Thermal Testing of Woven TPS Materials in Extreme Entry Environments

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Introduction

- The Heatshield for Extreme Entry Environment (HEEET) Project is funded by NASA's Space Technology Mission Directorate under the Game Changing Development Program (GCDP).
- HEEET seeks to mature a novel Woven Thermal Protection System (TPS) technology to enable in-situ robotic science missions recommended by the NASA Research Council Planetary Science Decadal Survey committee as outlined in Figure 1.
- Recommended science missions include Venus probes and landers, Saturn and Uranus probes, and high speed sample return missions.

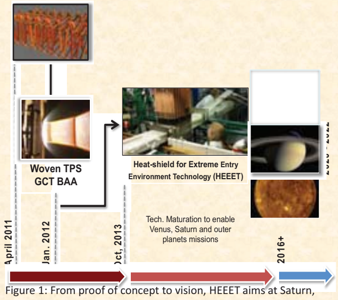

Figure 1: From proof of concept to vision, HEEET aims at Saturn, Venus, and Uranus missions.

Woven TPS – The Concept

- Woven TPS leverages the mature weaving technology that has evolved from the textile industry to design TPS with tailorable performance by varying the material composition and properties while controlling placement of fibers within a woven structure
- The resulting woven TPS can be ***designed and tailored*** to perform optimally for a wide range of entry environments without substantially changing the manufacturing and certification process
- The woven TPS approach utilizes commercially available weavers, using equipment, modeling and design tools to optimize the weave. This allows for the control of material composition and density resulting in tailored performance - by leveraging this technology NASA will not be burdened with maintaining the capability or having to accept the risk for material restart
- Woven TPS approach allows design and manufacture of ***ablative*** TPS materials by specific placement of fibers in a 3D woven structure illustrated in Figure 2

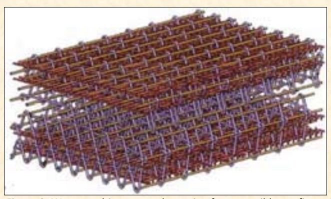

Figure 2: Weave architecture: schematic of one possible configuration.

Weaving flexibility allows :

- Ability to design TPS to meet specific mission needs
- Tailoring composition by weaving together different fiber types (carbon, glass, polymer, other)
- Tailoring density

Arc Jet Test Objectives

- The purpose of these test series is to evaluate the behavior of HEEET material performance in high/extreme entry conditions in current ground based testing facilities.
- The IHF and AEDC facilities have recently been upgraded to expand their testable envelope and testing at these higher conditions will be presented. Additionally, comparisons to heritage chop molded carbon phenolic (CMCP) and tape-wrapped carbon phenolic (TWCP) will be presented. Test conditions and example mission conditions are outline in Figure 3.

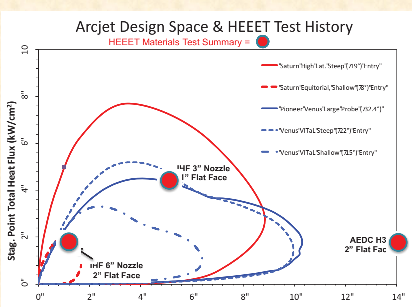

Figure 3: Design space for mission entry conditions for Saturn and Venus and test conditions history for arcjet facilities.

Testing in Ames Arc Jet Facility (IHF with 6" Nozzle)

Test Purpose:

- Evaluate the 3D woven HEEET TPS material in a simulated entry environment at heat fluxes approaching 1700 W/cm². TPS coupons had a 2-inch diameter flat face geometry.
- Primary objectives of this test series were:
  1. Demonstrate applicability of 3D Woven ablator concepts at high heat flux conditions: 1680 W/cm² actual– (cold wall) and ~1.3 atm stagnation
  2. Compare performance to heritage-like carbon phenolic materials
- Figure 4 illustrates the model assembly used in this test series. TPS stagnation models were mounted to a graphite adapter. Test articles were instrumented with one backface TC, inserted through the center of the model.

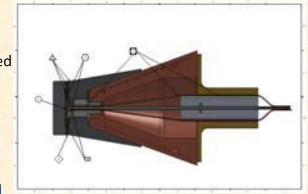

Figure 4: Model build for IHF 6" nozzle test of 2" flatface stagnation models.

