Defense Systems Information Analysis Center

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Research Into and Availability of Flexible Thermal Protection System (TPS) Materials

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A chief service of the DoD IACs is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry jointly conducted by DSIAC.

ABSTRACT

The Defense Systems Information Analysis Center received a technical inquiry requesting information on research into and availability of flexible thermal protection system materials. Materials engineering subject matter experts at the Texas Research Institute Austin, Inc. performed literature searches using the Defense Technical Information Center, open sources, and university libraries to provide a listing of the efforts to produce these material systems (mostly sponsored by the National Aeronautics and Space Administration) and identified several options in varying degrees of development and technology readiness levels.

Contents

List of Figures

1.0 TI Request

1.1 INQUIRY

What type of flexible hypersonic thermal protective materials have been researched and are available that are capable of surviving high-temperature, high-Mach environments to enable variable geometry hypersonic aircraft?

1.2 DESCRIPTION

The inquirer authored a Small Business Innovative Research topic pertaining to this and wanted to become familiar with previous efforts/research related to this discipline. Achieving the desired capabilities would enable variable geometry hypersonic vehicles to perform in-flight adaptation of aircraft aerodynamic surfaces in compliance with the most efficient shapes for each flight regime.

2.0 TI Response

The Defense Systems Information Analysis Center received support from subject matter experts (SMEs) in materials science and engineering from Texas Research Institute Austin (TRI Austin). The SMEs performed a literature search using a combination of open sources, Defense Technical Information Center, and university library resources to produce an answer to the technical inquiry.

2.1 AVAILABLE AND RESEARCHED FLEXIBLE TPS MATERIALS

The challenge associated with the requestor's technical inquiry is identifying a material or material system with elastic properties. Generally, materials that can stretch significant amounts are intolerant of high temperatures. As an example, carbon nanotubes are very strong and can withstand extreme temperatures but will break at only 1% elongation.

With that in mind, several potential candidate materials were identified that may warrant further investigation (note: almost all this work appears to be funded by NASA as part of their space program or hypersonic, point-to-point transportation initiatives).

2.1.1 NASA Thermal Blanket Material

The National Aeronautics and Space Administration (NASA) Langley has developed a flexible, lightweight, and portable TPS [1]. The flexible TPS's are multilayer thermal blankets designed to handle external temperatures of up to 2000 °F. Flight tests clearly demonstrate how these new heat-retardant materials can protect from extreme conditions. This system creates an environment for protecting equipment, facilities, and people from a high-intensity incident heat source, such as a fire. The system can be formed as a sleeping bag, a tent, a blanket, a vertical barrier, a curtain, a flexible rollup doorway, or a wrap.

This material likely does not have much strength, since it is a layered material, but the addition of carbon fiber cloth could be added to strengthen it. Such a modification might be possible to modify the construction of the material to meet requirements.

2.1.2 Ceramic Aerogels

A research group of scientists from universities in the United States, Saudi Arabia, and China reported on modifying ceramic aerogels for use as more flexible thermal insulators [2]. Ceramic aerogels are attractive for thermal insulation but have poor mechanical stability and degrade under thermal shock. The researchers designed and synthesized hyperbolic architecture ceramic aerogels with nanolayered, double-pane walls with a negative Poisson's ratio and a negative linear thermal expansion coefficient. The results were mechanical and thermal, with densities of ~0.1 mg/cm^3, superelasticity up to 95%, and near-zero strength loss after sharp thermal shocks (275 °C/s) or intense thermal stresses at 1400 °C, as well as a thermal conductivity of ~2.4 mW/m·K in vacuum and ~20 mW/m·K in air. This material offers an alternative to polymeric and carbonaceous insulating materials that can collapse or ignite to traditional aerogels, such as silica (SiO_2), alumina (Al_2O_3), silicon carbide (SiC), and boron nitride (BN), all of which have poor mechanical stability.

2.1.3 Grafoil

David Glass of NASA produced a paper in 2008 describing the use of ceramic matrix composites for use as a TPS in a hypersonic vehicle [3]. From this work, it is clear that there are no simple answers regarding high-temperature materials that are also elastic. There is at least one commercially-available form of flexible graphite called Grafoil.

Grafoil (produced by GrafTech) is a soft sheet form of compressed natural graphite made from exfoliated mineral flake (crystalline) graphite. Due to its flexible texture, it is commonly called flexible graphite (a generic, commercial term). Grafoil flexible graphite is used as a fluid sealing material and is resistant to heat, fire, corrosion, and aggressive chemicals. Since the graphite sheets are aligned, this material has thermal properties similar to graphite but is very flexible and can be formed into shapes.

2.1.4 HIAD Program using Polyimide

Previous work at NASA under the hypersonic inflatable aerodynamic decelerators (HIAD) project developed and tested polyimide aerogel films, which were found to compare favorably to pyrogel silica, aerogel blankets [4]. With material from the HIAD program, Figure 1 shows how an inflatable TPS allows a larger heat shield to be packed into a rocket fairing via the use of flexible polyimide material.

Ground testing for the HIADs was last done in 2017 [5], and the last update for the HIAD-2 project on NASA's website was in 2017. The current state of the program is unknown—a flight test had been planned for the 2018–2020 timeframe, but no information is available in public-released documents, and there is no indication that these tests moved forward to actual launch.

