AeroZero® Thermal Protection Systems (AZ-TPS) for Aerospace and Defense Transient Thermal Events (TTE)

Executive Summary

- AeroZero® TPS (AZ-TPS) are thin (often <200 um), lightweight thermal protection systems that significantly increase the working temperature of plastic and metal aerospace parts.
- AZ-TPS protected PEEK from up to 300 °C (572 °F) constant temperature heat exposure in this analysis by reducing the PEEK temperature more than 220 °C (>400 °F).
- Extended recovery time between transient thermal events significantly further extends the protection provided by AZ-TPS.
- AZ-TPS and AeroZero film have achieved a UL94 VTM-0 classification, the highest-level flame retardancy rating that can be obtained for thin films.

Background

AeroZero® is a thin, polyimide aerogel film that is used as the primary insulator in AeroZero Thermal Protection Systems (AZ-TPS) in aerospace and defense applications. AeroZero is a flexible, durable film with 85% porosity produced at 165 microns (0.0065 in, 6.5 mil) thickness and provides the thermal insulation, RF transparency, dielectric properties, and lightweight benefits of an aerogel with the ease of use and mechanical strength of a plastic film. AeroZero is an aromatic polyimide aerogel, and polyimides are widely accepted and used in aerospace and defense applications due to their exceedingly high thermal stability, excellent chemical resistance, and robust mechanical properties.

The unique combination of low thermal conductivity and diffusivity, high heat tolerance, ultra-low dielectric properties, high strength-to-density ratio – all in a very thin profiles combine to make AZ- TPS preferred options for demanding aerospace and defense thermal management applications, especially those with Transient Thermal Events (TTE). As a result, AZ-TPS have become essential solutions for product developers with challenging temperature control in limited spaces.

AeroZero film is manufactured using Blueshift's highly efficient, state-of-the-art polyimide aerogel production equipment, SP-1, which is the first in the world and incorporates emission controls and in-line solvent recycling. AeroZero film is combined with functional adhesives and protective films such as polymer films and metal foils to produce AZ-TPS.

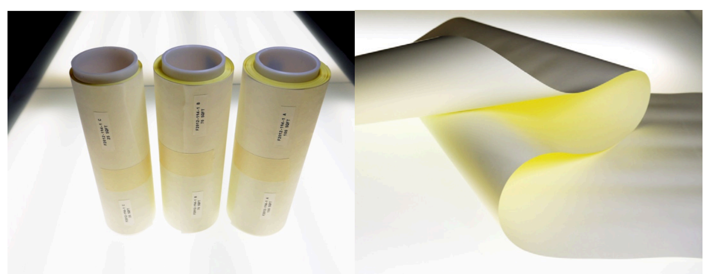

FIGURE 1
Left: Rolls of AeroZero polyimide aerogel film produced in continuous rolls in Massachusetts, USA. **Right:** Closeup of AeroZero film unrolled.

AZ-TPS are installed in aerospace and defense systems when challenging temperature or space restrictions exist that impede the use of legacy insulators. AZ-TPS are ideal for hot spot elimination and control of heat flow within confined spaces. AZ-TPS are the first Thermal Protection Systems (TPS) in the world that are manufactured in continuous rolls from polymer aerogels, and cut to shape in Blueshift's fabrication plant in central Massachusetts, USA. They are designed for high heat and tight space applications, most of them having less than 1 mm of available head space.

AZ-TPS consists of one or more layers of AeroZero with thickness 165 microns bonded with a 25 micron thick layer of silicone pressure sensitive adhesive (PSA). AZ-TPS Type 1 (single layer AeroZero) and AeroZero film both received a UL94 VTM-0 classification, the highest-level flame retardancy rating that can be obtained for a thin film.

