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# TEXTILE TECHNOLOGICAL PROPERTIES OF LAMINATED SILICA AEROGEL BLANKET

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**Summary**: Silica aerogel blankets made from silica aerogel integrated into nonwoven fabrics are superinsulative thin materials that can be also used in technical textiles and clothing. Textile technological properties of silica aerogel blanket laminated with a water vapour permeable membrane and polyester warp knitted fabric were studied. The five layers laminate had good mechanical properties, and was resistant to rubbing, was water vapour permeable, hydrophobic and oleophilic material with good thermal insulation. Laminated material is a little too heavy to be used as clothing and also a little rigid. Silica aerogel is prone to crushing during use. The laminate will be softer and more flexible after being used for a certain time. Analysed laminated silica aerogel blanket is suitable for technical textiles, such as sleeping bags, flexible protective covers such as outdoor pillows, wheelchairs pillows for winter conditions, for personal protective garments, etc.
**Keywords**: silica aerogel, laminated silica aerogel blankets, clothing.

## 1. INTRODUCTION

Protection clothing for workers in cold storages of food industry, divers, construction workers, alpinists, pilots of ultra light planes and similar professions as well as also garments for homeless people must be effective in thermal protection in conditions at very low environment temperatures. Classic heat insulating materials, like wool knitting, nonwovens, fibres, down and fluff as filling, neoprene, etc. are usually very voluminous, and prevent body movement.

Despite many new solutions, that enable today's famous smart and functional materials, there is still a lack of efficient and environmentally friendly materials that would enable clothing comfort of active persons at extremely low temperatures.

A relatively new superinsulative material, silica aerogel, with the lowest thermal conductivity among all known solid materials is now in the market and is used for buildings and plumbing pipes thermal insulation.

In the research our aim was to get the answers to the following questions: whether this material is suitable for thermal insulation of clothing and if yes, how it can be used in clothes, and what are its advantages and weaknesses.

Chemically, silica aerogel is silicon dioxide ($SiO_2$), an inorganic material manufactured from silica sand. Silica aerogel is chemically identical to sodium silicate (waterglass). From the year 1968 it has been prepared by S. J. Teichner's sôl-gel method [1] from alkoxide precursors, $Si(OR)_4$, such as tetramethoxy silanes, TMOS, $Si(OCH_3)_4$) or saturated tetraethyl orthosilicates, TEOS, $Si(OCH_2CH_3)_4$. Alkoxide precursors are activated firstly by hydrolysis in a mixture of water and a parent alcohol to silicic acid, which reacts into dimers, trimers, etc. and finally gives a colloidal solution (sôl) with cyclic structures of 3−6 silicon atoms. With addition of basic substances (–$NR_3$, R = H, alkyl) colloid solution converts into alcogel with a crosslinked polymer structure of $SiO_2$ in alcohol. Silica aerogel is prepared by extracting the liquid component from a gel with supercritical drying. This allows the liquid to be slowly removed from the gel without causing the solid matrix in the gel to collapse from capillary action, as would happen with conventional evaporation [1, 2]. Development of silica aerogel today is directed towards cheaper production, which is based on water glass and drying of the gel at atmospheric conditions. Silica aerogel has an amorphous nonporous structure with about 80−99.8 % of air nanopores, high surface area (500−1200 $m^2/g$), low den-

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sity (0.003−0.35 g/cm$^3$) and low thermal conductivity (0.015 W/mK) [1].

The process of making aerogel blankets, that could be easier for use than pure silica aerogel, has been developed. Aerogel blankets are a composite material with a fibrous batting as reinforced component in a matrix from silicon aerogel. Aerogel blankets can be bent into a bale, similarly to a pure fibrous batting material. Silica aerogel blankets are prepared in a discontinuous one-step process, where a fibrous batting made from different textile fibres (glass, partially carbonised acrylic fibres, polyester microfbres, etc.) is used as a fibre-reinforced component [3] and a sôl alkoxide precursor for in situ polymerisation into a gel (Figure 1).