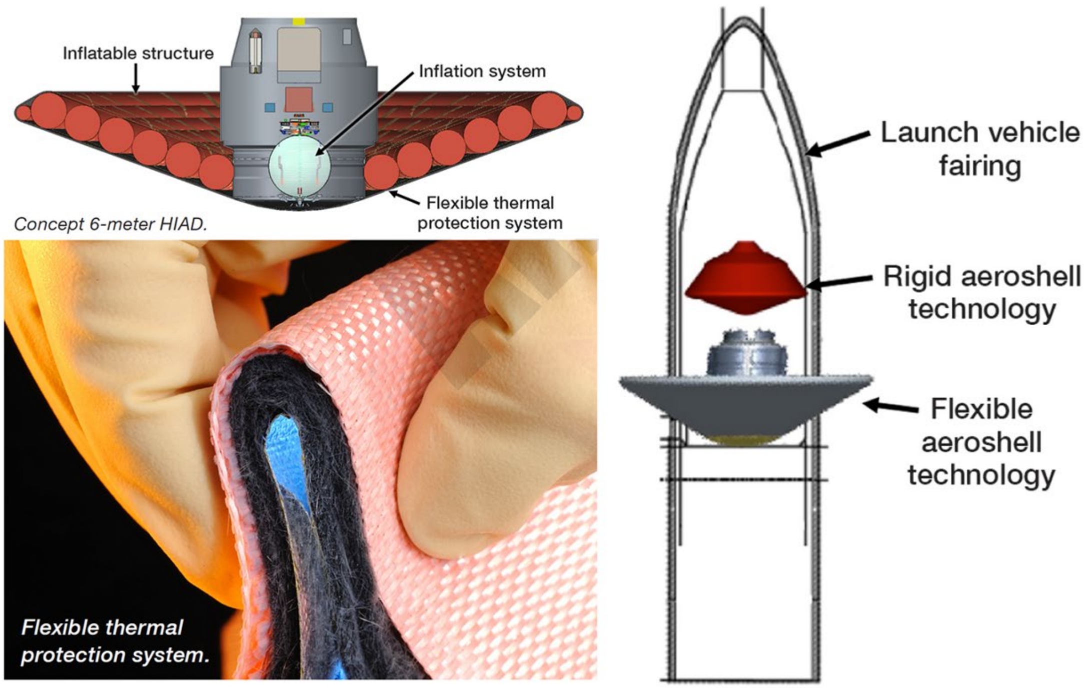

Figure 1: An Inflatable TPS Packing a Heat Shield Into a Rocket Fairing *(Source: NASA).*

2.1.5 Hypersonic Gap Filler Materials

In support of NASA's Orion program, materials currently under development include felt or woven material precursors impregnated with polymers (i.e., PICA), additives to improve ablation and insulating performance, and the block form of Avcoat ablator. The ideal binder would be a flexible, low glass transition temperature polymer with a high decomposition temperature/char yield (comparable to phenolic) and a high (>1%) strain to failure compatible with cured epoxy, phenolic, and/or cyanate ester. Scientists produced a novel copolymer elastomer that has a very low glass transition (≤100 °F) and a decomposition temperature on par with typical phenolic ablatives. This resin can be highly filled to tune ablative properties and is compatible with glass and carbon fabric substrates [6].

2.1.6 Knitted TPS

Another potential NASA technology is the use of a knitted TPS (Figure 2) that could potentially be used to form three-dimensional (3-D) and integrated structures. One example listed is that internal struts could be knitted directly into a two-dimensional (2-D) face sheet, making the joint an integral part of the structure. Ablative thermal protection materials made from carbon fiber substrates impregnated with resin, especially phenolic, and various other components have and are being developed for demanding atmospheric entries. The carbon fiber can be short or chopped fiber arranged in a rigid (e.g., FiberForm) or flexible substrate (felts) or woven into 2-D or 3-D structures. Introducing other fibers to make graded or tailored microstructures is being investigated in a current Office of the Chief Technologist program.

Figure 2: Image of Knitted TPS Material With a Cutout for a Fastener Pass-Through ***(Source: NASA).***

An alternative way to form the substrate and place fibers at exact locations to control local properties is through knitting. Knitted fabrics are much more elastic than woven fabrics and can stretch up to 500%, depending upon the yarn and pattern. Knitted fabrics will drape and fit a form, and knitting can be used to shape a part and introduce holes and tabs. Initiating other fibers in sections or by the stitch is well known. Commercial knitting companies can make complex structures from a variety of yarns.

The field of textile technology has developed many techniques and model structures that could be adapted for developing thermal protection systems, including 3-D and graded structures. From this, NASA discussed how it should be possible to form a thermal protection material by infiltrating phenolic or other polymers and/or additives into the knitted carbon structure. Infiltration techniques developed for rigid and other preforms would be modified for these structures. The advantage of the proposed technique is the ability to make a thermal protection system that can be shaped in advance but has the flexibility to conform to complex shapes. The approach will reduce joints and seams. This project was last updated on NASA's website in 2012 and is at a technology readiness level of 2 [7].

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