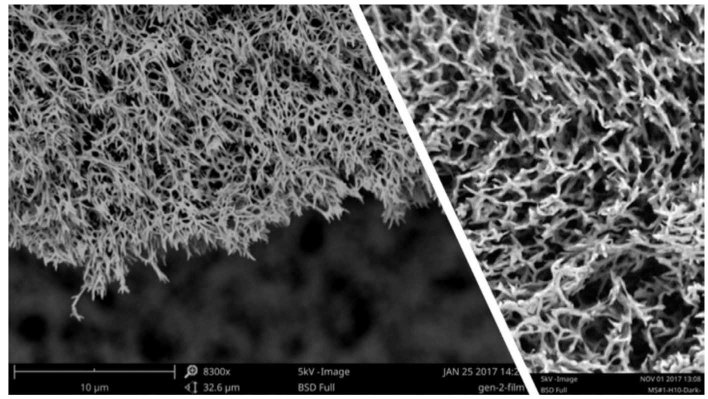

FIGURE 2
SEM image showing nanoporous structure.

Thermal Properties Defined

Thermal Conductivity:[1] The thermal conductivity λ , of a material is a measure of its ability to conduct heat under steady state conditions. Heat transfer occurs at a lower rate in materials of low thermal conductivity than in materials of high thermal conductivity. For example, metals typically have relatively high thermal conductivity and are very efficient at conducting heat, while the opposite is true for insulating materials like engineering plastics and foams. Correspondingly, materials of high thermal conductivity are widely used in heat sink applications, and materials of low thermal conductivity are used as thermal insulation. The reciprocal of thermal conductivity is thermal resistivity.

For simple applications, Fourier's law of thermal conduction (Eqn 1) shows that local heat flux, ***q***, is equal to the product of thermal conductivity, λ , and the negative local temperature gradient (***T2 - T1***) in one direction, ***x***. The heat flux is the amount of energy that flows through a unit area per unit time.

Eqn. 1. Fourier's Law of Thermal Conduction, describing thermal conductivity, λ :

$$q = -\lambda \frac{T_2 - T_1}{L}$$

The thermal conductivity is often treated as a constant, though this is not always true. While the thermal conductivity of a material generally varies with temperature, the variation can be small over a significant range of temperatures for some common materials. In anisotropic materials, the thermal conductivity typically varies with orientation.

Thermal Diffusivity:[23]
The thermal diffusivity, α, of a material is the thermal conductivity divided by density and specific heat capacity at constant pressure (Eqn. 2). It measures the rate of heat transfer of a material by conduction during changes of temperature.

The higher the thermal diffusivity, the faster the heat propagation, because the substance conducts heat quickly relative to its specific heat capacity or 'thermal bulk'.

A very effective method used for measuring thermal diffusivity of high thermally conductive solids is the flash method. This transient technique features short measurement times, is non-destructive, and provides values with excellent accuracy and reproducibility. The flash method involves uniform irradiation of a small, disc-shaped specimen over its front face with a very short pulse of energy.

In the flash method, the time-temperature history of the rear face of the sample is recorded through high-speed data acquisition from an optical sensor with a very fast thermal response. Based on this time-dependent thermogram of the rear face, the sample's thermal diffusivity, α, is determined from the thickness (L) of the sample and the time the thermogram takes to reach half of the maximal temperature increase ($t_{1/2}$).

Specific Heat Capacity:[4] In thermodynamics, the specific heat capacity, c_p, of a substance is the heat capacity of a sample of the substance divided by the mass of the sample. Informally, it is the amount of energy that must be added, in the form of heat, to one unit of mass of the substance in order to cause an increase of one unit in temperature.

