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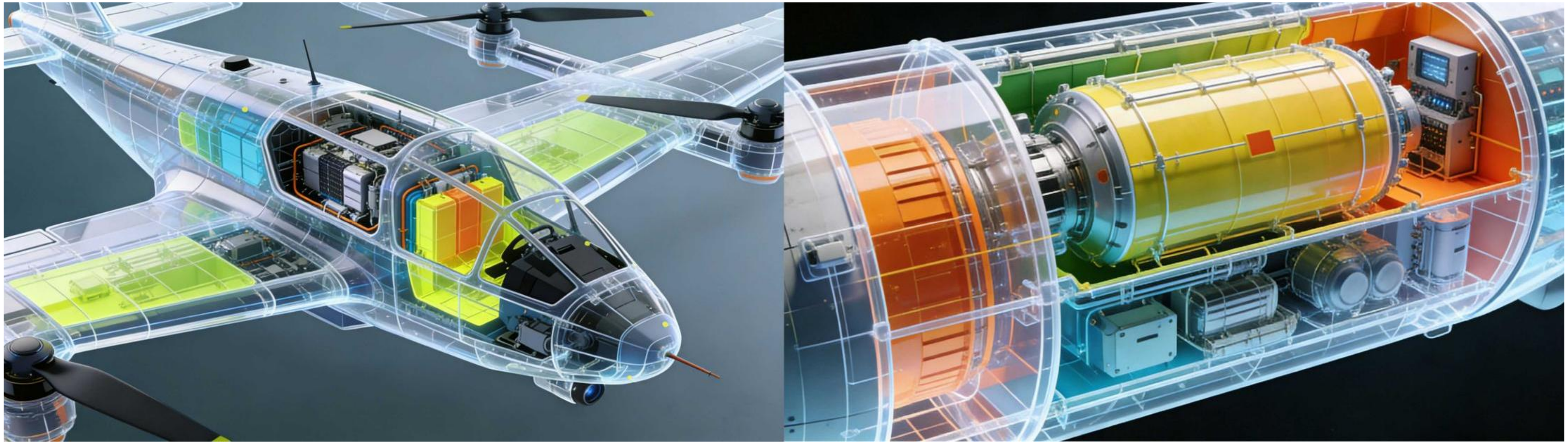
High-Silica Fiberglass Yarn for Thermal and Electrical Insulation in Aerospace and UAV Applications

Abstract

This technical article explores the application of high-silica fiberglass yarn (HSF, $SiO_2 \geq 96\%$) as a critical material for thermal and electrical insulation in aerospace and unmanned aerial vehicle (UAV) systems. The analysis focuses on non-propulsive components, specifically power compartments and internal/external structural insulation. A comparative assessment against aramid and carbon fibers is presented, evaluating key parameters such as operational temperature, dielectric strength, mechanical strength, density, and cost-effectiveness. Material selection matrices are proposed for various operational scenarios.



Power compartments and internal/external structural insulation of aerial vehicle

1. Introduction

Modern aerospace and UAV design demands lightweight, reliable, and high-performance insulation materials to protect sensitive avionics, battery systems, and structural components from extreme thermal and electrical environments. High-silica fiberglass yarn emerges as a versatile candidate, balancing excellent thermal resistance with inherent electrical insulation properties.

2. Application Scenarios and Operational Requirements

2.1 Power Compartment/Battery Bay Insulation:

Primary Function: Contain thermal runaway events, prevent heat propagation to adjacent structures, and provide electrical isolation.

Key Requirements: High temperature resistance (short-term exposure up to 1000-1200°C), excellent dielectric strength, low thermal conductivity, and flame retardancy.

Operational Environment: Potential for rapid temperature spikes, presence of high-voltage components.

2.2 Internal Structural & Avionics Bay Insulation:

Primary Function: Shield flight control computers, wiring harnesses, and sensors from ambient heat (e.g., from skin friction, engine bay radiant heat).

Key Requirements: Continuous operating temperature resistance (~500-700°C), effective thermal barrier, vibration damping, and low out-gassing.

Operational Environment: Moderate but sustained temperatures, need for long-term reliability.

