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

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Background

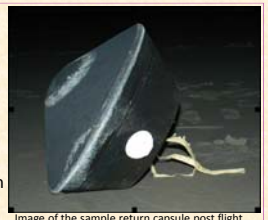


Image of the sample return capsule post flight with PICA as the forebody TPS.

- 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

Dragon-pre and post flight images provided courtesy of Space-X.

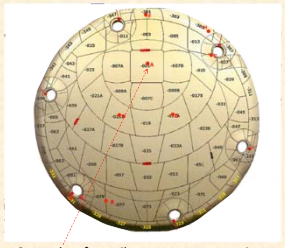
	Stardust	Dragon - 1
Peak Heat Flux (Total)	1000 W/cm^2	~ 50 W/cm^2
Peak Heat Load	28 kJ/cm^2	
Location of Peak Heating	Stagnation Point at Geometric Apex	Windward shoulder
Configuration	Single piece	Tiled configuration

Core Location and Extraction

Stardust

Near stagnation core, flank core, and edge slice extracted

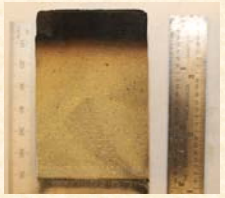
Dragon - 1



Core taken from tile nearest to stagnation point

Stardust stagnation core

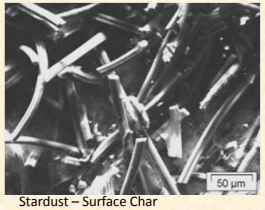
Stardust flank core



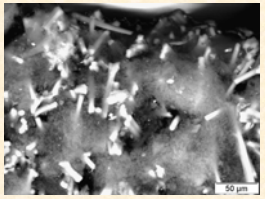
Dragon core

- Cores extracted using a diamond core drill
- Substructure and bond material also evaluated
- Stardust - PICA was directly bonded to the composite carrier structure
- Dragon-1 - PICA-X had a strain isolation pad at the carrier structure to TPS interface

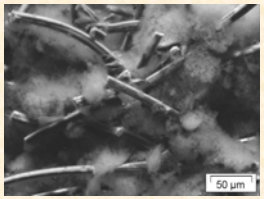
Microstructural Comparison



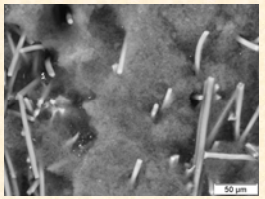
Stardust – Surface Char



Dragon -1 – Surface Char



Stardust – Virgin

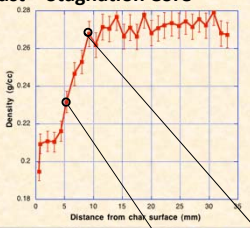


Dragon -1 – Virgin

- 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

Density Profiles

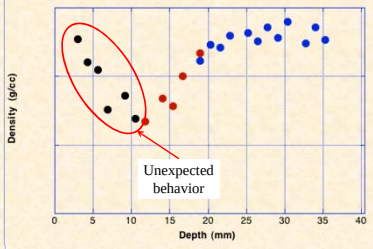
Stardust – Stagnation Core



Four distinct regions observed in density profile

1. Low density char region close to the ablated surface – this region is devoid of the high surface area charred phenolic material
2. Char region – having both the carbon substrate and charred phenolic constituents
3. Pyrolysis region transitioning from char to virgin
4. Virgin material

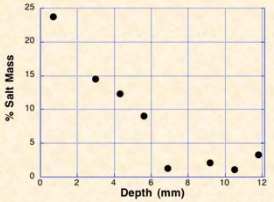
Dragon-1 Core



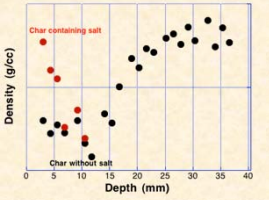
Three distinct regions observed in density profile

1. Char region – having density comparable to virgin material at ablated surface – unexpected!
2. Pyrolysis region transitioning from char to virgin
3. Virgin material

- Dragon – 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



High salt content present in outer char layer



Removing salt contributions from density profile results in expected trend

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

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