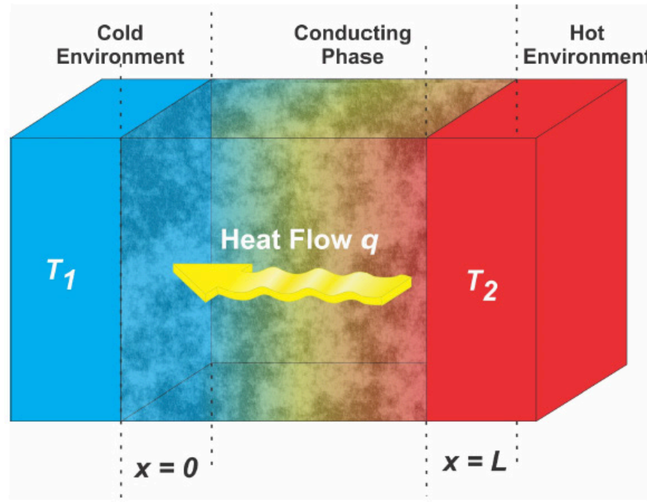

FIGURE 3
Heat flow from hot to cold environments.

Eqn. 2. Definition of Thermal Diffusivity, α, where α is the thermal diffusivity, λ is the thermal conductivity, ρ is the density, and c_p is the specific heat capacity.[2,3]

$$\alpha = \frac{\lambda}{\rho \cdot c_p}$$

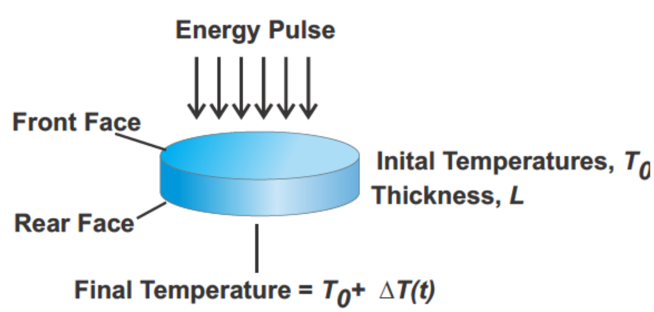

FIGURE 4
Flash method for directly measuring thermal diffusivity.[2,3]

How Does AeroZero® Compare?

A powerful tool for helping in materials selection is offered by the Ashby plot.[5] This is a scatter plot displaying two or more properties of materials or classes of materials. These plots are convenient because they provide useful information not only on which material displays the highest (or the lowest) property, but also the ratio between the two properties.

In the example Ashby plot below, the thermal conductivity and thermal diffusivity of several classes of materials are plotted. For applications requiring thermal insulation, materials having especially low values for both properties are most desirable. Various polymers, elastomers and foamed materials generally provide these properties, with AeroZero providing an ideal combination of both properties.

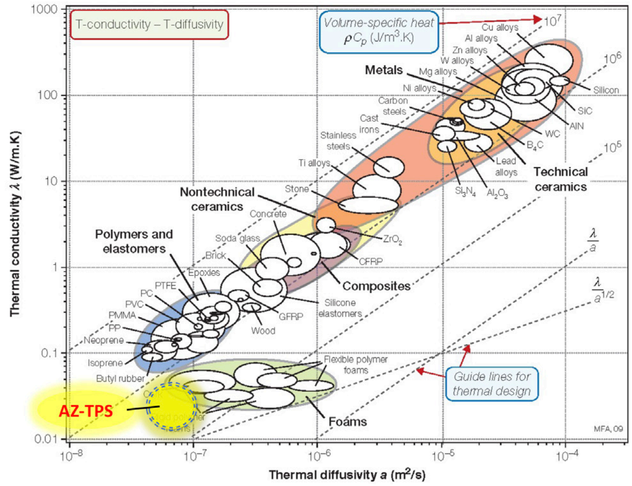

FIGURE 5
AeroZero thermal properties plotted on the Ashby Thermal Conductivity-Thermal Diffusivity Chart[6]

In another representative Ashby plot, the thermal expansion and thermal conductivity of several classes of materials are plotted. Similarly, for applications requiring dimensional stability while also providing superior thermal protection, AeroZero is a preferred option.