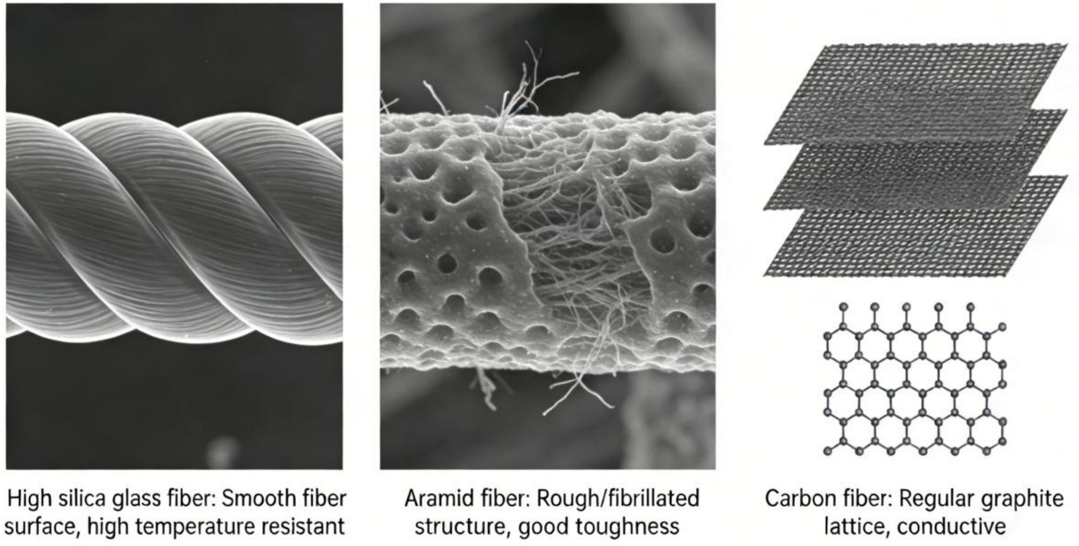
2.3 External Non-propulsive Insulation:

Primary Function: Protect composite air-frames from aerodynamic heating, exhaust plume impingement (for UAVs with rear-mounted engines), and lightning strike effects.

Key Requirements: Good mechanical abrasion resistance, weathering stability, combined thermal and electrical insulation, and adhesion to composites.

Operational Environment: Exposure to varying atmospheric conditions, UV radiation, and potential mechanical wear.

3. Material Performance Comparison



Micro structure of HSF yarn, Aramid fiber and Carbon fiber

The following table compares the fundamental properties of High-Silica Fiberglass (HSF), Aramid, and Carbon Fiber relevant to insulation applications.

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The fundamental properties of High-Silica Fiberglass (HSF), Aramid, and Carbon Fiber

Property	**High-Silica Fiberglass (HSF)**	**Aramid (e.g., Kevlar®)**	**Carbon Fiber**
Max Continuous Use Temp.	**~1000° C**	~250-350° C	~400-500° C (in inert atm.)
Short-Term Peak Temp.	**Up to 1200° C**	Degrades above 450° C	Oxidizes above 500° C
Dielectric Strength	**Excellent (High Insulator)**	Good	**Conductive (Not an Insulator)**
Tensile Strength	Good	**Excellent**	**Exceptional**
Density	~2.2 g/cm³	~1.44 g/cm³	~1.6-1.8 g/cm³
Thermal Conductivity	**Very Low**	Low	High (along fiber axis)
Primary Advantage	**Best combined high-temp & electrical insulation**	Best mechanical toughness & impact resistance	Best stiffness & strength-to-weight
Key Limitation	Brittle compared to aramids	Poor UV & high-temp stability	Electrically conductive, oxidizes at high temp

Remark：The data is based on Lab testing conditions, the adjustment shall be done as per application environment

