Insulated Tension Membrane (Architectural Membrane and Aerogel)

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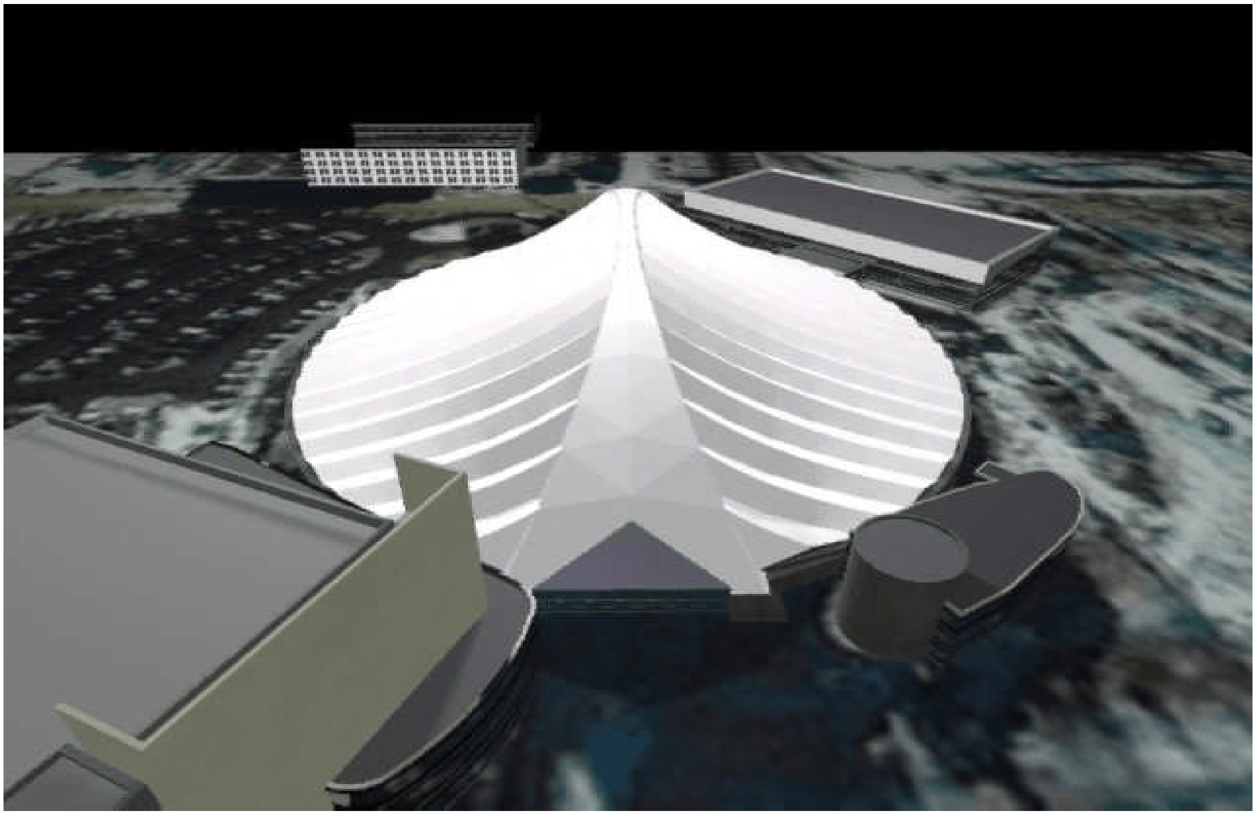
Since the 1970's the tension membrane industry has been built on several key aspects: freedom of form which leads to signature design opportunities, strong light weight materials that yield efficient high performance design, and the diffusion of natural light. With success come competition and the realization that deficiencies exist in the membrane technology that we promote. As an example, in the enclosed stadium and arena market, greater emphasis today is placed on energy efficiency and the push to minimize heating and cooling loads. Large long-span enclosed roof applications of the 80's and 90's began to shrink as retractable roofing systems became the norm and insulated metal panel became the competition.

