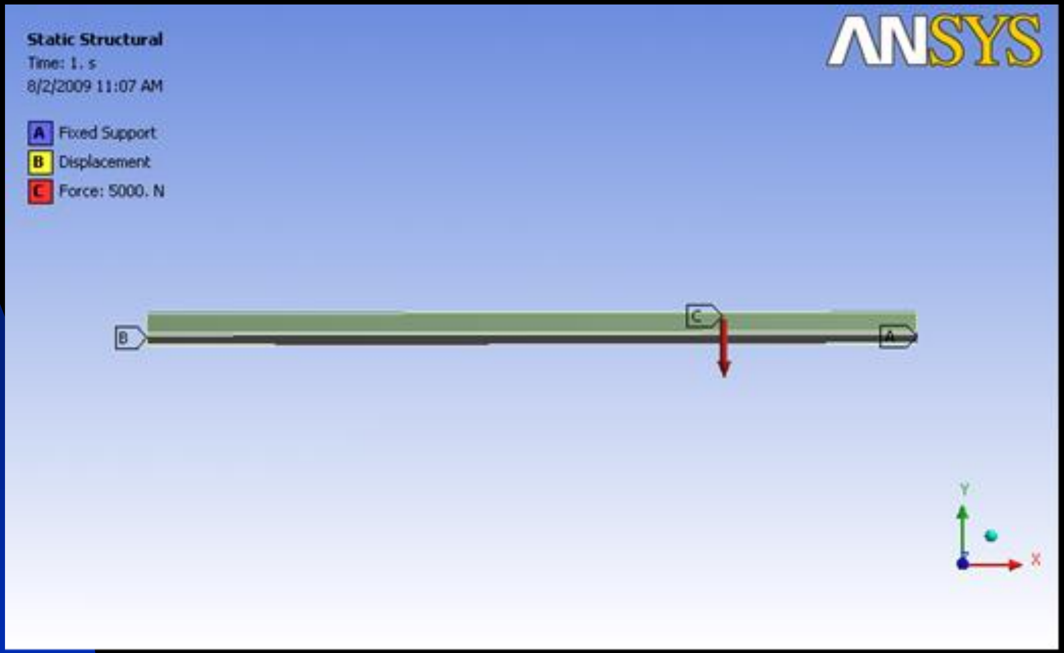
Testing to Determine VIP Shear Modulus

- Create Finite Element Analysis model of the test
  - All variables know except the “Effective Modulus”
  - Determine “Effective Modulus” to fit the test data
  - “Effective Modulus” is 13.1 MPa for this adhesive, barrier film, fiberglass core
  - Computer model can then be used for other VIP stress-skin panel dimensions
  - Can be used to compare the VIP as a core for a stress-skin panel to other core materials

Comparison to Common Stress-Skin Panel Cores

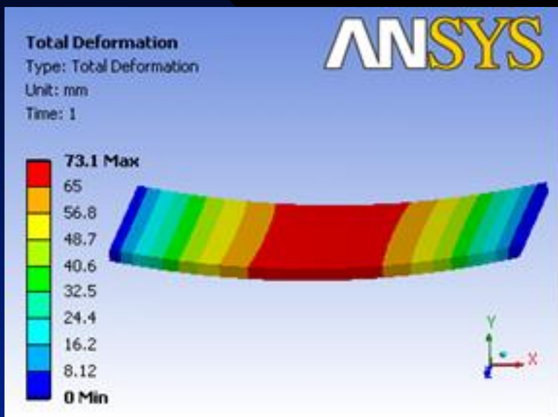
- Assume the application must have some thermal performance requirement
- Assume there is a bending stiffness requirement
- Assume core thickness is 25.4 mm
  - Except low density urethane foam also modeled at 100 mm thickness (common for thermal applications)
- Stress-skin panel size 1 x 0.5 meter
- Skins of the stress-skin panel are
  - 30% random glass reinforcement
  - Thermoset polyester resin
  - 2.5 mm thick

