PICA Variants With Improved Mechanical Properties

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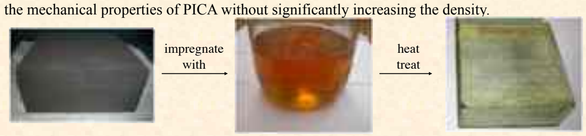
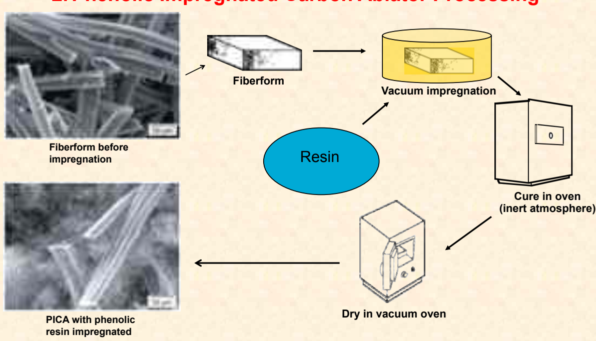
1. Background

• Phenolic Impregnated Carbon Ablator (PICA) is a member of the family of Lightweight Ceramic Ablators (LCAs) and was developed at NASA Ames Research Center as a thermal protection system (TPS) material for the Stardust mission probe that entered the Earth's atmosphere faster than any other probe or vehicle to date.
• PICA, carbon fiberform base and phenolic polymer, shows excellent thermal insulative properties at heating rates from about 250 W/cm^2 to 1000 W/cm^2.
•The density of standard PICA - 0.26 g/cm^3 to 0.28 g/cm^3 - can be changed by changing the concentration of the phenolic resin.
•By adding polymers to the phenolic resin before curing it is possible to significantly improve the mechanical properties of PICA without significantly increasing the density.



Carbon Fiberform Resin PICA

2. Phenolic Impregnated Carbon 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 Low density PICA: density = 0.229 g/cm^3
Thermal Diffusivity = 0.929 mm^2/s
Thermal Conductivity = 0.188 W/mK

Ames Standard PICA: density = 0.280 g/cm^3
Thermal Diffusivity = 0.677 mm^2/s
Thermal Conductivity = 0.167 W/mK

4. Focus of This Work

1. Improve existing low density PICA-like ablators by reducing brittleness and increasing strength without increasing density.

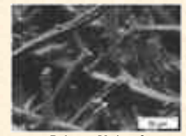
2. Understand key parameters that control the thermal and mechanical properties of low density, porous ablators using PICA as a model system.

3. Discover and develop new advanced ablators.

5. First Generation Polymer Variants of PICA

Low density PICA (control)

Polymer Variant 1



Polymer Variant 2

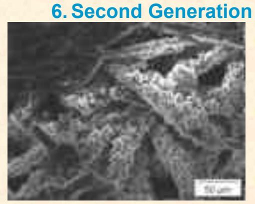
Polymer Variant 3

Polymer Variant 4

Polymer Variant 5

Adding polymers to the phenolic resin still resulted in poor morphology due to low concentration of phenolic resin. Densities are similar to low density PICA (≈0.24 g/cm^3) due to same concentration of phenolic resin.

6. Second Generation Polymer Variants of PICA



2nd Generation Variant: density = 0.287 g/cm^3
Thermal Diffusivity = 0.794 mm^2/s
Thermal Conductivity = 0.201 W/mK

2nd Generation Variant: density = 0.302 g/cm^3
Thermal Diffusivity = 0.741 mm^2/s
Thermal Conductivity = 0.198 W/mK

Increasing the phenolic loading improves the morphology, but the morphology is also dependant on the chemistry and the interaction between the polymer and the carbon fibers. In the two images above, the polymer appears to be attracted to itself and the fibers. Increasing the amount of additive used increases the density, but has minimal effects on the morphology and thermal conductivity.

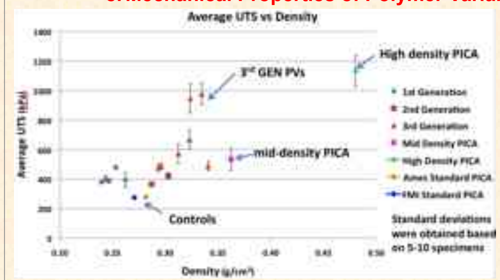
7. Third Generation Polymer Variants of PICA

3rd generation: density = 0.312 g/cm^3
Thermal Diffusivity = 0.838 mm^2/s
Thermal Conductivity = 0.231 W/mK

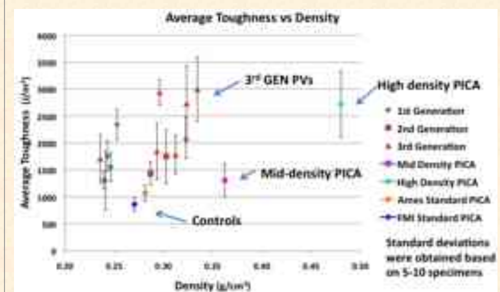
3rd generation: density = 0.323 g/cm^3
Thermal Diffusivity = 0.889 mm^2/s
Thermal Conductivity = 0.253 W/mK

Adding polymers to the phenolic resin and changing the solvent changed the morphology (compared to the 2nd generation) and the interaction between the polymer and the carbon fibers.

8. Mechanical Properties of Polymer Variants



The best third generation polymer variant PICA samples have an ultimate tensile strength (UTS) greater than three times that of standard PICA controls. Mid-density PICA and high density PICA are PICA made with increased concentration of phenolic resin without additives.



The best third generation polymer variant PICA samples have a toughness that is three times greater than that of standard PICA controls.

The best third generation polymer variant PICA sample has a strain-to-failure that is about 60% greater than that of standard PICA controls.

9. Future Work

When funds become available, large-scale arc jet testing will be performed and research will continue to increase the strain-to-failure of polymer variants of PICA.

10. Summary

•Polymers can be added to the phenolic resin used to make PICA to obtain a desirable morphology and improved mechanical properties.
•Data obtained shows that the toughness of PICA can nearly be quadrupled and that the ultimate tensile strength can be tripled by adding polymers to the resin.

Acknowledgment

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