A need for insulation that maintains the key aspects of a tension membrane structure is required. Aerogel, discovered in the 1930's is the world's lightest and best insulating solid. Aerogel has unique qualities that make it a good fit for the membrane industry. As the world's lightest solid, a 25 mm (1 inch) thick blanket weighs in at 1.76 kg/m^2 (0.36 lb/ft^2) and a typical Tensotherm Architectural Membrane system weighs 3.55 kg/m^2 (0.73 lb/ft^2) and provides an incredible U0.56 (R10) insulation value. Other key advantages of aerogel include translucent properties; because the material is 95% air it is upwards of 70% light translucent when combined with membrane, 3% light transmission is maintained for a 25 mm (1 inch) thick composite system. Acoustic performance of a building is also greatly enhanced with the presence of aerogel. Do to aerogel's unique nano-pore structure the material drastically reduces the speed of sound to 100m/s, making aerogel one of the best sound absorbing materials in existence. Aerogel is hydrophobic with a contact angle of 150^o it pushes moisture away from itself and can never become saturated, infinitely maintaining its insulation properties and making it resistant to mold and mildew. Another key aspect of aerogel is its compressibility, because the material has the lowest thermal conductivity of any known substance in existence, it insulates better than air (thermal conductivity of aerogel = 12 mW/m-K thermal conductivity of air = 24 mW/m-K), making air the weak link of the system. This property lends itself well to a Tensotherm composite panel, when the system is tensioned or supported by a cable the aerogel insulation within the composite will compress, air is squeezed from the insulation system and the U value decreases, making the insulation more efficient. By comparison standard insulations such as fiberglass and mineral wool depend on luft (air) to maintain insulation capacity therefore a composite system is unattainable and the forces of gravity and moisture quickly degrade insulation efficiency. Lastly, aerogel is a green product, not only does it ensure energy efficiency with its high insulation properties and allowance of natural daylight, it is also produced with the world's most abundant raw material sand and it is infinitely reusable, its useful life will continue beyond that of a membrane structure.

Flower atop a monolith of aerogel with a flame from a torch beneath

Crystal form of aerogel

Aerogel is not a new product it was discovered by Steven Kistler in 1931 but the methods and means to produce the product were both dangerous and costly. Aerogel at its inception was produced with a supercritical drying method incorporating ethanol and high pressure. Monsanto Corporation attempted to mass produce the product in the 1950's but the volatile nature of the process caused a factory explosion and the product was shelved. In the 1980's the material was resurrected by BASF and in the 2000's Cabot Corporation consolidated intellectual property and developed a new less volatile subcritical drying process. The subcritical process makes the product safe to produce and cost effective for use is specialty applications such as tension membrane structures.



Graphic rendering of the Talisman Center, Calgary, Alberta, Canada

In 2006 Tensotherm was developed to solve an insulation challenge at the Talisman Center in Calgary, Alberta, Canada. The Talisman Center contains an Olympic size swimming pool, platform diving pool and a full scale gymnasium with running track. Originally built in 1982 the roof incorporated a built-up membrane system consisting of a structural PTFE fiberglass outer layer, a fiberglass insulation layer on a web belt system and a PVC liner. Over time the insulation was attacked by moisture as the vapor barrier broke down, resulting in the fiberglass insulation becoming saturated. The saturation of the fiberglass insulation nullified the U value and spawned a breeding ground for mold and mildew. The challenge was to combat Calgary's cold dry climate with extreme -40^{o}C temperatures and the facilities massive moisture source while maintaining natural daylighting across the 16,000 m^2 membrane surface area. With a requirement of U0.47 (R12), the Talisman Center and the City of Calgary wanted a high tech solution; incorporating aerogel into a composite membrane was the clear solution.

