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Abstract Title: MSFC Thermal Protection System Materials on MISSE-6

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Abstract best fits in (check all that apply): [ ] Breakthrough Innovations [ ] Missiles & Missile Defense [X] MISSE [ ] Space Exploration [ ] Orbital Technologies & Operations [ ] Hypersonic & Responsive Operations

Please consider my abstract for (check all that apply): [X] Oral Presentation [ ] General Poster Session [ ] SBIR Poster Session [ ] Student Poster Session

What Classification is Your Presentation? Unclassified

What Distribution Level is Your Presentation? Unlimited

Degree(s) held by Lead Author: B.S. Materials Engineering

Where degree(s) was received: Virginia Polytechnic Institute

Current Position: Senior Materials Engineer

Co-Authors (Include Full Name and Company/Organization):

Peter Valentine NASA/MSFC

Michael Gubert US Army

Abstract:

The Lightweight Nonmetallic Thermal Protection Materials Technology (LNTPMT) program studied a number of ceramic matrix composites, ablator materials, and tile materials for durability in simulated space environment. Materials that indicated low atomic oxygen reactivity and negligible change in thermo-optical properties in ground testing were selected to fly on the Materials on International Space Station Experiment (MISSE)-6. These samples were exposed for 17 months to the low Earth orbit environment on both the ram and wake sides of MISSE-6B. Thermo-optical properties are discussed, along with any changes in mass.

List Special Presentation Requirements:

Please email the completed abstract submission form to:
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Thermal Protection System Materials on MISSE-6

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US Army / Redstone Arsenal

National Space and Missile Materials Symposium
June 2010

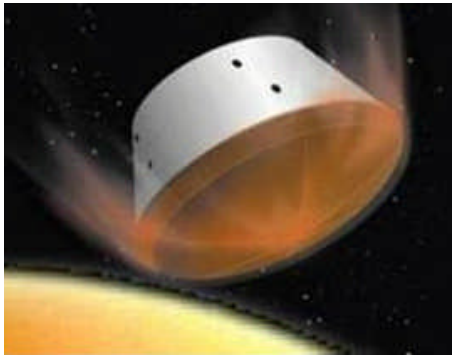
- Acknowledgements
  - Julie Henkener, system manager, Rajib Dasgupta, previous system manager, and Dr. John Alred, deputy system manager for ISS M&P
  - Dr. Gary Pippin, Boeing Research & Technology, for estimated environmental exposures.
  - Bill Kinard, MISSE chief scientist (retired), Karen Gibson, Ray Seals, and Sandie Gibbs, LaRC
  - Beth Cook and Twila Schneider, Advanced Materials for Exploration program
  - The various government and industry suppliers of the materials tested in the LNTPMT and MISSE-6 projects.
  - Gerald Russell of the Aviation and Missile Research, Development, and Engineering Center (AMRDEC)

Presentation Outline

- Atomic oxygen studies as part of Lightweight Nonmetallic Thermal Protection Materials Technology Project
- Selection of LNTPMT materials for MISSE-6
- Additional material from Marshall
- Optical Property Measurements
- Discussion

Lightweight Nonmetallic Thermal Protection Materials Technology Project

- Multi-center effort (MSFC, ARC, GRC, LaRC) which also included industry
- Increase in TRL for thermal protection
- Optimize heatshields for direct entry, aerobraking or aerocapture missions
- Due to changing priorities at NASA, was only funded for first year of planned four-year project



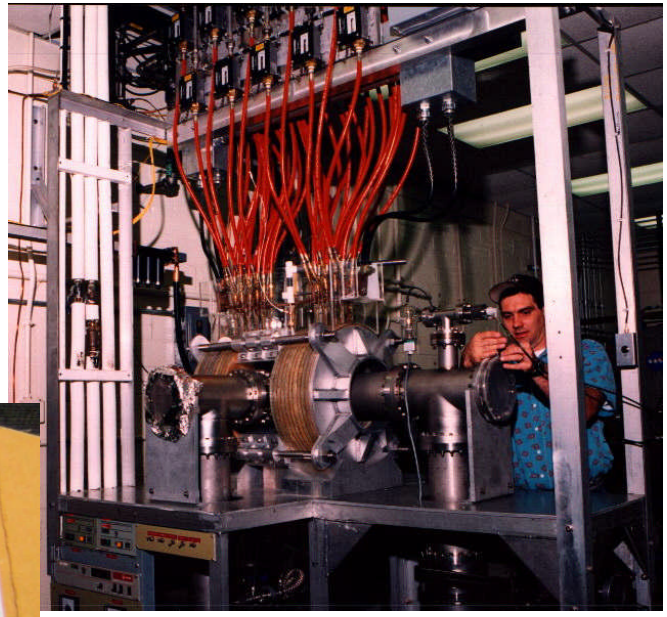
Lightweight Nonmetallic Thermal Protection Materials Technology Project