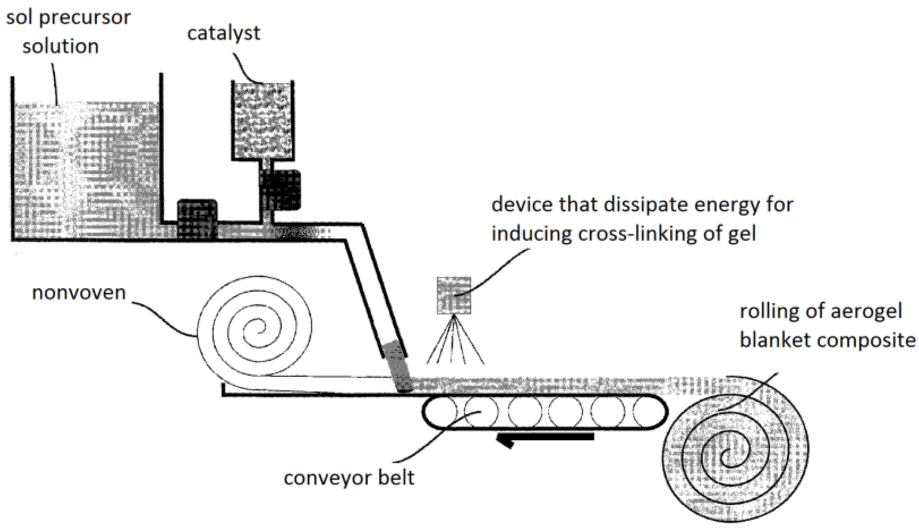



*Figure 1. Scheme of preparing a silica aerogel blanket [3]*

Aerogel blankets have conductivity value of about 14 mW/(mK) and are distinguished from pure silica aerogel by their good flexibility [4]. Commercial production of silicon aerogel blankets began around the year 2000. Mechanical and thermal insulating properties of aerogel blanket can be varied by the types of fibres, blanket thickness, additives such as soot and, metal powders etc.

Aerogel blankets are successfully used today in building and construction sector as an effective thermal insulation material. They can be effectively used in applications that require acoustic or infrared suppression, fire protection and thermal insulation.

NASA was the first to use pure aerogel patches for thermal insulation of space suits [5]. The use of silicon aerogel blankets for thermal insulation of clothing with up to ten times better thermal insulation properties in comparison to classic insulative materials should enable a much thinner insulative material for clothing to protect a human body in extreme temperature environments.

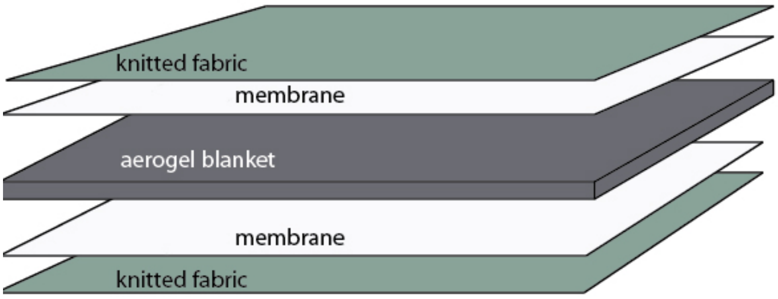
Hereinafter textile-technological properties of laminated aerogel blanket in order to assess its usefulness in clothing and other textile technical applications, like sleeping bags, tents, are presented etc.

## 2. METHOLOGY

### 2.1 Materials

For our research an aerogel blanket Spaceloft® 3251 (Aspen Aerogels, USA) was used where the silica aerogel was imbedded in a nonwoven from polyester microfibres.The silica aerogel blankets produced dust at handling, because the brittle silica aerogel crushed at bending. Fine dust is very oleophilic and gives an unpleasant feeling in contact with human skin. Because of this, aerogel blankets must be protected against the proliferation of dust into the surroundings when they are used in garments.

The silica aerogel blanket was laminated with pre-prepared laminate of monolithic breathable membrane Platilon® M2234 made from polyether block amide (PEBA) (Bayer Material Science Co., Germany) and fine warp knitted fabric made from polyester filament yarns. Lamination of silica aerogel blanket was made industrially in Zvezda SPT Kranj (Slovenia) in a hot melt gravure procedure by a dot bonding with a reactive polyurethane. The aerogel blanket was laminated on both sides (Figure 2) to get a 5-layered composite.