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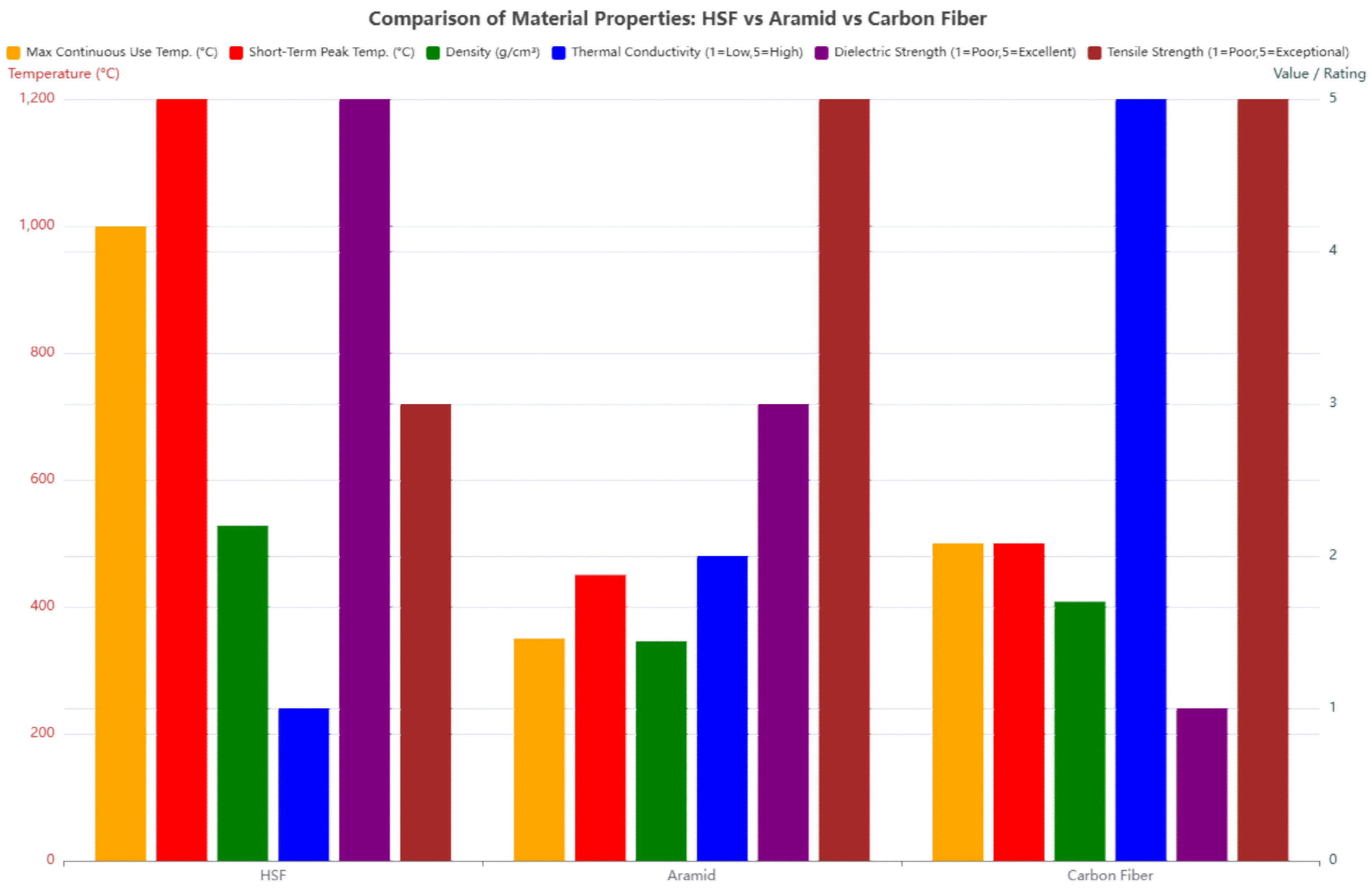
Chart of HSF, Aramid fiber and Carbon fiber



4. Material Selection Strategy and Hybrid Solutions

Selection is driven by the primary threat (heat, electricity, impact) and specific location requirements.

Scenario A: High-Temperature Electrical Insulation (e.g., Power Busbars, Battery Module Separators)

Threat: High voltage + potential arc flash / thermal event.

Solution: HSF Alone. Its superior and stable dielectric strength at elevated temperatures is unmatched. Neither aramid (lower temp limit) nor carbon (conductive) are suitable as primary insulators here.

HSF yarn application for thermal and electric insulation

Scenario B: Impact-Resistant Thermal Barrier (e.g., Insulation near landing gear bays, access panels)

Threat: Mechanical abrasion/vibration + moderate heat.

Solution: Aramid Alone or Aramid/HSF Hybrid. Use aramid fabrics where toughness is paramount below 350°C. For higher temperatures, a hybrid fabric with an aramid base for strength and an HSF surface layer for thermal protection can be optimal.

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Compatible Component List for Aramid Impact & Thermal Barrier

Component	Temperature Range	Primary Application	Structural Suggestion
Engine Nacelle / Pylon Thermal-Acoustic Insulation Liner	≤ 250° C	Impact resistance, thermal insulation, noise reduction	Aramid fabric + flame-retardant matrix, layered composite
Fuselage / Wing Leading Edge Bird Strike & Thermal Protection Layer	≤ 200° C	Impact resistance, anti-icing, thermal insulation	Aramid fabric sandwich, co-bonded/cocured with skin
Cabin Firewall / Thermal Barrier	≤ 200° C	Fire containment, thermal insulation, impact resistance	Aramid non-woven / fabric + flame-retardant adhesive film
Rocket Body Cryogenic & Impact Protection Layer	-196° C to 200° C	Cryogenic toughness, impact resistance, thermal insulation	Aramid fabric + cryogenic-compatible matrix

