Progress in Manufacturing & Characterizing Domestic Lyocell PICA (PICA-D) and Comparison to Heritage PICA

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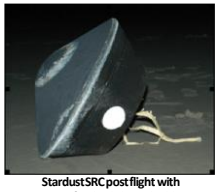
1. Background – PICA and PICA Sustainability

State of the Art Low Density Carbon Phenolic Ablators

- Phenolic Impregnated Carbon Ablator (PICA) is a low density (~ 0.27g/cm^3) ablator first used as the forebody heatshield for the Stardust sample return capsule where it was used as a single piece heatshield
- Since Stardust, PICA was used on the Mars Science Lab (MSL) in a tiled configuration, on the OSIRIS-REx sample return capsule as a single piece and slated for Mars 2020 as a tiled configuration



Stardust SRC post flight with PICA forebody heat shield (0.8m max. diameter)

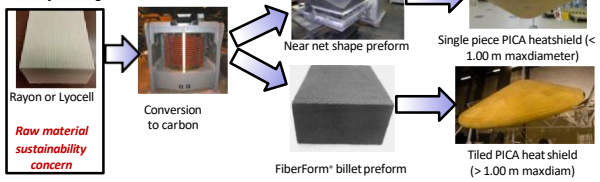
- In 2016 NASA ARC learned that the heritage rayon utilized in PICA was stopping production, leading to a flight-qualified PICA sustainability challenge
- In FY16/17, NASA ARC was funded by SMD/PSD to address PICA rayon sustainability
- Lyocell Based PICA (PICA-D) was manufactured and limited testing performed showing it to be a good candidate as a potential replacement for heritage rayon

2. Establishment of PICA-D as a Replacement for Heritage PICA

- In FY17, SMD-PSD funded ARC to manufacture and perform limited property and aerothermal characterization of Lyocell-based PICA
  - FY17 task successfully completed limited testing that indicated the viability of PICA-D as a potential replacement for heritage PICA

PICA Processing Steps

Role of Rayon/Lyocell in PICA Manufacturing



Lyocell is a sustainable domestic source of a "rayon alternative" fiber that can be used in the manufacture of carbon FiberForm®, the precursor to PICA.

Material Property Characterization

- In FY17, 3 billets of PICA-D were manufactured to support testing
  - Limited In-plane (IP) tension, through-thickness (TT) tension, and through thickness thermal conductivity at 100F and 350F were conducted and compared to heritage rayon PICA
- Overall these results are in family with production rayon PICA – however additional testing is needed as only a few coupons were evaluated
  - Limited property data had substantial scatter – detailed testing planned for FY18/19

Mechanical Property Comparison

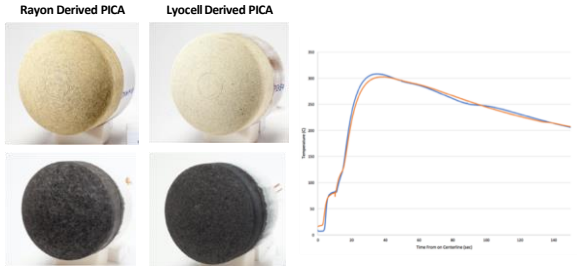
	Density (g/cc)	Failure Stress (psi)
Average Lyocell IP properties	0.28	246.48 (vs 190 for rayon PICA)
Average Lyocell TTT properties	0.28	44.03 (vs 49.6 for rayon PICA)

Thermal Property Comparison

Billet ID	Specimen ID	Thermal Conductivity (BTU-in/hr-ft^2-^{o}F) at 100°F	at 350°F
Average Lyocell TTT properties		0.939	1.32
Average Rayon TTT properties		1.22	1.66

Arc Jet Characterization

- 3 arcjet conditions were tested in FY17
  - NF proposers provided guidance on test conditions
  - All conditions will be repeated in FY18/19 to demonstrate data repeatability



Recession Comparison

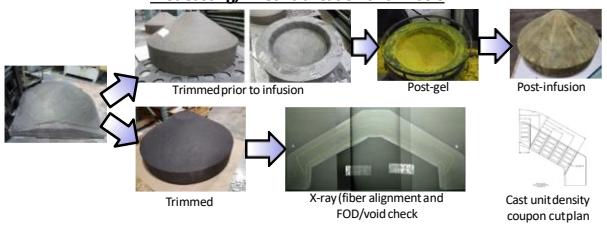
Material	Average centerline recession (1550W/cm^2 and 1.3 atm)	Average centerline recession (400W/cm^2 and 0.3atm)	Average centerline recession (220W/cm^2 and 0.08atm)
Lyocell Derived PICA	4.0mm	6.02mm	3.79mm
Rayon Derived PICA	4.2mm	5.97mm	3.89mm