The key element to the Tensotherm composite is the carrier of the aerogel. The goal was to firmly hold the aerogel, maintain system flexibility, evenly distribute the aerogel within the system and minimize the impact to the translucency of the aerogel. An aerogel blanket was developed using bi-component polymer fibers as a strong reliable carrier mechanism. To prove the worthiness of the blanket it was tested on a vibration system to determine if the fiber weave could maintain its hold on the aerogel. A simple drum vibrator system was fitted with a frame to hold a 200 mm (8 inch) square sample of 8 mm (0.25 inch) thick aerogel blanket at 30^{o}. Baseline K value of 21.73 mW/m-K was measured for the 8 mm (0.25 inch) aerogel blanket and the sample was vibrated at 20 Hz (0.2 Hz is a typical frequency of a tensioned membrane structure due to wind) for 6 hours. Upon conclusion of the test a re-measurement yielded a K value 21.89 mW/m-K, no significant K value loss, the recorded loss was within the measurement error of the devise. The test was conducted for hundreds and hundreds of hours with no loss of K value.

Aerogel blanket

Drum vibrator with aerogel blanket

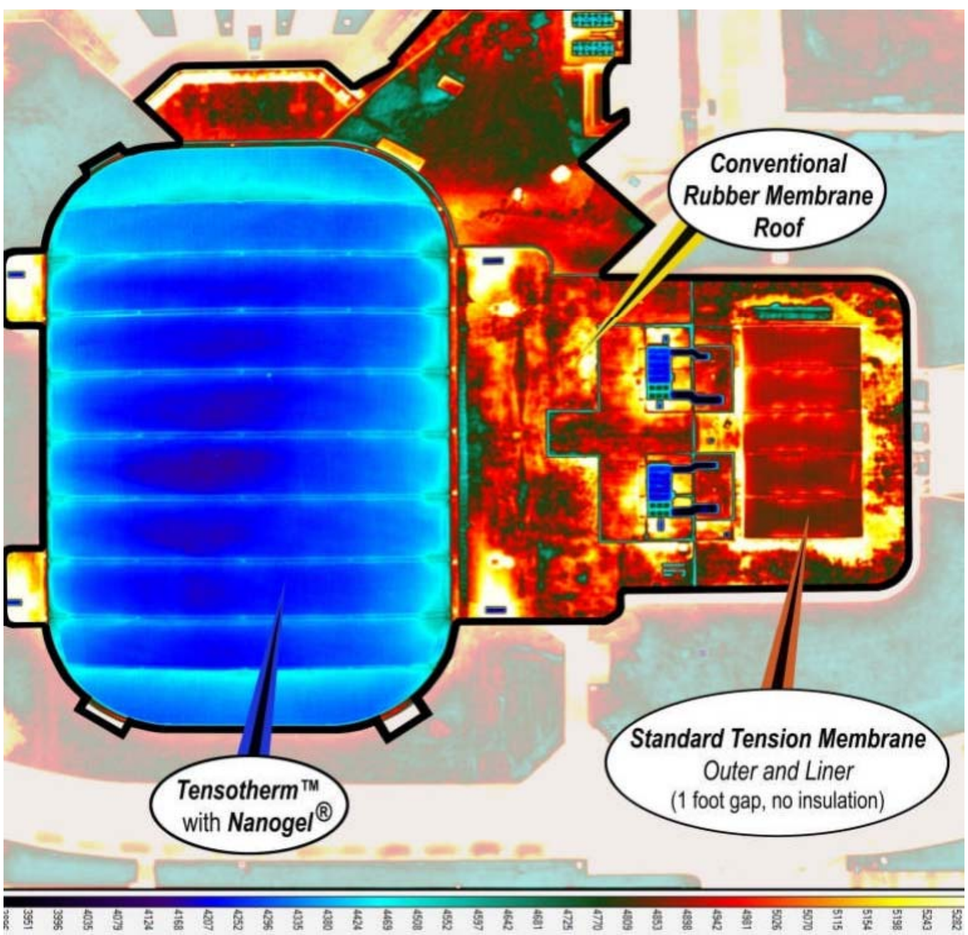
Along with the aerogel carrier a mechanical means to fasten the aerogel blanket to the membrane composite was required, and patterning techniques had to be developed as the Tensotherm composite consists of three materials with different characteristics. The method of mechanical attachment of the aerogel blanket to the membrane composite is a proprietary system and had to be proven before it could be built. The experimental system was subject to cyclic loading on a "snap" test machine to simulate flutter of a membrane system. The apparatus holds the ends of the sample and cycles the sample at the center attaining full tension at the top and bottom of the cycle. The sample was subject to thousands of cycles to determine the impact on the mechanical connections.