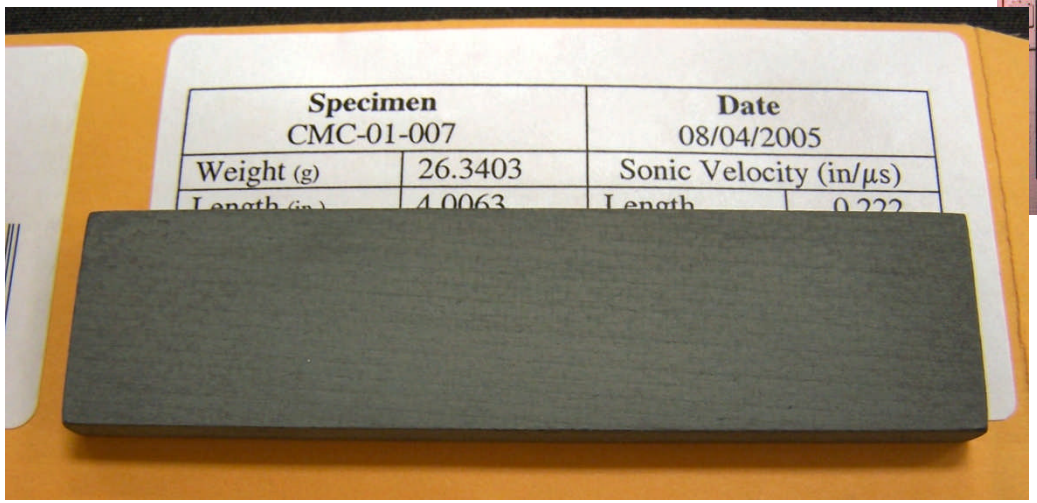
- Environmental testing of ceramic matrix composites, ablator materials, and tile materials
  - Atomic oxygen
  - Radiation
  - Meteoroid/orbital debris impact
- Arcjet testing at ARC and AEDC – was to have occurred in second year of project
- Laser Hardened Materials Evaluation Laboratory (LHMEL) Testing at Wright-Patterson Air Force Base

Lightweight Nonmetallic Thermal Protection Materials Technology Project – AO Testing

Samples exposed to ~2 x 10^{20} atoms/cm^2 5 eV atomic oxygen

Comparable fluence to wake side of MISSE-6



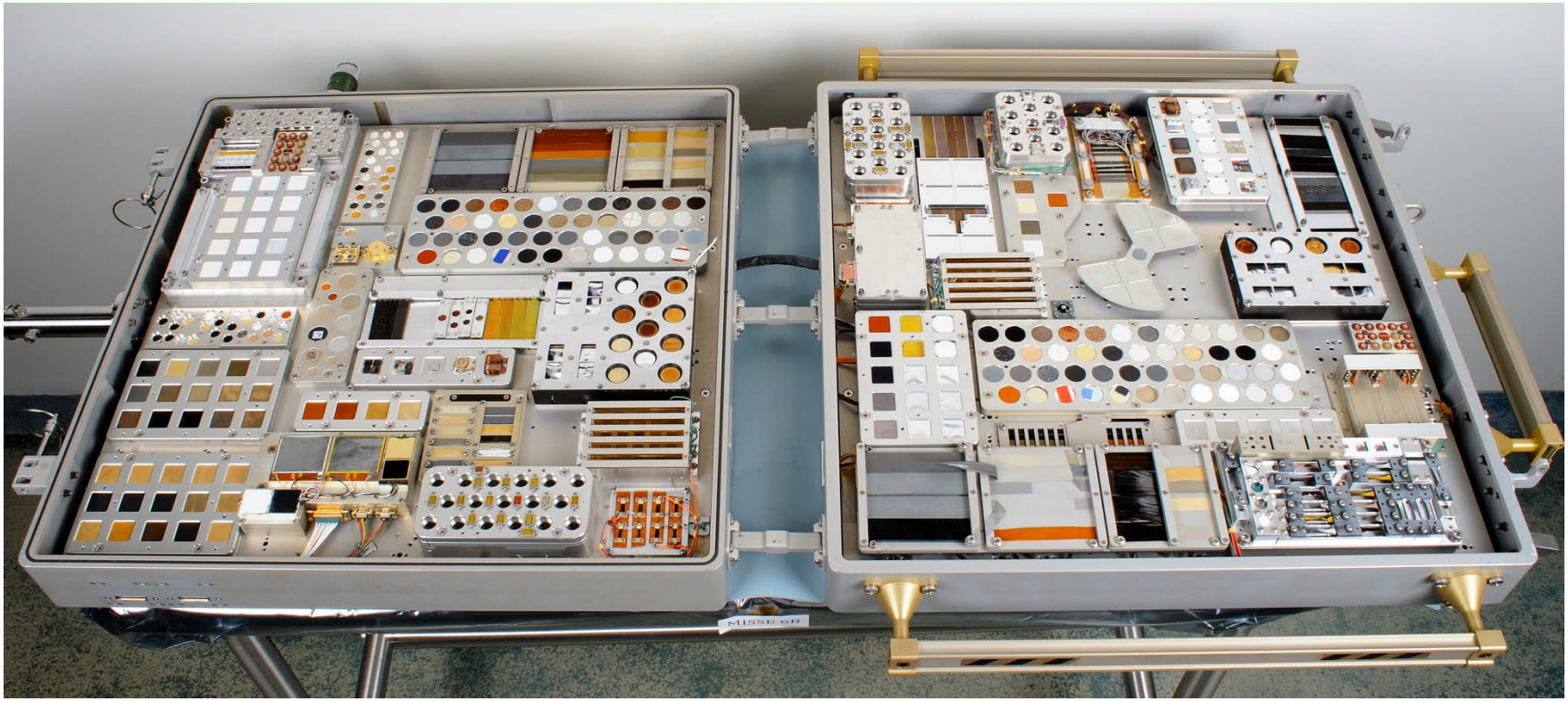


Material Class	Manufacturer --- TPS Material
Lightweight Ablatives	NASA-ARC / Fiber Materials Inc. (FMI) --- PICA-15 NASA-ARC --- SIRCA 15F ATK Thiokol --- MX4926 Low Density Carbon Phenolic Boeing Company --- BLA-20 ITT Industries --- Acusil II International Paint --- Chartek Minteq International Inc. --- RX2390 **Raytheon Missile Systems --- Hotblox** **Raytheon Missile Systems --- Hotblox Lite**
Rigid Reusable Ceramic Tiles	**NASA-ARC / Boeing Company --- AETB-12 w/TUFI and RCG** **NASA-ARC / Boeing Company --- BRI-20 w/HETC and RCG**
Ceramic Matrix Composites (CMC's) and C-C	ATK Thiokol --- RTV-impregnated C-C **C-C Adv. Technologies (C-CAT) --- ACC-6 with SiC coating** **GE Energy CCP --- C/SiC with MCM700 coating** **Hyper-Therm HTC --- Hybrid C-SiC/SiC sandwich panel** **MER Corp. --- C-C with SiC-HfC coating** **Physical Sciences, Inc. (PSI) --- HyBase D C-C with SiC coating**
Ballute Thin Film Materials	Dropped from LNTPMT Phase I Effort **Materials from Ball Aerospace, L'Garde, and Nexolve flown**

Significant mass loss of RTV- impregnated C-C observed during ground testing led to elimination as a candidate material for MISSE-6.