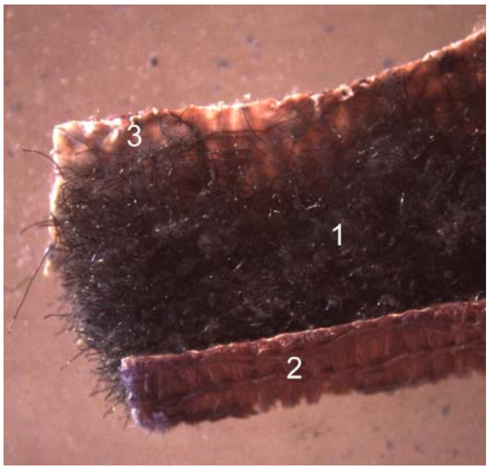




*Figure 2. Left: schema of a five layered laminated silica aerogel blanket and its stereomicroscope view: right: a cross section of laminated aerogel blanket: 1 – aerogel blanket, 2 – laminated knitted fabric with a membrane*

## 2.2 Methods

Morphological properties of materials were tested by stereomicroscope Leica EZ4 D (Leica Microsystems, Germany) and by a scanning electron microscope (Joel JSM-6060LV, Japan).

The following textile-technological properties were tested:

− thickness (ISO 5084 : 1996),
− mass per unit area (EN 12127 : 1999),
− moisture regain (ISO/TR 6741-4 : 1996),
− tensile properties (ISO 5081 : 1996) on strips of width 50 mm, with initial length of 100 mm, test speed 100 mm/min,
− stiffness (ASTM D 1388-64 method A : 1975): strip length 150 mm, strip width 25 mm,
− adhesion between aerogel blanket and a membrane (EN 15619 : 2008), and
− thermal conductivity ($\lambda_x$) was determined at conditions on a measuring device (Figure 3), where a heat flow through a sample and a reference plate with a known thermal conductivity ($\lambda_n$) was stationary. The sample together with three copper plates for measuring temperatures $T_1$, $T_2$ and $T_3$ and a glass reference plate of thickness $d_n$ = 4 mm was placed between the upper hot and lower cold metal cylinders. The upper cylinder and a copper plate ($T_3$) loaded the sample with a pressure of 5.39 kPa. Thermal conductivity was calculated by equation 1.

$$\lambda_x = \lambda_n \times \left(\frac{dx}{dn}\right) \times \left(\frac{T_2 - T_1}{T_3 - T_2}\right) (W/mK) \qquad (1)$$

*Figure 3. Device for measuring thermal conductivity*

## 3. RESULTS AND DISCUSSION

The silica aerogel blanket Spaceloft® 3251 is a flexible material of dark grey colour, with hydrophobic and oleophilic properties, thermal conductivity of 0.013 W/(mK) at 0 °C, and 0.016 W/(mK) at 100 °C [6]. It is made from nonwoven polyester microfibres with average diameter of 10 μm and the melting point at 236 °C. The grey colour of aerogel blanket originates from fibres and silica aerogel which contains small metal particles to reduce the influence of thermal radiation from the environment. Silica aerogel is a matrix component in the Spaceloft® 3251. It is brittle and prone to crushing (Figure 4).

Laminated silica aerogel blankets have been found to be easily cut, sewn and glued, similarly to nonwoven materials. During these processes aerogel dust always occurred. It was the dust put down around on working surfaces, from where we removed it effectively by suction. When handling aerogel blankets we always used a protective mask and also protective gloves, because silica aerogel dust is markedly oleophilic, quickly drying out the skin and causing unpleasant feelings.

The textile-technological properties of laminated silica aerogel blanket Spaceloft® 3251 and its components are presented in Table 1.

