Supporting Information

High-Silica Fiber Felt/Ti_3SiC_2 Reinforced Phenolic Aerogel Composites for High-Temperature Thermal and Mechanical Performance

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Table S1 Compressive strength retention at 10% strain (x=0, 25, 50 ,75)

Ti_3SiC_2 (wt%)	Compressive strength (MPa)		Compressive strength retention rate (%)
	HS/FRF-x	HS/C-x	
0	1.330	0.180	13.55
25	1.809	0.348	19.24
50	2.436	0.554	22.75
75	2.747	0.972	35.40

Table S2 Toughness of HS/FRF-x and HS/C-x at 10% strain (x=0, 25, 50 ,75)

Ti_3SiC_2 (wt%)	Toughness ($MJ \cdot m^{-3}$)	
	HS/FRF-x	HS/C-x
0	0.0671	0.0082
25	0.0870	0.0150
50	0.1078	0.0244
75	0.1227	0.0618

Table S3 HS/FRF-x compressive strength and thermal conductivity percentage increase relative to HS/FRF-0 (x=0, 25, 50 ,75) and specific compressive strength of HS/FRF-x at 10% strain

Samples	**Compressive strength /MPa**	**Strength percentage increase**	**Thermal conductivity /($W \cdot m^{-1} \cdot K^{-1}$)**	**T.C. percentage increase**	**Specific compressive strength ($N \cdot m/g$)**
HS/FRF-0	1.330	-	0.0414	-	3.344
HS/FRF-25	1.809	35.9%	0.0644	55.8%	4.671
HS/FRF-50	2.436	83.1%	0.0938	126.7%	4.529
HS/FRF-75	2.747	106.4%	0.1017	145.9%	4.367

Key findings:

- Non-linear enhancement characteristics: The improvement in mechanical properties exhibits a diminishing marginal trend (the increment from 25→50 wt% is 47.2%, while that from 50→75 wt% is only 23.3%). In contrast, the increase in thermal conductivity continuously accelerates, indicating that the "insulation–reinforcement" synergistic efficiency deteriorates at high ceramic contents.
- Comprehensive performance inflection point: HS/FRF-25 achieves the optimal

balance across three key indicators—it exhibits the peak specific compressive strength (4.671 N·m/g, representing a 39.7% increase compared to HS/FRF-0); the increase in thermal conductivity remains relatively controllable (+55.8%, still maintaining ultra-low thermal conductivity characteristics); and it yields the highest strength gain per unit increase in thermal conductivity (optimal strength/thermal conductivity ratio).

Mechanism analysis of the trade-off: In the low ceramic content range (0–25 wt%), the rigid ceramic phase effectively bridges the fiber skeleton, significantly enhancing load transfer efficiency. Meanwhile, the continuous aerogel network and high porosity structure still dominate the heat transport pathways, resulting in limited degradation of thermal insulation performance. When the ceramic content exceeds 25 wt%, the ceramic phase gradually forms continuous heat conduction pathways, causing the growth rate of thermal conductivity to outpace the mechanical gains, thereby leading to a decline in the "performance-to-insulation" cost-effectiveness.

Application-oriented recommendations:

- For lightweight insulation-prioritized scenarios: HS/FRF-25 is recommended, as it offers an optimal combination of high specific strength and low thermal conductivity.
- For structural load-bearing prioritized scenarios: HS/FRF-50/75 may be selected, where a moderate sacrifice in insulation performance is acceptable in exchange for higher absolute strength.

Table S4 Specific strength/thermal conductivity ratio of HS/FRF-*x* (*x*=0, 25, 50 ,75) at 10% strain

Samples	**Thermal conductivity /(W·m^{-1}·K^{-1})**	**Specific compressive strength /(N·m·g^{-1})**	**Specific strength /thermal conductivity ratio**
HS/FRF-0	0.0414	3.344	80.78
HS/FRF-25	0.0644	4.671	72.53
HS/FRF-50	0.0938	4.529	48.28
HS/FRF-75	0.1017	4.367	42.94

Data analysis reveals that although HS/FRF-0 exhibits the highest ratio (80.78), its absolute specific compressive strength remains relatively low (3.344 N·m·g^{-1}) and lacks ceramic-phase reinforcement, rendering it insufficient for practical thermal protection applications requiring structural integrity. Among Ti_3SiC_2-containing

composites, HS/FRF-25 achieves the optimal performance index (72.53), markedly surpassing HS/FRF-50 (48.28) and HS/FRF-75 (42.94). This superiority originates from the concurrent realization of peak specific compressive strength (4.6709 $N \cdot m \cdot g^{-1}$) and only a moderate thermal conductivity increase (0.0644 $W \cdot m^{-1} \cdot K^{-1}$), thereby achieving an ideal balance between mechanical reinforcement and thermal insulation retention. This index, together with the specific strength maximum and thermal conductivity evolution trend, forms a tripartite evidence chain that robustly validates 25 wt% Ti_3SiC_2 as the critical composition for balanced thermo-mechanical performance.