Ames flew a separate set of candidate TPS materials.

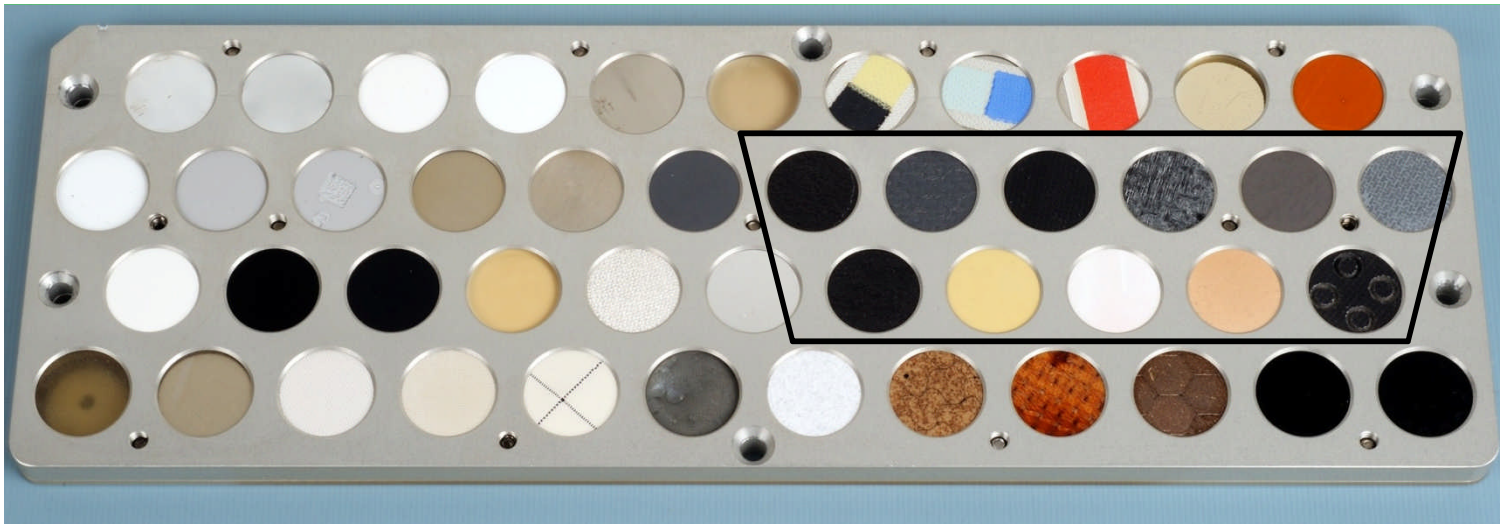
Lockheed-Martin also flew a set of superlightweight ablator candidate TPS materials