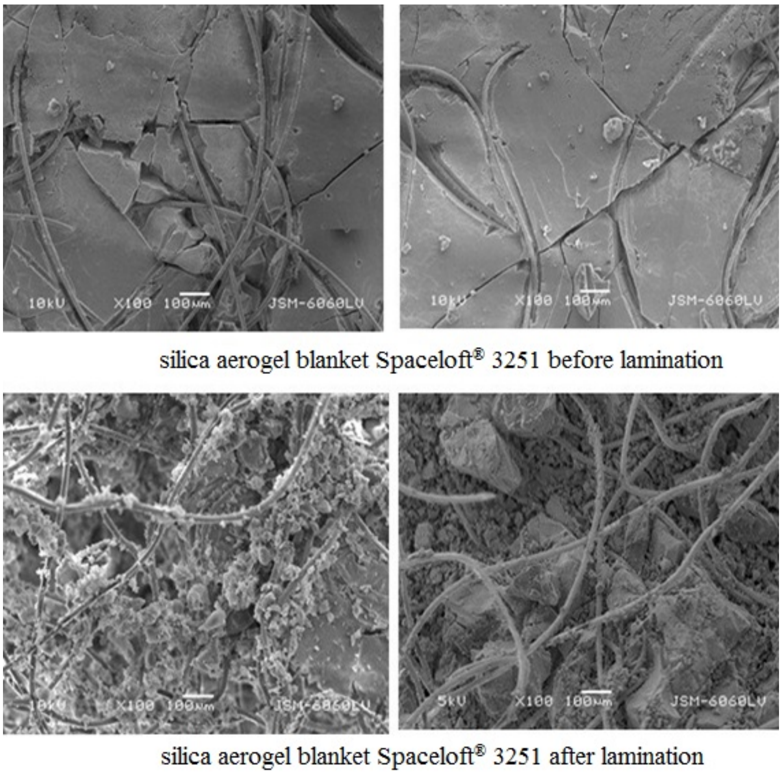



*Figure 4. Surface view of silica aerogel blanket with cracks before lamination (upper) and a much crushed structure of silica aerogel blanket after lamination and after removal of membrane with knitted fabric(lower)*

*Table 1. Textile-technological properties of 5-layered laminate of silica aerogel blanket silica aerogel blanket Spaceloft® 3251, laminated warp knitted fabric with a solid membrane and ofl*

| Properties | Laminated silica aerogel blanket | Silica aerogel blanket (from laminate) | Laminated knitted fabric with a membrane | Membrane |
|---|---|---|---|---|
| Density ($g/cm^3$) | 0.205 | 0.150 | 0.426 | 0.737 |
| Mass per unit area ($g/m^2$) | 616 | 402 | 106 | 25 |
| Thickness (mm) | 3.01 | 2.51 | 2.50 | 0.33 |
| Moisture regain (%) | 2.39 | 2.13 | 2.70 | 6.07 |
| Breaking force - longitudinal direction (N) | 319.6 | 13.8 | 134.9 | 6.0 |
| Breaking force - transverse direction (N) | 1037.1 | 14.4 | 251.9 | 5.2 |
| Breaking elongation - longitudinal direction (%) | 26.3 | 159.6 | 30.5 | 66.1 |
| Breaking elongation - transverse direction (%) | 23.5 | 107.1 | 18.6 | 69.5 |
| Bending length - longitudinal direction (cm) | 16.48 | − | 3.63 | 1.36 |
| Bending length – transverse direction (cm) | 28.58 | − | 4.49 | 1.03 |

The laminated silica aerogel blanket is a very light material with volume density of only 0.205 $g/cm^3$. At thickness of 2.51 mm the mass per unit area was amounted at only 616 $g/m^2$, which is appropriate for using in outerwear garments for personal protection in extreme cold environment conditions.

Thickness of nonlaminated aerogel blanket Spaceloft® 3251 was declared 3 mm, but in the laminate it amounts to 2.51 mm. In the lamination process the aerogel blanket was moved continuously between two heated rollers for applying thermoplastic adhesive. The rollers affected the blanket by certain compression and bending forces that caused a significant crushing of silica aerogel and partial softening of silica aerogel blanket. The technology that was used enabled only one-side lamination at once, so that the aerogel blanket had to pass between the rollers two times to be laminated on both sides. A nonwoven made from polyester microfibres embedded in silica aerogel could not relax either into the original positions and thickness after lamination process probably because the microfibres have very low modulus of elasticity. The attached silica aerogel on fibres also hindered their relaxation.