For a given test condition (same run time) initial results indicate that recession and in-depth temperature between a Lyocell derived PICA and a heritage rayon-derived PICA are comparable

3. Establishment of PICA-D Expanded Capability

- 9 billets of FiberForm were manufactured in FY17 to optimize the process using Lyocell fibers
  - Billets spanned the spec density range and billet FiberForm target densities were achieved
- Development and fabrication of three 0.8-m net-shaped FiberForm heatshield blank (OSIRIS REx scale) were also completed in FY17
  - Density targets in all 3 net cast blanks were achieved
- Process refinements and lessons learned have been documented
- Limited Non Destructive Evaluation (NDE) completed on the Lyocell near net shape FiberForm unit to evaluate fiber alignment and check for off-nominal features
- FY18/19 work will expand on the work performed in FY17 and demonstrate repeatability as well as increase single piece net cast dimensions to >1.2-m

Net Casting, Billet Fabrication and Infusion



Acknowledgements

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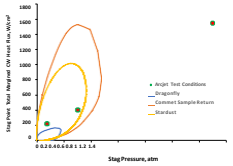
4. Exploration of Lyocell PICA (PICA-D) for Future Missions

In FY18/FY19, NASA Ames is leading an effort funded by SMD-PSD to characterize and extend the capability of PICA-D to Establish Lyocell PICA as a Drop-In Replacement for Heritage PICA

- Establishing PICA-D as a "drop in replacement" will allow missions to depend on and design missions with PICA without any risk typical of a replacement.
- Establishing the extended capability of PICA-D will allow Sample Return Missions with higher entry speed that were not considered before.

Task 1: Establish PICA-D as a Drop-in replacement for Heritage PICA

- Develop comprehensive material property database
- Perform comprehensive arcjet test campaign
- Develop PICA-D Thermal Response Model utilizing arcjet test data and new material property database

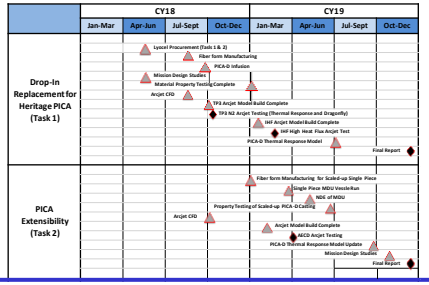


Target Conditions	Objective
~ 220W/cm^2 and 0.08 atm (4" iso-q)	thermal response, recession
~ 400W/cm^2 and 0.3 atm (4" iso-q)	thermal response, recession
~ 1550W/cm^2 and 1.3 atm (4" iso-q)	Failure mode evolution, thermal response, recession

Task 2: Establish the Expanded Capability (Extensibility) of PICA-D

- Demonstrate Manufacturing and Scale-Up of a Single Piece Heatshield at a Scale of 1.6m Diameter
- Establish Expanded Design Space of PICA-D
- Publish all PICA-D Data for current and future missions

5. PICA-D Project Schedule



6. Progress / Summary

- **Engaged with MSR - MSR provided shape will be the candidate for extensibility task to demonstrate single piece casting. Also, MSR relevant conditions will be included in our arc jet testing and may define the outer boundary test point for PICA-D (13.5 km/s; 1.2m diameter capsule)**
- **FMI site visit in late June. MSR EEV lead system engineer accompanied the visit**
- **FMI has built a 1.2 m aeroshell fiber-form using Lyocell and utilizing molding equipment on hand. Confidence in casting a single piece fiber form from Lyocell have been demonstrated**
  - FMI is designing a larger mold for casting fiber form up to 1.6 m
- **FMI has graphitized 10 tons of Lyocell and are completing PICA infusion of FiberForm billets**
- **FMI plans to deliver PICA-D billets in early September to support arc jet and property testing**
  - Visit to FMI planned to finalize material property test matrix.
- **Ames team has finalized arc jet test conditions relevant for Dragonfly Testing to take place in October**
  - Preparations for Oct 2018 arc jet testing ongoing (test article design, environments..)
- **Establishing PICA-D as a "drop in replacement" will allow missions to depend on and design missions with PICA without any risk typical of a replacement and establishing the extended capability of PICA-D will allow Sample Return Missions with higher entry speed that were not considered before.**