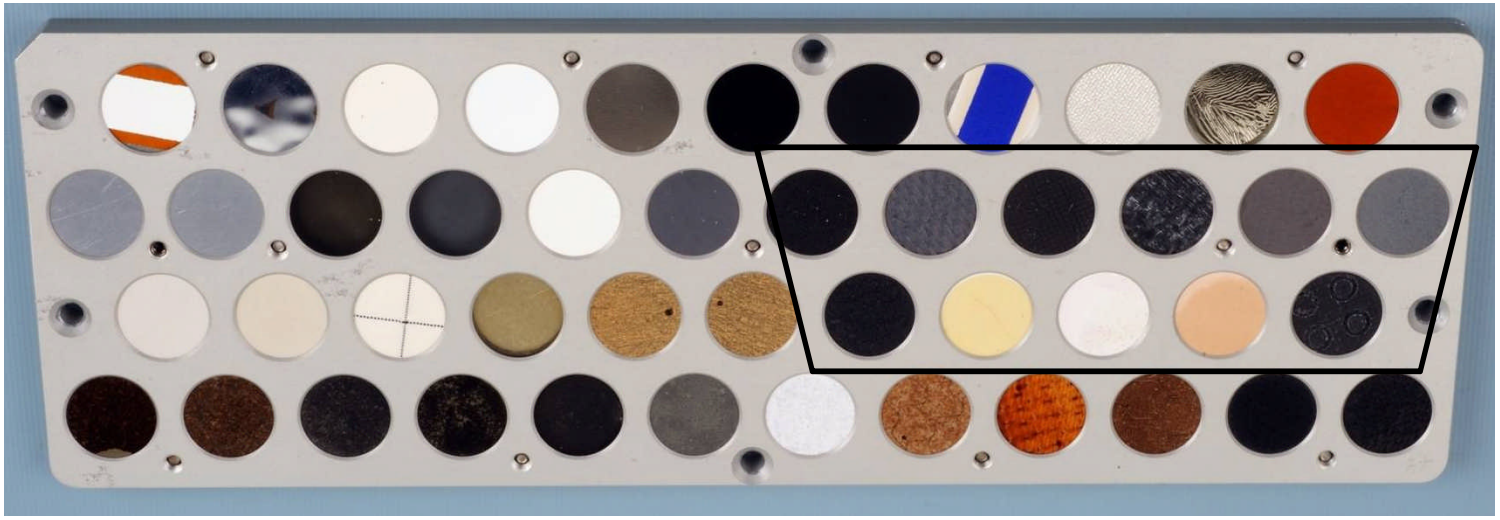
MISSE-6B Wake / Ram

Photo courtesy of Langley Research Center

Thermal Protection System Materials on MISSE-6



Ram



Wake

MISSE-6 Environmental Exposure