The membrane was used in particular to protect the laminated aerogel blanket against losses of silica aerogel dust that emerged at bending. The membrane keeps the laminated aerogel blanket water vapour permeable and water resistant. The used Platilon® membrane was also stretchable enough, mechanically resistant (Table 1) and impermeable for aerogel dust.

The silica aerogel blanket Spaceloft® 3251 is hydrophobic and also a very oleophilic material (Figure 5). At 21 °C and 85 % of relative humidity laminated silica aerogel blanket absorbed only 2.39 % of moisture.

Tensile properties of the laminated silica aerogel blanket (Table 1, Figure 6) are different in longitudinal and transverse directions as a result of anisotropic structure of laminate: almost 3-times higher breaking force in transverse direction than in longitudinal direction corresponds to a higher breaking force of knitted fabric in transverse direction in comparison to longitudinal direction. Silica aerogel blanket with a very low breaking force in both directions is a mechanically weak material which does not contribute much to the tensile properties of the laminate as a whole. Likewise, the tensile properties of laminate are not a simple sum of tensile properties of their components, because they are interconnected by thermoplastic adhesive.

The laminated aerogel blanket Spaceloft® 3251 is a highly rigid material especially in longitudinal direction (Table 1). In comparison to the laminated knitted fabric with a membrane, it has more than six times higher bending length in transverse direction and more than four times higher bending length in longitudinal direction.

Delamination force between laminated knitted fabric with a membrane and silica aerogel blanket was tested on a sample distance of 200 mm and is comparable for transverse and longitudinal directions (Figure 7). Adhesion was very good on one side of laminate only, while on the other side it was low and at some places there was even no adhesion. This means that the conditions of lamination were not appropriate.

water drops on silica aerogel blanket surface
oil drops on silica aerogel blanket surface

*Figure 5. Silica aerogel blanket Spaceloft® 3251 hydrophobic (left) and oleophilic (right) properties*

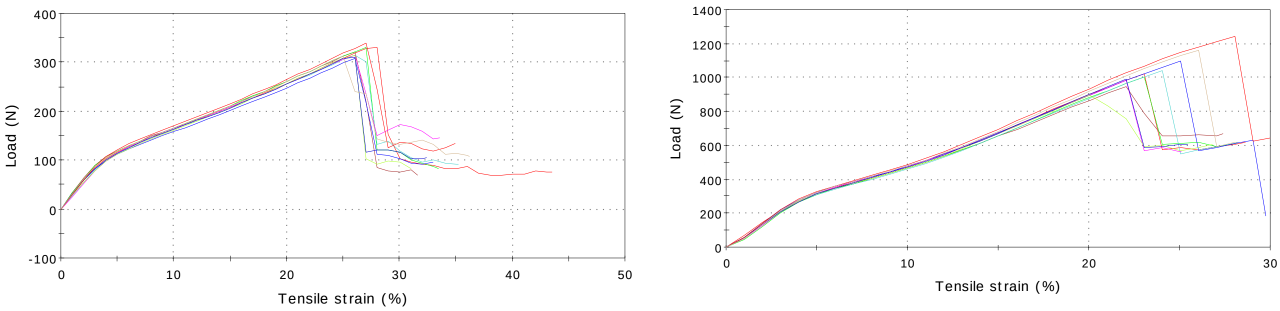



*Figure 6. Tensile diagrams of laminated silica aerogel blanket Spaceloft® 3251 in longitudinal (left) and transversal (right) directions*