Snap test apparatus to test mechanical fastening of aerogel blanket

During the development of the Tensotherm composite for the Talisman Center a retrofit project emerged in Virginia, USA that required an insulated roofing system and the client wanted to maintain translucency. The Dedmon Center, originally and air dome, was to be re-built as a tension structure with trusses and Tensotherm. Although the Tensotherm system was developed for the Talisman Center, the Dedmon Center would become the first project to incorporate aerogel insulation in a tension membrane structure. The specification required a U0.51 (R11) and Tensotherm did not disappoint.

Interior of completed Dedmon Center Gymnasium

Thermal scan imagery confirmed that the actual installed Tensotherm product performed far better than laboratory tests predicted.

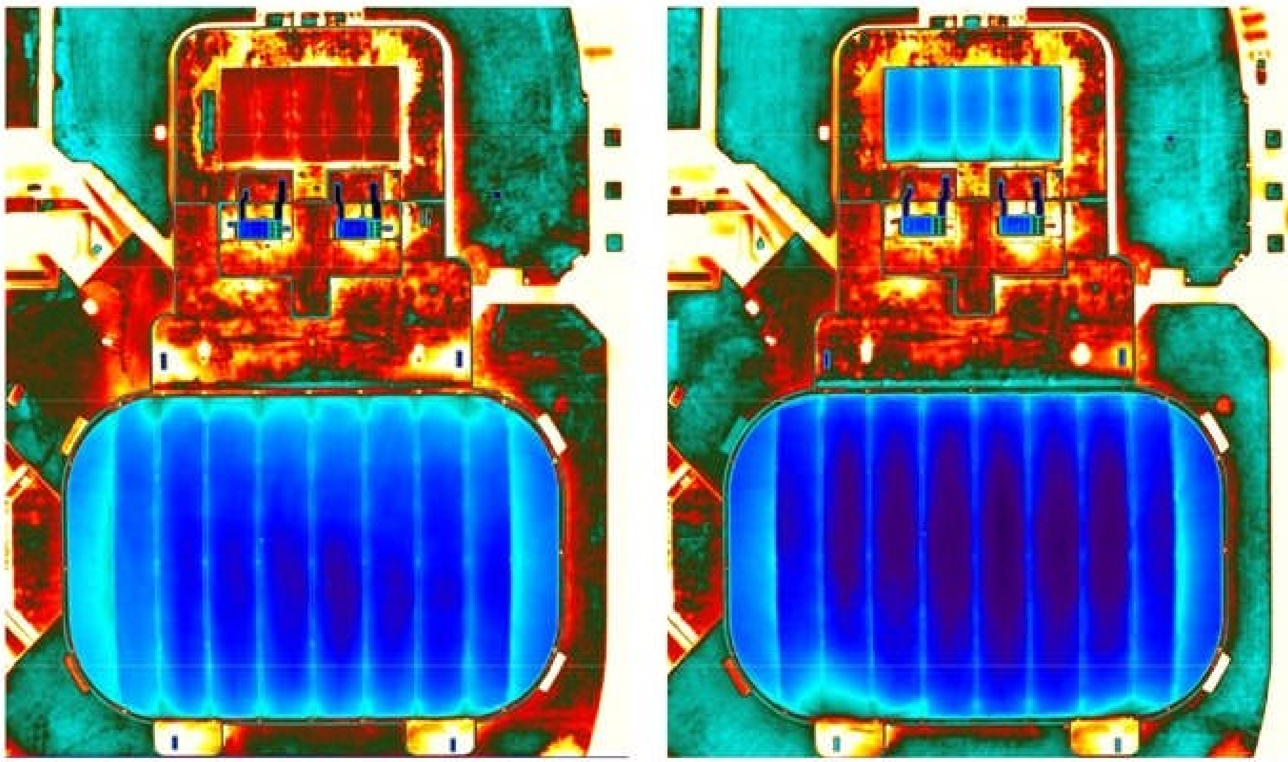


Thermal scan image Dedmon Center March 2009

Surface temperature readings were taken simultaneous with an aerial thermal scan yielding incredible results. The surface temperature of the exterior skin of the Tensotherm composite was recorded as -1^{o}C (30^{o}F), very close to the outside air temperature of -3^{o}C (27^{o}F) while the inside surface of the liner was 20^{o}C (68^{o}F). The thermal scan also proved how well the aerogel insulation was distributed within the blanket as a consistent blue is prevalent throughout the roof even after manufacturing, shipping and installation. Conversely the original pool structure that consisted of a tensioned membrane outer and liner with a 300 mm (12 