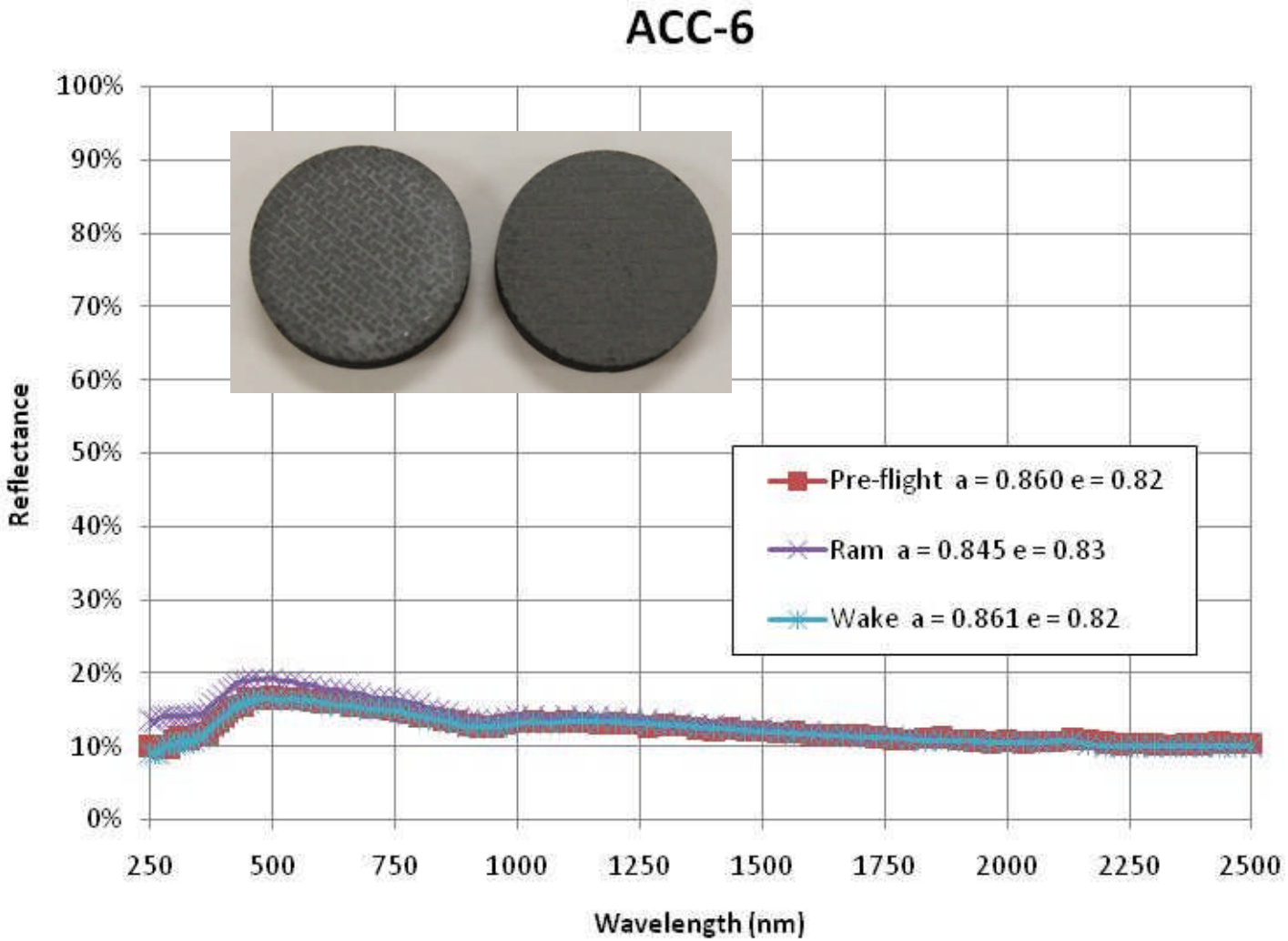
Ram-facing side

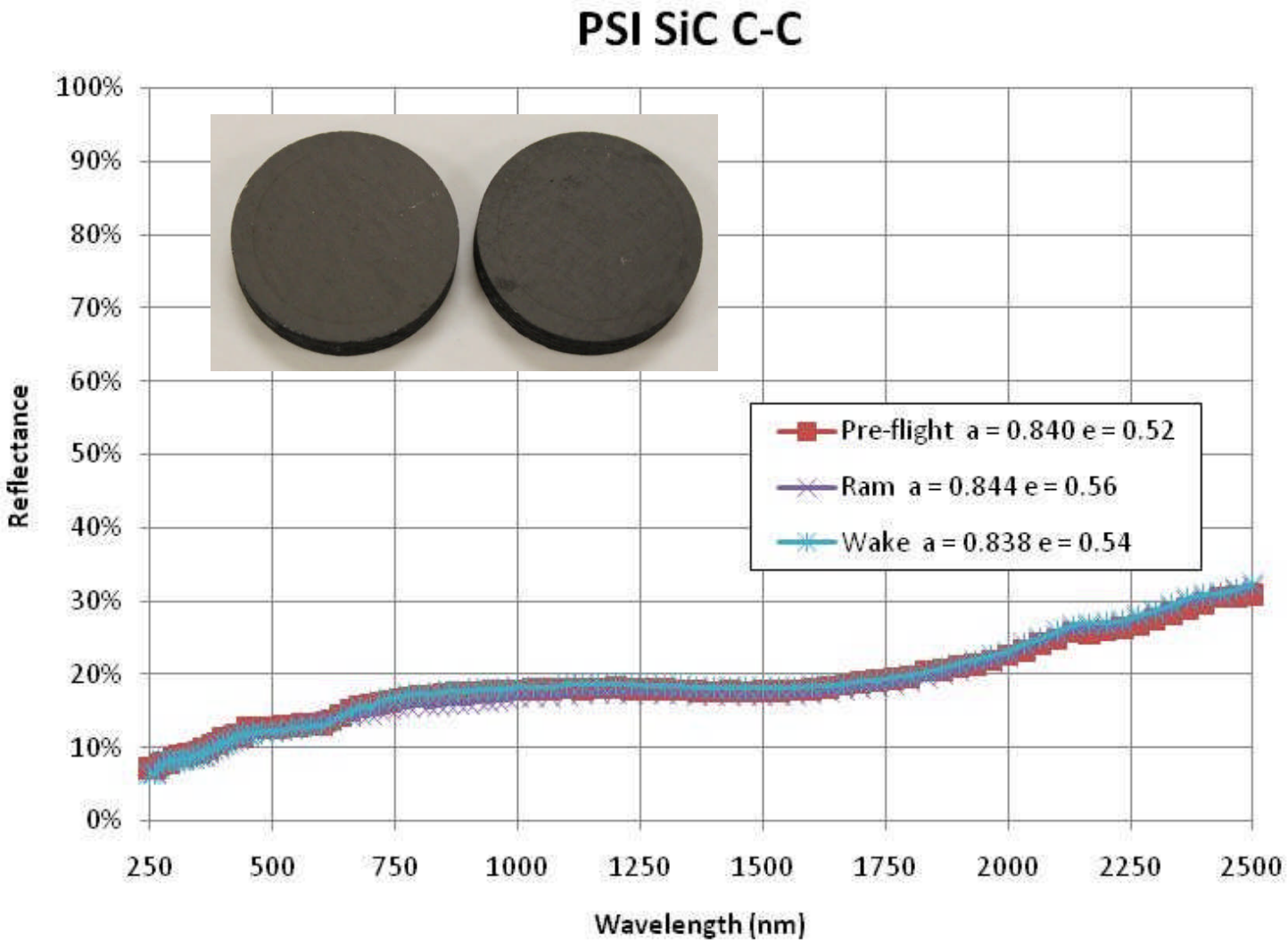
- ~2 x 10^{21} atoms/cm^2 atomic oxygen
- ~ 2,600 equivalent sun-hours UV

