Post-Flight Evaluation of PICA & PICA-X - Comparisons of the Stardust SRC & Space-X Dragon 1 Forebody Heatshield Materials

M. Stackpoole, D. Kao, V. Qu and G. Gonzales
NASA Ames Research Center, Moffett Field CA 94035, ERC Inc., Moffett Field, CA 94035

Background
- Phenolic Impregnated Carbon Ablator (PICA) was developed at NASA Ames Research Center
- PICA was an enabling TPS material for the Stardust mission where it was used as a single piece heatshield
- PICA has the advantages of low density coupled with efficient ablative capability at high heat fluxes

More recently, PICA was chosen as the primary heatshield for the successful Mars Science Lab (MSL) and the upcoming OSIRIS-REX missions
- Space-X developed a variant, PICA-X, and used it as the heatshield material for its Dragon spacecraft, which successfully orbited the Earth and re-entered the atmosphere during the COTS Demo Flight 1 in 2010 and subsequent ISS resupply missions
- Post-flight analysis was previously performed on the Stardust PICA heatshield material. Similarly, materials testing and analyses were recently performed on a PICA core from the COTS demo flight to evaluate its ablation performance and post-flight properties.

Post-Flight Analysis Objectives
For Stardust – when the core analysis was completed, PICA was the baseline forebody TPS for CEV (Orion) & MSL – tasks most relevant to CEV were prioritized.
Forebody heatshield objectives (aerothermal and material response):
1. Determine unusual surface features indicating off-nominal aerodynamic performance, off-nominal TPS performance, or pre-entry damage
2. Measure in-depth char and transition layer of TPS at select locations to determine spatially varying integrated heat load
3. Measure in-depth properties of Phenolic Impregnated Carbon Ablator (PICA) TPS, to compare to pre-flight models and arc-jet tested samples
4. Measure residual bond strength to assess aging effects

For Dragon-1: small effort under a Reimbursable Space Act Agreement (RSAA) to update thermal response model
1. Properties such as density, thermal conductivity needed for that effort.
2. Core provided to aid that effort – this work is also a “cost effective” approach of getting the core analyzed for Space-X

Core Location and Extraction
Stardust
- Near stagnation core, flank core, and edge slice extracted
- Stagnation core, flank core, and edge slice extracted

Dragon - 1
- Core taken from tile nearest to stagnation point
- Core taken from tile nearest to stagnation point

Microstructural Comparison
Stardust – Surface Char
- Stardust – Surface Char

Dragon - 1 – Surface Char
- Dragon - 1 – Surface Char

Stardust – Virgin
- Stardust – Virgin

Dragon - 1 – Virgin
- Dragon - 1 – Virgin

Both material microstructures are similar with a fibrous preform surrounded by a high surface area phenolic phase
- PICA-X virgin and char have higher density than Stardust era PICA
- The charred phenolic high surface area phase is absent in the Stardust PICA outermost char region but present in PICA-X
- No evidence of fiber oxidation (thinning) in either variant of PICA in the char region

Stardust – Stagnation Core
- Four distinct regions observed in density profile
- Low density char region close to the ablated surface – this region is devoid of the high surface area charred phenolic material
- High density charred phenolic region
- Pyrolysis region transitioning from char to virgin
- Virgin material

Dragon-1 Core
- Three distinct regions observed in density profile
- Char region – having density comparable to virgin material at ablated surface – unexpected!
- Pyrolysis region transitioning from char to virgin
- Virgin material

Drum - 1 had an ocean landing therefore compositional analysis was completed to determine if salts were present
- Surprisingly the salt content was very high at the surface accounting for ~25% of the mass of the surface char
- On correcting for salt content a density profile very similar to Stardust PICA was obtained

Summary
- Stardust and Dragon offer rare opportunities to evaluate materials post-flight - this data is beneficial in understanding material performance and also improves modeling capabilities
- Both materials performed well with no unusual ablation performance
- The PICA family of materials span a density range - low-density to mid-density variants have been developed

Acknowledgement
The authors would like to acknowledge Space-X for providing the Dragon – 1 core material for this study. Tom Squire and Frank Milos are also acknowledged for technical discussions.