Performance of Conformable Ablators in Aerothermal Environments

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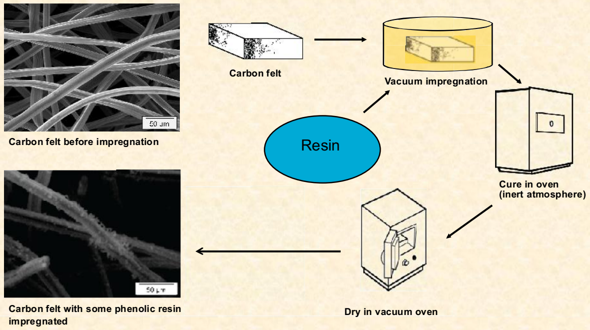
1. Background

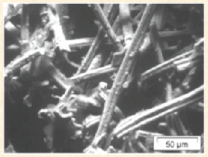
- Thermal blankets protect space vehicles in areas that reach up to 371 °C (700 °F) upon entry into an atmosphere. They are mainly used for their insulative properties and low density, but their flexibility is also very beneficial.
- Conformable ablators have sparked interest due to their potential to withstand relatively high heating rates (>250 W/cm^2) while having the ability to be molded to the desired shape during processing.
- Conformable ablators consist of a felt base (such as carbon felt) and a resin, which, upon curing, shows good thermal insulative properties at heating rates of 200 W/cm^2 or higher.
- The density of conformable ablators depends on the density of the felt used and concentration of resin, but is usually in the range of 0.20 g/cm^3 to 0.30 g/cm^3.
- Conformal heatshields offer several advantages compared to rigid heatshields, including potential lower thermal conductivity, lower thermal stresses, lower risk of failure due to crack growth, and ease of installation.
- Conformal heatshields are probably less expensive, since they can be made in one piece compared to tiles for a rigid heatshield.

2. Conformable Ablator Processing

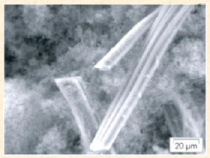


3. Importance of Morphology in Ablator Systems

Morphology refers to the microstructure of an ablator system and the location of phenolic polymer (or infiltrant) relative to the fiber substrate used.

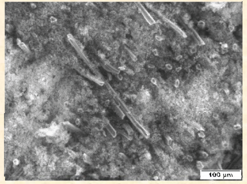


Example of Poor Morphology

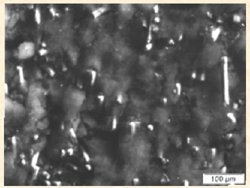


Example of Good Morphology

Previous work on rigid ablator systems has shown that morphology is directly related to the thermal diffusivity of an ablator. The presence of phenolic polymer in the space between the fibers, as seen in the image on the right, above, decreases the heat transfer due to radiation through the material, thereby decreasing the thermal diffusivity. (Thermal diffusivity data was obtained using a Netzsch Laser Flash Analyzer.)



Ames Standard Conformable PICA: density = 0.16 g/cm^3
Thermal Diffusivity = 0.43 mm^2/s
Thermal Conductivity = 0.06 W/mK



Ames Higher Density Conformable PICA: density = 0.23 g/cm^3
Thermal Diffusivity = 0.25 mm^2/s
Thermal Conductivity = 0.05 W/mK

4. Focus of This Work

1. Test several conformable ablators in the same aerothermal environment and evaluate their performance.
2. Down select to two conformable ablators that will be further tested and evaluated to compare their performance in an aerothermal environment and their thermal and mechanical properties.
3. Down select to one conformable ablator that will be advanced to TRL 5 or 6 by end of 2013.

5. Conformable Ablators Investigated

Two carbon felts, made by FMI (Fiber Materials, Inc.) and Morgan AM&T, were used to make the conformable ablators in the table on the right. Morgan's felt was flat and had no wrinkles, while FMI's carbon felt was not completely flat and had wrinkles on one side of the felt.