Comparison to Common Stress-Skin Panel Cores

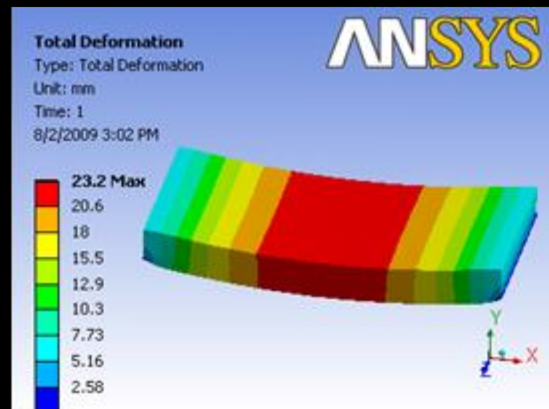


- Right edge of bottom skin fixed (could not move)
- Left edge of bottom skin fixed in “Y” (could not move up or down)
- Entire surface of the flat skin uniformly loaded with 5000 N load
  - Arrow in graphic just an illustration – was uniformly loaded

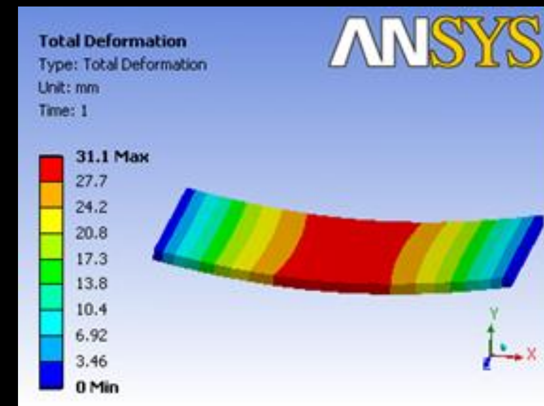
Comparison to Common Stress-Skin Panel Cores



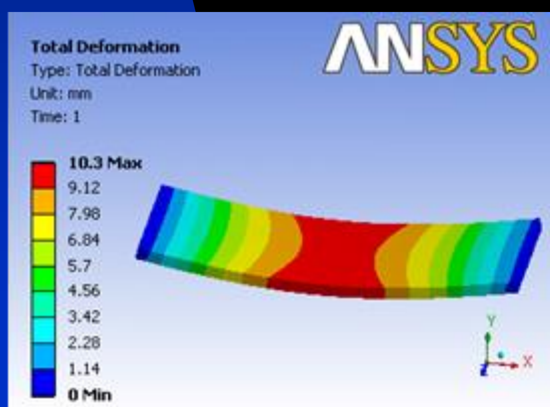
25 mm core of 32 kg/m³ urethane foam



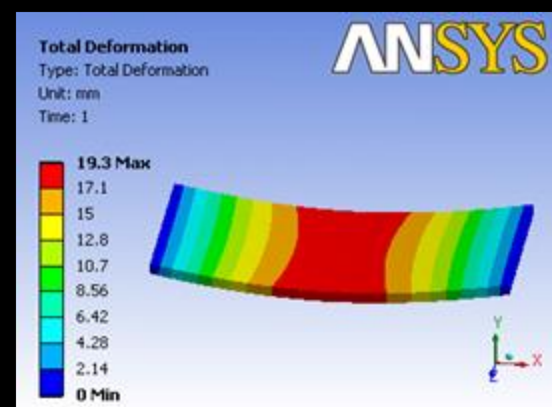
100 mm core of 32 kg/m³ urethane foam



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)

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%

Conclusions

- The stress-skin panel with VIP core can provide significant structure while providing very high thermal performance
- The VIP stress skin panel out performed thermally and structurally the 32 kg/m^3 and 96 kg/m^3 urethane foam
- Some of the cost of the vacuum panel can be credited to the structural capability
- If both structural and thermal performance is desired, a stress-skin VIP can have increased value