THERMOSTRUCTURAL TESTING OF PICA-D FOR NASA PLANETARY SCIENCE MISSIONS

Milad Mahzari[1], Keith Peterson[2], Derek Shannon[3], Matthew Gasch[4], Suman Muppidi[5], Michael Wright[6]
NASA Ames Research Center, [1] milad.mahzari@nasa.gov, [2] keith.h.peterson@nasa.gov,[4] matthew.j.gasch@nasa.gov, [5] suman.muppidi@nasa.gov, [6] michael.j.wright@nasa.gov.
Lockheed Martin Space, [2] derek.m.shannon@lmco.com

Brief Presenter Biography: Milad Mahzari is an Aerospace Engineer in the Entry Systems and Vehicle Development Branch at NASA Ames Research Center. He has been involved in the design and analysis of entry vehicles and Thermal Protection Systems (TPS) for multiple NASA projects. He is currently serving as the TPS lead for the Dragonfly mission to Titan, and the TPS Cognizant Engineer (CogE) for Mars Sample Retrieval Lander (SRL).

Background: Phenolic Impregnated Carbon Ablator (PICA) has been flown as the heatshield TPS material for many NASA planetary science missions. Due to a supply issue with the heritage Rayon fibers used in PICA fabrication, NASA started a project in 2017 to develop a sustainable replacement for PICA using a domestic fiber source. Lyocell was identified as an alternative to the Rayon-based precursor leading to the development and testing of the replacement material, PICA-D (Domestic) [1]. PICA-D's processing steps and manufacturing specification largely adopt those used for heritage PICA. Extensive material property and arcjet testing showed that PICA-D performance met the specification requirements, and its properties and thermal performance were largely in family with heritage PICA. PICA-D was selected as the heatshield TPS material for two upcoming NASA planetary science missions, the Dragonfly mission to Titan and Mars Sample Retrieval Lander (SRL).

PICA-D Thermostructural Concerns: While most PICA-D thermal and mechanical properties are very similar to PICA, early test data suggested that PICA-D is stiffer under tension in the in-plane (IP) direction, with higher strength but lower strain-to-failure. This is believed to be caused by minor process modifications necessary to address equipment and ingredient availability at the PICA-D manufacturing vendor. Preliminary thermostructural analysis using Finite Element Methods (FEM) tools predicted IP compressive failure in the near-surface layers of PICA-D, for both Dragonfly and SRL flight environments. This failure mode is caused by the material being constrained when it thermally expands at the high temperatures experienced during atmospheric entry. Further analysis uncovered additional failure modes in through-the-thickness (TTT) shear and tension. The early analytical predictions were based on a mix of measured and estimated PICA-D properties since measurements for a full set of mechanical properties were not available. Furthermore, FEM predictions defined failure in the traditional linear sense and did not account for the non-linear capability of the material or the complex behavior of charred TPS materials at high temperatures. While additional mechanical property testing and higher-fidelity analysis techniques can improve the accuracy of stress predictions, the team believed that analysis is not the final indicator of a failure, and a subsystem-level test under combined thermal and mechanical loads is needed to certify the material's performance. MSL, Mars2020 and Orion also adopted a similar approach.

Thermostructural Testing: A two-pronged approach was pursued for the thermostructural qualification of PICA-D and demonstrating that the material and heatshield design have adequate capability for both SRL and Dragonfly design environments. The first part was to improve the accuracy of analytical predictions through a comprehensive characterization of PICA-D mechanical properties. These tests have improved our understanding of PICA-D behavior at elevated temperatures under compression, resulting in a reduction of IP compressive stress levels in FEM predictions. However, they have also uncovered additional properties where PICA-D differs from heritage PICA, leading to new concerns related to TTT shear performance.

The second, and more critical, part of the qualification approach was subsystem-level tests of PICA-D to demonstrate material capability under flight-relevant combined mechanical and thermal loads. The team performed testing in two different facilities. The Laser-Hardened Materials Evaluation Laboratory (LHMEL) and National Solar Thermal Test Facility (NSTTF). Both tests involved conforming PICA-D coupons to pre-defined radii of curvature in a vacuum chuck tool to simulate mechanical loads. The thermal boundary condition was simulated at LHMEL using a CO_2 laser beam focused on the target with optics, and at NSTTF using a heliostat field focusing solar energy on a test coupon situated at the top of a tower. The solar tower facility proved to be a better choice for testing PICA-D thermostructural failure modes due to the larger size of heating spot (24" at NSTTF vs 8" at LHMEL) and a more uniform heat flux profile. Both features are critical for inducing flight-like stresses in the test coupon. Figures 1 and 2 display the test setup at both facilities.



Figure 1. Testing of PICA-D at NSTTF Solar Tower (left: View from behind the test stand on top of the tower, right: Filtered image of the test coupon during test)

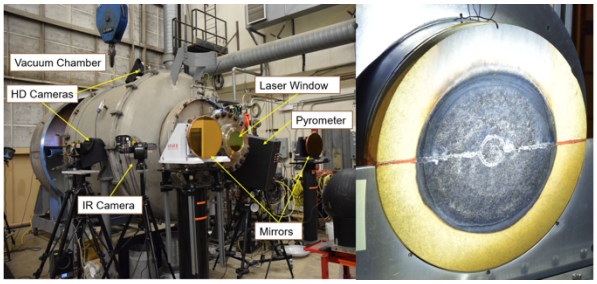


Figure 2. Testing of PICA-D at LHMEL (left: Vacuum chamber and instrumentation, right: post-test picture of a coupon with RTV gap filler and a repair plug)

Scope of the Presentation: At the 20th IPPW in Marseille, the authors presented their plans for PICA-D qualification and testing [2]. Over the past three years, the combined Dragonfly and SRL teams have completed six test entries at LHMEL and NSTTF facilities, with another one planned for March/April 2026. The team has also concluded a comprehensive mechanical property measurement campaign at Kratos test labs resulting in improved understanding of PICA-D mechanical behavior and increasing the accuracy of FEM predictions. The final presentation will review findings and results from these test campaigns and provide an update on the status of PICA-D qualification for these missions.

References:

[1] D. Ellerby, et al., "Sustaining Phenolic Impregnated Carbon Ablator (PICA) for Future NASA Missions Including Discovery and New Frontiers",16th International Planetary Probe Workshop, 2019.

[2] M. Mahzari, et al., "Thermostructural Qualification of PICA-D for NASA Planetary Science Missions", 20th International Planetary Probe Workshop, 2023.