Felts used

	Density (g/cm^3)	Thickness (in.)
FMI Felt	0.13	0.7
Morgan Felt	0.08	1.0

Arc Jet Test Conditions

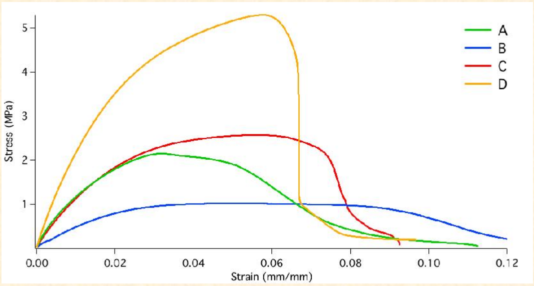
Sample	Heat Flux (W/cm^2)	Pressure (atm)	Exposure Times (s)
FMI Felt with silicone	540	0.35	20
All other materials	540	0.46	20 and 30

Conformable Ablators Tested

Sample Description	Sample ID	Diameter (in.)	Density (g/cm^3)	Areal Density (g/cm^2)
FMI Felt with standard phenolic loading	A	3	0.24	0.28
Morgan Felt with standard phenolic loading	B	3	0.21	0.41
Morgan Felt with high phenolic loading	C	3	0.26	0.50
FMI Felt with standard phenolic loading plus additive	D	3	0.30	0.34
Morgan Felt with silicone	E	3	0.26	0.54
FMI Felt with silicone	F	3	0.22	0.31

6. Mechanical Properties of Conformable Ablators

Stress Strain Curves of Conformable Ablators with Phenolic Resin



Sample Description	Sample ID	Density (g/cm^3)	UTS (kPa)	Energy Density at UTS (J/m^3)	Strain at UTS (%)	Modulus (Mpa)
FMI Felt with standard phenolic loading	A	0.24	2043	40600	3.00	139
Morgan Felt with standard phenolic loading	B	0.21	1030	37600	4.92	50
Morgan Felt with high phenolic loading	C	0.26	2586	90100	4.91	145
FMI Felt with standard phenolic loading plus additive	D	0.29	5229	198000	5.46	250

7. Arc Jet Data on Conformables

Results from 20 second exposure

Sample Description	Heat Flux (W/cm^2)	Pressure (atm)	Exposure Times (s)	Stagnation Recession (mm)	Change in Backface Temp (°C)	Time to Max Backface Temp (s)	Maximum Surface Temp (°C)
FMI Felt with standard phenolic loading	540	0.46	20	7.0	88.7	109	2810
Morgan Felt with standard phenolic loading	540	0.46	20	8.2	54.9	543	2840
Morgan Felt with high phenolic loading	540	0.46	20	5.8	42.5	946	2770
FMI Felt with standard phenolic loading plus additive	540	0.46	20	5.0	89.8	160	2750
Morgan Felt with silicone	540	0.46	20	9.6	64.3	440	3034
FMI Felt with silicone	540	0.35	20	6.0	130	105	2406

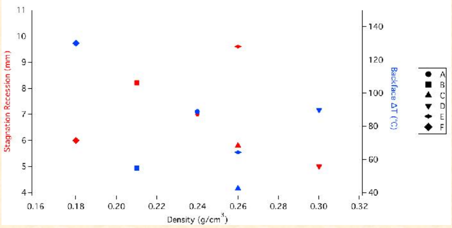
*Tested at Johnson Space Center (JSC)

All other samples were tested in the Interactive Heating Facility (IHF) at the NASA Ames Research Center

Results from 30 second exposure

Sample Description	Heat Flux (W/cm^2)	Pressure (atm)	Exposure Times (s)	Stagnation Recession (mm)	Change in Backface Temp (°C)	Time to Max Backface Temp (s)	Maximum Surface Temp (°C)
FMI Felt with standard phenolic loading	540	0.46	30	9.4	200	87	2760
Morgan Felt with standard phenolic loading	540	0.46	30	11.5	65	409	3002
Morgan Felt with high phenolic loading	540	0.46	30	8.9	51	730	2595
FMI Felt with standard phenolic loading plus additive	540	0.46	30	7.2	180	94.3	2740
Morgan Felt with silicone	540	0.46	30	15.5	77	224.3	3034

All samples were tested in the Interactive Heating Facility (IHF) at the NASA Ames Research Center



Plot of stagnation recession and the change in backface temperature for the 20 second exposure vs. density.

- Based on performance and ease of manufacturing for scaling up in the future, samples C and F were chosen for further testing.
- Both materials had low recession, especially sample F which has low density. The higher backface ΔT is likely contributed to its lower thickness.

8. Future Work

Samples C and F have been made in a geometry that conforms to part of a cone and be exposed to 250 W/m^2 in the IHF at NASA Ames Research Center for further analysis.

9. Summary

•Although the FMI felt with phenolic and an additive (sample D) had the best mechanical properties and the least recession, it was not selected for further testing because of concerns with manufacturing large pieces.

•The high phenolic loading in the Morgan felt (sample C) was responsible for the low recession and low change in the backface temperature.

Acknowledgment

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