Table I - Heating environment for IHF 2-inch flat face stagnation models as measured on a 2-inch Flat face calorimeter.

Cold wall Heat Flux 2-in flat face (W/cm²)	Stagnation Pressure (atm)	Shear (Pa)
1680	1.3	0

- Images of pre- and post-test specimens are shown in Figure 5. All ablated uniformly and did not exhibit any unusual failure modes. The HEEET materials performed well. The post-test images do not indicate any unusual features on the test surface. Carbon phenolic was also tested and behaved in a controlled manner. Some delamination of the chopped material was observed in the CMCP material.

Figure 5: HEEET material (left), TWCP-20 degree (mid.), and CMCP (right). Pre test images on top, Post test images on the bottom.

Testing in Ames Arc Jet Facility (IHF 3" Nozzle)

Test Purpose:

- Evaluate the HEEET TPS at extreme heat flux conditions, ~5000 W/cm² (cold wall) and ~5 atm. TPS coupons had a 1-inch diameter flat face geometry as diagramed in Figure 6. Figure 7 shows pre and post-test images.
- Primary objectives of this test series were:
  1. Demonstrate applicability of 3D Woven ablator concepts developed under the Woven TPS project at extreme heat flux/pressure .

Table 1 – CFD calculated heating environment on 1-inch flat face model.

CW Heat Flux 1-in flat face (W/cm²)	Stagnation Pressure (atm)	Shear (Pa)
4800	6	0

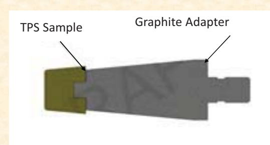

Figure 6: Model design for 3" nozzle test in IHF facility.

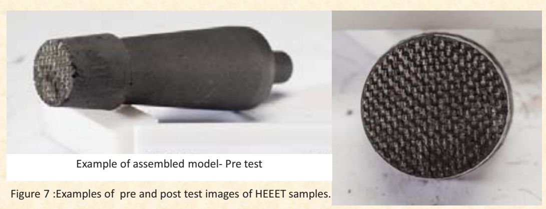

Figure 7 :Examples of pre and post test images of HEEET samples.

- All samples evaluated ablated uniformly with no unusual failure modes developed.

Testing at AEDC Facility (H3)

Test Purpose:

- Evaluate the 3D woven HEEET down-selected architecture in a turbulent heating environ under extreme stagnation pressure, 14 atm and ~1850 W/cm²
- Primary objectives of this test series was:
  1. Demonstrate applicability of HEEET composition at extreme pressure
  2. Compare performance to heritage CMCP
- Figure 8 shows the model schematic. Each sample was attached to machined carbon model holder that was then attached to the facility sting arm.

Table III - CFD calculated heating environment on AEDC 2-inch flat face model.

CW Heat Flux 2-in Flat face (W/cm²)	Stagnation Pressure (atm)	Shear (Pa)	Distance From Nozzle (in)
1850	14	0	3

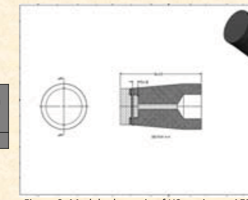

Figure 8: Model schematic of H3 testing at AEDC.

- Photographs of pre- and post-test are shown of the HEEET acreage material (Figure CMCP (Figure 10)
- The HEEET material ablated very uniformly and did not exhibit any unusual failure mode to the model conditions being more severe at the edges, and limitations in the thickn material available, the insulating layer at the edges was exposed. In the future the rec layer would be sized to specific mission conditions and this flexibility is a benefit of this t woven architecture.
- Chop molded carbon phenolic was also tested. Some delamination of the chopped m was observed in the CMCP material and the final surface appears somewhat uneven as in Figure 10.

Figure 9: HEEET acreage material pre-test and during test. Remaining recession layer in center of test area remains smooth despite higher recessions on edge.

Figure 10: CMCP pre and post-test images. Final surfac rougher compared to HEEET material.

Summary

- Facility upgrades have widened the envelope for ground-based testing capabilities allowi extreme conditions to be tested
- HEEET material performed well in all 3 test series.
- No unexpected failure modes were observed
- Heritage carbon phenolic materials were tested alongside HEEET to make performance comparisons.
- Based on these arcjet results in extreme entry environments, HEEET woven material opti viable alternatives to heritage carbon phenolic.

Acknowledgements

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