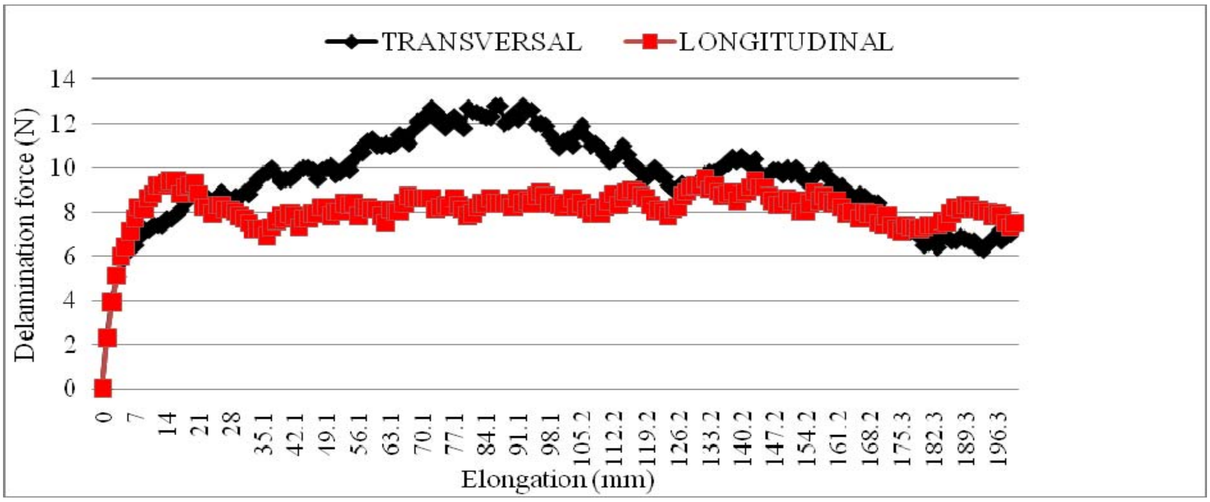



*Figure 7. Delamination force of laminated silica aerogel blanket*

Measured thermal conductivity of laminated aerogel blanket Spaceloft® 3251 was 0.0474 W/(mK). The value is more than twice higher compared to silica aerogel blanket. It is comparable to classic thermo insulative materials, such as Neoprene or Thinsulate.

## 4. CONCLUSSIONS

On the basis of the measured textile technological properties of laminated silicon aerogel composite Spaceloft® 3251 (Aspen Aerogels, Inc., USA) with a water vapour permeable membrane and polyester warp knitted fabric we have found out that the laminate has good mechanical properties and provides good thermal insulation. But the material is a bit too heavy and rigid to be used in clothing, which would make it uncomfortable; however, because the silica aerogel is inclined to crushing during use, this makes the clothes softer and more pleasant to wear.

For the usage of aerogel composite a proper selection of membrane and thermoplastic adhesive is the most important in order to limit spreading of aerogel dust into surroundings, which deteriorates the material handle and in particular its thermal insulation properties. The analyzed laminate is suitable for sleeping bags, protective coverings and seat covers of wheelchairs for winter conditions, etc.

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ТЕКСТИЛНО-ТЕХНОЛОШКЕ ОСОБИНЕ ЛАМИНАТА ПРЕКРИВАЧА ИЗ СИЛИКАТНОГ АЕРОГЕЛА

**Сажетак**: Прекривачи, израђени интегрисањем силикатног аерогела у нетканe текстиле, су суперизолациони и танки материјали, који се такође могу користити као технички и одјевни текстили. Текстилно-технолошке особине ламината прекривача, ламинираног мембраном, пропустљивом за водену пару, и полиестарском тканином, плетеном по основи су биле испитане. Ламинат, изграђен из пет слоја, показао је добре механичке карактеристике, отпорност на трљање, пропустљивост за водену пару, хидрофобност и липофобност, као и добру топлотну изолацију. Због велике тежине и крутости, израђени ламинирани материјал није примјерен за одијевање. Током коришћења, силикатни аерогел је био склон ломљењу и након одређеног времена је постао мекши и флексибилнији. Анализирани ламинат прекривача из силикатног аерогела је прикладан за техничке текстиле, попут врећа за спавање, за флексибилне заштитне покриваче, попут спољашњих јастука, за јастуке на инвалидским колицима у зимским условима, итд.

**Кључне ријечи**: силикатни аерогел, ламинат прекривача из силикатног аерогела, одјећа.