Aramid Impact-Resistant Thermal Barrier

Scenario C: Structural Heat Shield with Stiffness Requirement (e.g., External heat shield on a UAV pylon)

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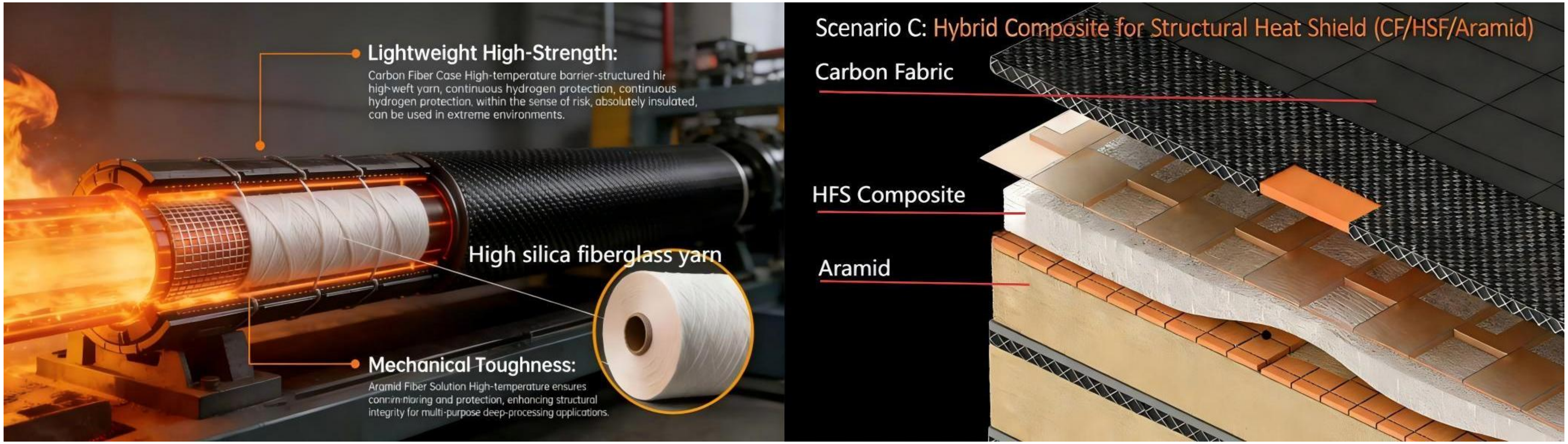
Threat: Aerodynamic heating + need for structural rigidity.

Solution: Carbon Fiber/HSF Composite. A laminate with carbon fiber providing structural stiffness and an HSF layer as the thermal barrier. This separates the load-bearing function from the insulation function efficiently. Note: An insulating layer must separate carbon from any electrical components.



Hybrid Composite of HSF/Aramid fiber/Carbon fiber

Scenario D: Lightweight General Thermal Blanket (e.g., Avionics bay wrap, wire loom protection)

Threat: Radiant and convective heat, need for flexibility and low mass.

Solution: HSF Alone. Offers the best balance of high-temperature capability, low thermal conductivity, and electrical safety in a lightweight, flexible fabric form.

5. Conclusion

High-silica fiberglass yarn is not a universal replacement for aramid or carbon fiber but a specialized material that excels in the niche where **high-temperature resistance and electrical insulation are simultaneously required.** In aerospace and UAV insulation design:

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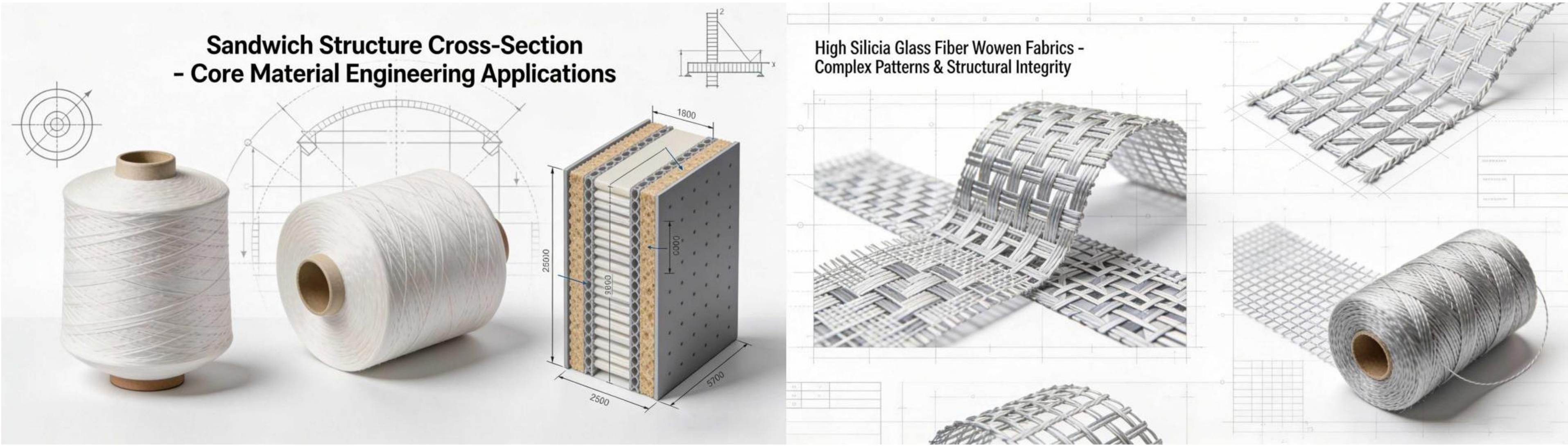