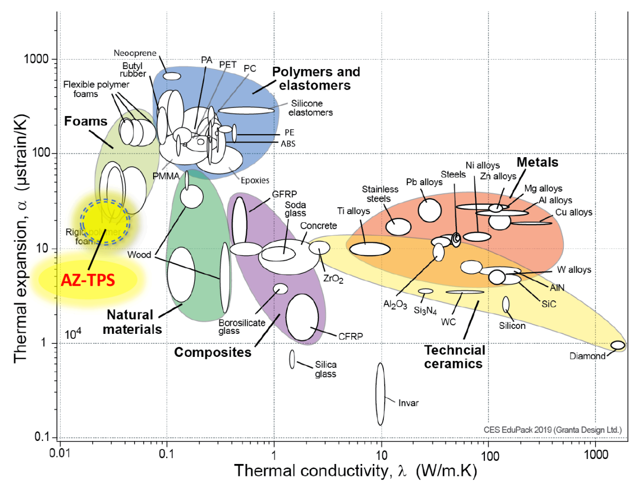

FIGURE 6
AeroZero thermal properties plotted on an Ashby Thermal Expansion-Thermal Diffusivity Chart[7]

Case Study: AZ-TPS Thermal Protection of PEEK, Cyclic Heating 500 °C, with a 30-Second Recovery.

Application Profile

This application represents the insulation properties of Blueshift materials shielding a common aluminum surface. The infinitely thick aluminum substrate is protected by AZ-TPS consisting of one, two, or three layers of Blueshift AeroZero® material, each layer with a thickness of 165 microns. The AeroZero film(s) are bonded to each other with a 25-micron layer of silicone pressure sensitive adhesive (PSA), and also bonded to the aluminum with a 25-micron-thick layer of silicone PSA.

Methodology

For the same layer configuration as the other cases, a series of 3 thermal pulse cycles is applied, each lasting 5 seconds at 500 °C, then resting for an extended period of 30 seconds before the next pulse. The temperature at the topmost surface of the PEEK substrate is monitored throughout the thermal pulses to determine the rate and extent of temperature rise. The results are plotted in **FIGURE A.**

Result

While a relatively small increase in maximum temperature occurs between cycles at the PEEK/PSA interface, in part due to the extended recovery time between cycles, the AZ-TPS maintains the temperature significantly below the thermal load. For a 500 °C (932 °F) load, the maximum temperature reached after 3 cycles is only 156 °C (313 °F), an indication that a single layer of AeroZero is providing nominally 344 °C (619 °F) of protection from the initial thermal load.

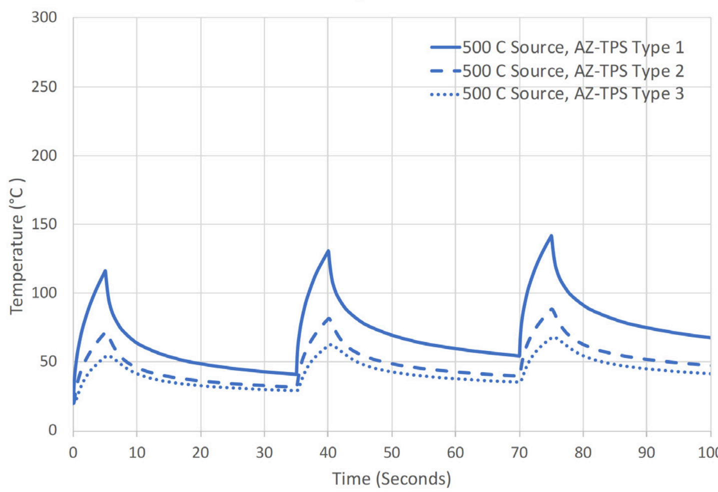

FIGURE A

Temperature as a function of time for PEEK substrate protected by AZ-TPS Type 1 subjected to cyclic 500 °C pulse loads with 30 seconds recovery time between pulses.

Takeaways

During repeated heating / cooling thermal cycles and transient thermal events, AZ-TPS provides continued thermal protection of the substrate.

Blueshift products are manufactured under a certified AS 9100D/ ISO 9001:2015 Quality Management System facility.
See our website for more information on Blueshift products.

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