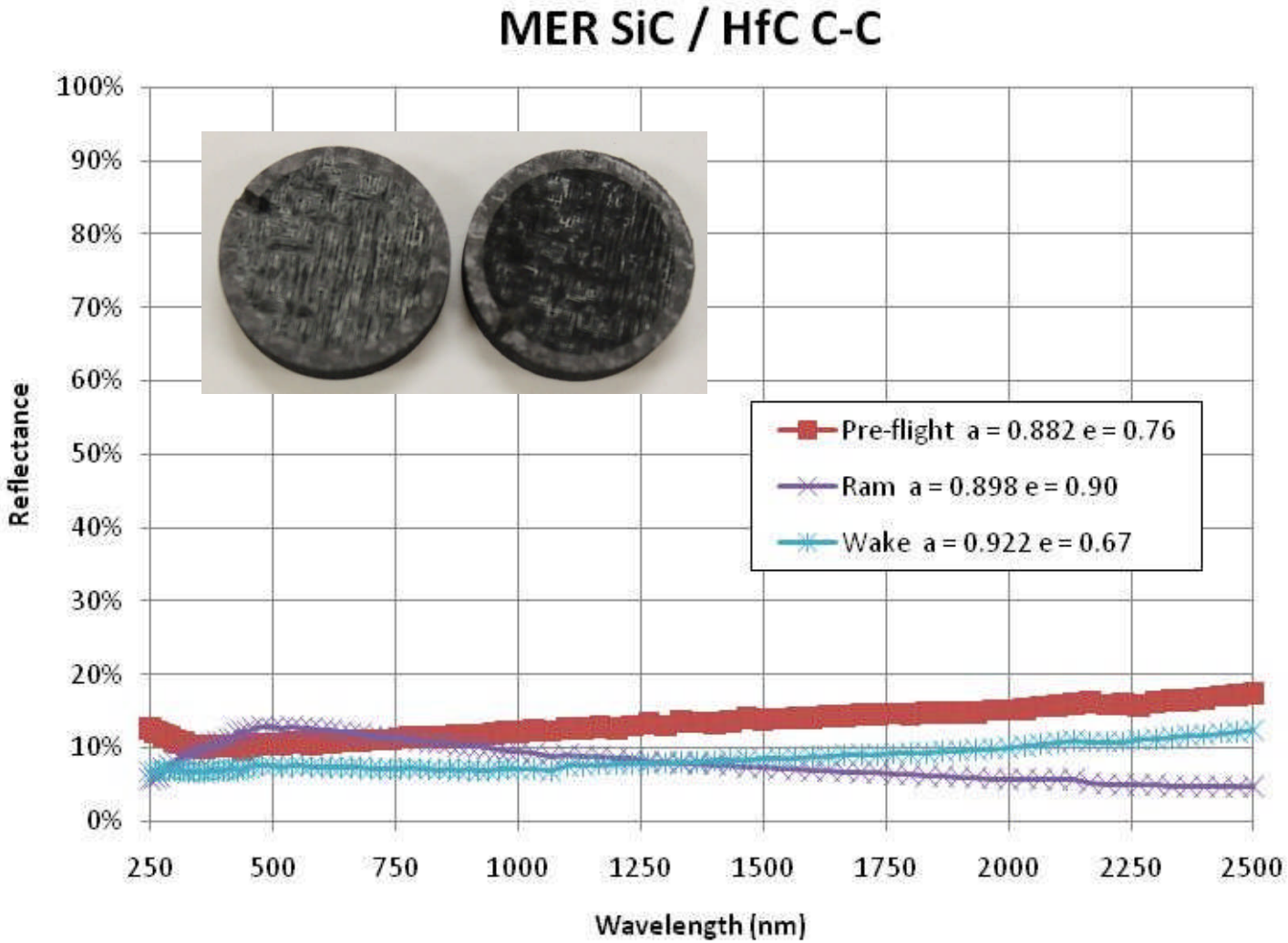
Wake-facing side

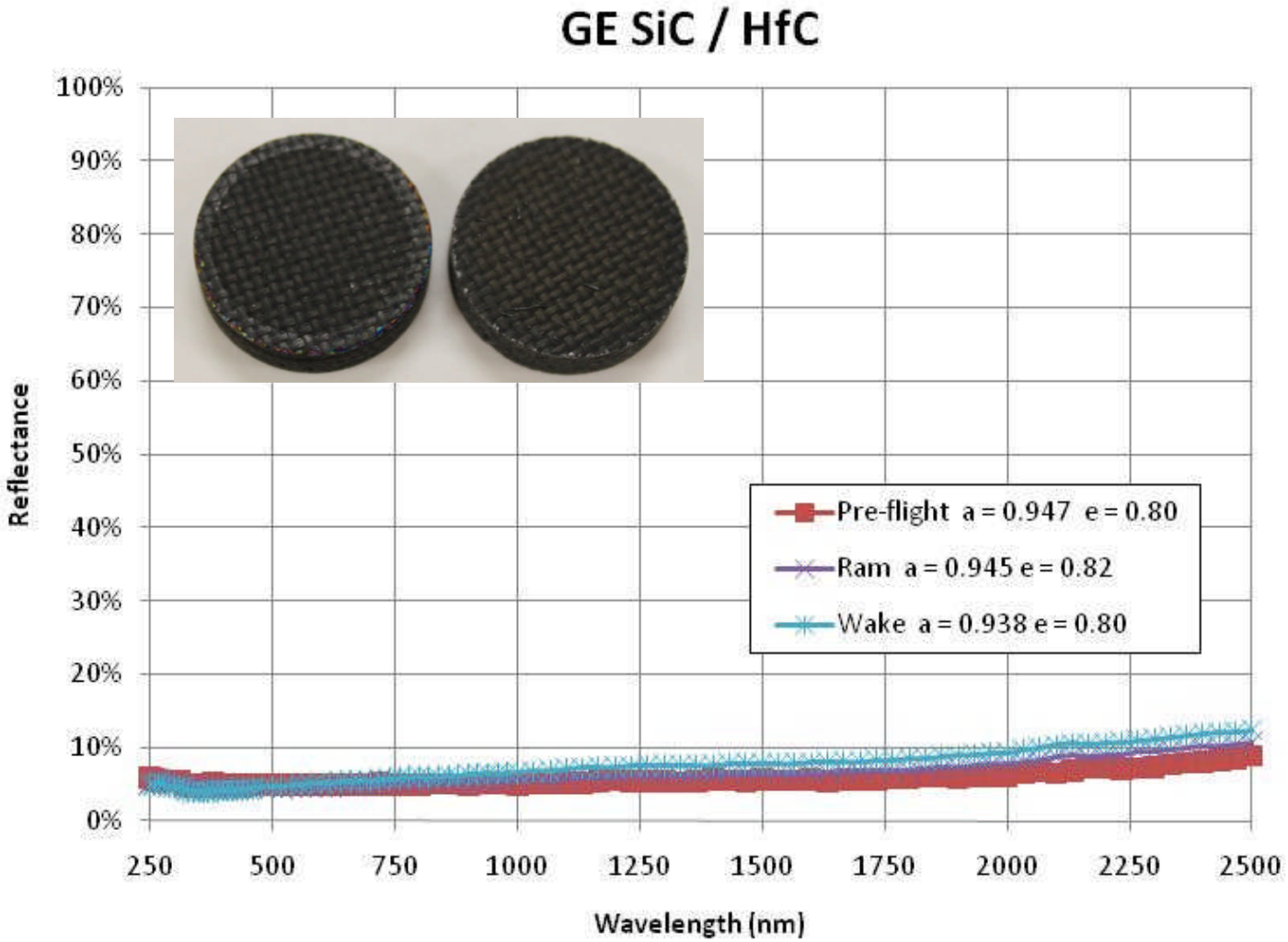
- ~1.4 x 10^{20} atoms/cm^2 atomic oxygen
- ~ 1,950 equivalent sun-hours UV