High silica yarn, fabric and composite

HSF is the **default choice for primary thermal-electrical insulation** in power systems and high-temperature zones.

Aramid is selected where **impact resistance and toughness** are critical at lower to moderate temperatures.

Carbon Fiber is integrated into **structural heat shields** where stiffness is a driver, but always paired with an insulating layer like HSF.

The future lies in engineered **hybrid composites** (e.g., HSF/aramid weaves, HSF as a core in carbon sandwich panels), which allow designers to tailor material systems to meet the multifaceted demands of next-generation aerospace vehicles, optimizing for weight, performance, and safety.

Technical Terminology Clarification: Silica Fiberglass vs. Silica Yarn

Silica Fiberglass vs. Silica Yarn: Material vs. Product Form

Comparison Dimension	Silica Fiberglass	Silica Yarn (High-Silica Yarn)
Core Definition	**Base Material Category**. Refers to any glass fiber with silica (SiO_2) as the main component (>50%).	**Finished Product Form**. Specifically refers to **continuous yarn** made from **high-purity silica fibers** (SiO_2 ⩾ 96%) via twisting/plying processes.
Composition & Process	Broad composition range (e.g., E-glass: ~52-56% SiO_2, C-glass: ~65%). Made by melting and drawing.	**High-purity specific**. Made by **acid-leaching** special glass fibers to remove metal oxides, boosting SiO_2 to **96%-99%+**, then spun into yarn.
Performance Focus	Properties vary by type: • **E-glass**: General purpose, good insulation & strength. • **C-glass**: Acid-resistant. • **S-glass**: High strength/modulus.	**Performance optimized for extreme conditions**: • **Ultra-high temp resistance** (1000° C+ continuous). • **Minimal thermal conductivity** (superior insulation). • **Excellent dielectric strength**. • **High chemical stability** (except HF/strong alkalis).
Physical Form	**Primary forms**: • Continuous rovings • Chopped strands • Woven fabrics/mats (made from rovings)	**Specific yarn form**: • Singles or plied yarns • Defined yarn count (Tex, Denier) • Ready for weaving, knitting, sewing

Comparison Dimension	Silica Fiberglass	Silica Yarn (High-Silica Yarn)
Primary Applications	**Wide-ranging, as reinforcement/functional material**: • Composite reinforcement (FRP) • Insulation substrate • Filtration media • Building insulation wool	**Focused on high-end insulation**: • High-temp industrial blankets/sleeves • Firefighting gear, curtains, blankets • Aerospace thermal protection • High-temp sealing/wrapping
Analogy	Like **"Steel"** – a broad material category with many grades.	Like **"Stainless Steel Wire of a specific grade"** – a finished product form for specific applications.

Key Takeaways:

HSF vs. Aramid/Carbon: HSF excels where **both extreme heat resistance and electrical insulation** are required simultaneously. It is not a direct replacement but a specialized solution.

Material vs. Product: **"Silica Fiberglass"** is the general material name. **"Silica Yarn"** (or **"High-Silica Fiberglass Yarn"**) refers specifically to the high-purity, yarn-form product ready for demanding insulation applications. In aerospace contexts, the latter is typically the subject of discussion.

Note on UAV Terminology:
In this article, **"UAV" (Unmanned Aerial Vehicle)** is used as the standard technical term within the aerospace industry, emphasizing the vehicle as a complete system. Other common terms include "Unmanned Aircraft" (formal/regulatory) and "Drone" (general/public).

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