inch) air gap offers minimal insulation value. The surface temperatures of the outer membrane and liner membrane are both 5^{o}C (42^{o}F), a clear indication of thermal heat transfer. When this thermal image was introduced to the owner it was determined to retrofit the pool structure with Tensotherm. It was determined that U0.9 (R6) would meet the requirements of the code and that the building would benefit from the increase in translucency as the composite was required to be 16 mm (0.625 inch).

Interior of completed Dedmon Center Pool

For research purposes it was decided to rescan the building one year later to check the performance of the new Tensotherm pool roof but to also confirm the performance of the one-year-old Tensotherm gymnasium roof. The results were better than expected. Not only did the pool roof have similar characteristics of the gymnasium roof, it can be seen that the performance of the gymnasium roof is increasing with time. The results were unprecedented, as explained above the thermal scan imagery proves that the effect of gravity packing the aerogel crystals tightly together decreased the U value of the system in one year's time. More research is ongoing but it can be assumed when insulating with aerogel degradation factors need not be considered when designing mechanical systems. This is an important consideration as equipment redundancy may be decreased and lifecycle energy modeling is more consistent.



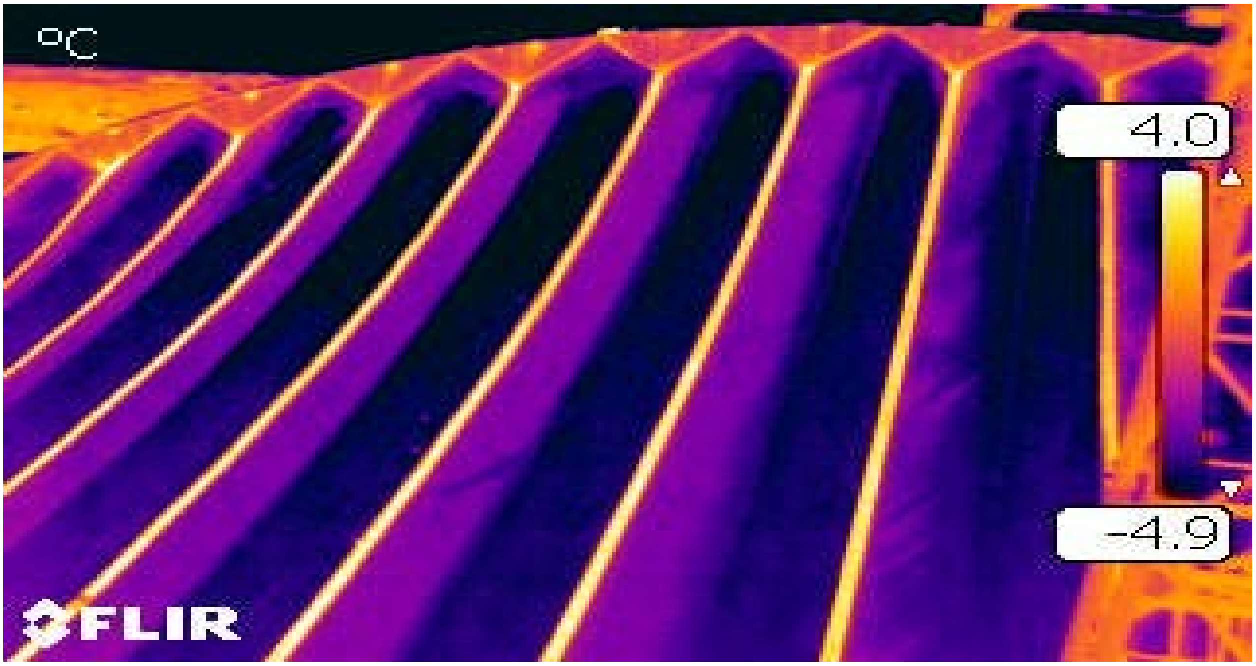
Side by side comparison of thermal scan image Dedmon Center March 2009 and March 2010

The Talisman Center was recently completed and poses a severe challenge to the Tensotherm composite system. Unlike the Dedmon Center the Talisman Center conditions are extreme, temperatures dip below -40^{o}C, the presence of a moisture source in the form of an Olympic size pool and building positive pressure drive the performance of the composite. The Tensotherm composite vapor barrier was as much of a challenge as managing the aerogel insulation within the system. To date the system has performed as advertized, hand held thermal images confirm the Tensotherm system is once again exceeding laboratory tested values and expectations. Aerial thermal scan photography is scheduled for March of 2012 to coincide with images taken before construction when the building consisted of a built-up saturated fiberglass insulation system.


Exterior of completed Talisman Center


Interior of completed Talisman Center gymnasium side

Interior of completed Talisman Center pool side



Thermal photograph of Tensotherm performance during construction (no closures installed)

Tensotherm allows our industry to expand from a shelter product to a premium roofing product. The product allows the industry to grow as a new market has been opened to the tension membrane industry. Direct competition with insulated single ply membrane and insulated metal panel will reinforce the benefits of insulated tension membrane roofing and limit the risk to clients. The advantages are distinct and the benefits pronounced. The efficiency of Tensotherm will change the course of our industry.

Not since 1972 when the first tension membrane structure incorporating PTFE fiberglass material was installed at Laverne College has a product had as much potential as Tensotherm. As noted above, aerogel is the lightest solid in the world, comprised of 95% air. The material is virtually transparent. The material is the best insulation on the planet and is the only material on the planet that insulates better than air. It is extremely water repellant; with a contact angle of 150 degrees the material will never promote mold or mildew. The material can manage sound very well as it slows the speed of sound to 100 m/sec.

The key targets to the industry are maintained:

- Freedom of form is not compromised with a Tensotherm membrane structure.
- The light weight cladding system is maintained as Tensotherm allows the support structure to be designed as efficiently as a single layer tension membrane structure.

- Tensotherm allows diffusion of full spectrum light.

New targets are realized:

- When comparing aerogel to conventional insulation materials such as mineral wool and fiberglass the conclusion is clear: aerogel is a superior product. In a tension membrane structure the insulation distinction is more apparent, as compression of insulation will occur as the membrane system is supported by steel and cables. Conventional insulation must maintain an air pocket to generate low U value. Compressive forces applied by steel, cables and gravity will compress conventional insulation resulting in an increased U value; however, these same effects pack the aerogel particles closer together within the Tensotherm composite, decreasing the U value.

- Moisture is another detrimental factor of conventional insulation. Tensotherm has a robust vapor barrier, but the presence of aerogel is a second line of defense against vapor infiltration, the U value will not be affected by moisture. Aerogel is hydrophobic and will never promote mold and mildew growth.

- Sound management is realized with Tensotherm, the presence of aerogel can absorb high frequency sound better than conventional insulation products. The aerogel distinction is realized in its ability to absorb low frequency sound at a rate ten times more efficient than conventional insulation.

The materials are proven; the market is to be developed; insulated tension membrane will compete with conventional roofing applications in familiar areas such as structural efficiency. In the case of mechanized roofing applications, mechanization efficiency is realized as less weight leads to less horsepower and smaller motors to drive the system. Acoustical efficiency is increased, as secondary systems are eliminated since the aerogel insulation can function as an insulator and a sound manager. Superior insulation reduces equipment cost for heating and cooling and increases lifecycle efficiency over time. The Tensotherm system will reduce maintenance costs and have a long service life. Tensotherm insulation properties are permanent, U values will be maintained with time and may show a reduction over time. The installation techniques of the Tensotherm composite are the same as for single layer membrane, leading to schedule and program improvements over conventional roofing applications.