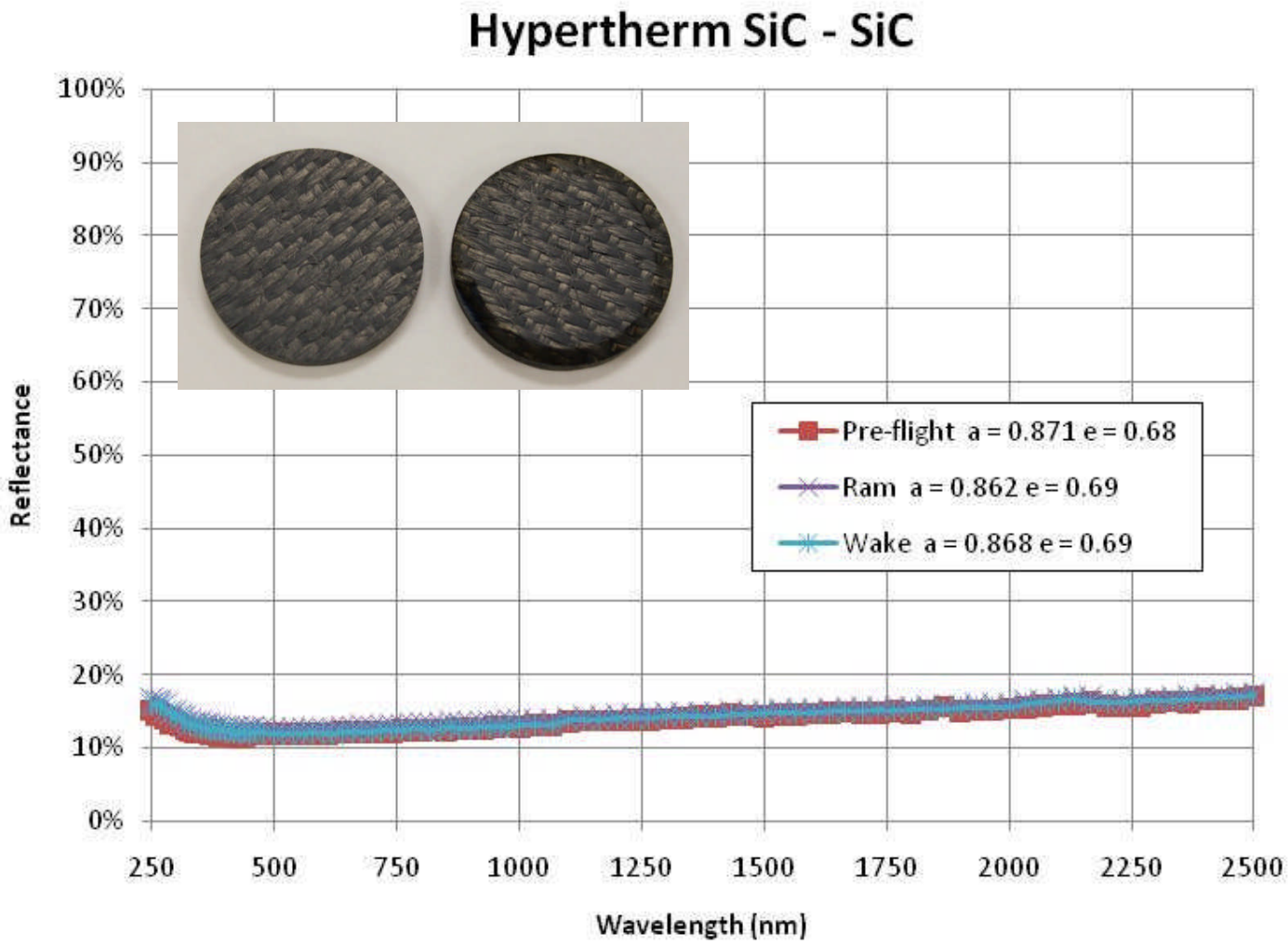
>8,400 thermal cycles of +40/-40 °C

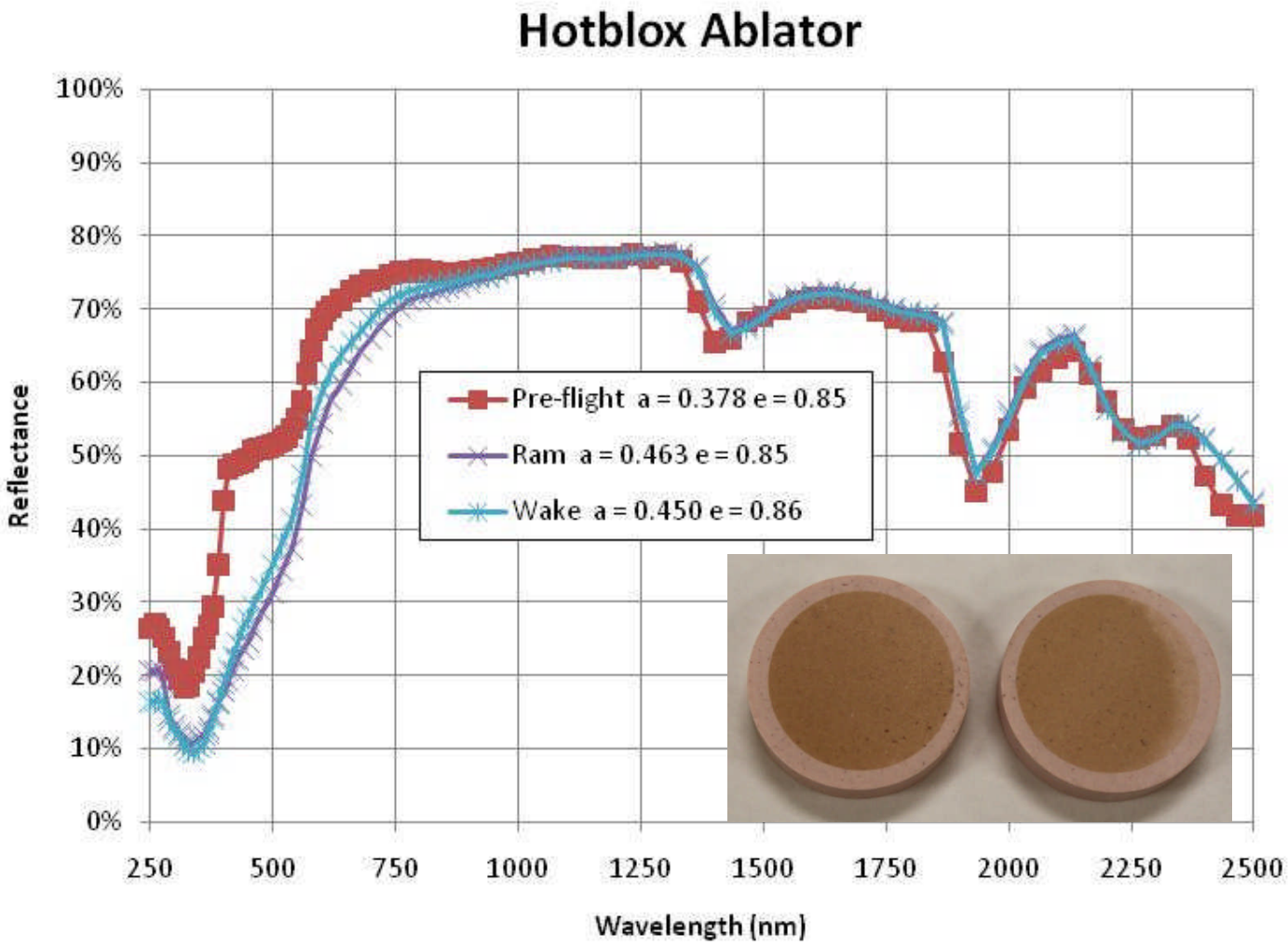

ACC-6
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Reflectance
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)
Pre-flight a = 0.860 e = 0.82
Ram a = 0.845 e = 0.83
Wake a = 0.861 e = 0.82

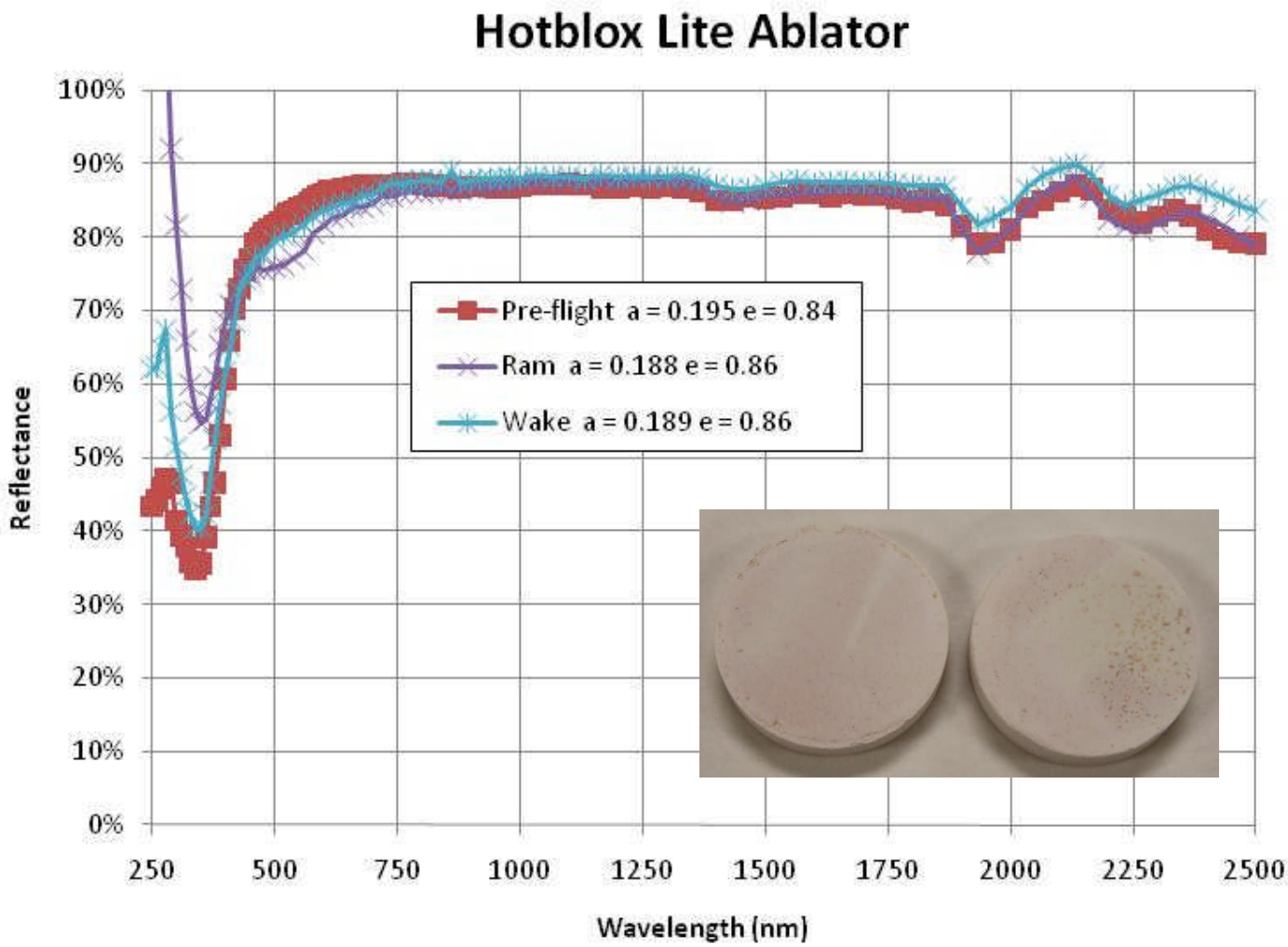

PSI SiC C-C
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Reflectance
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)
Pre-flight a = 0.840 e = 0.52
Ram a = 0.844 e = 0.56
Wake a = 0.838 e = 0.54


MER SiC / HfC C-C
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Reflectance
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)
Pre-flight a = 0.882 e = 0.76
Ram a = 0.898 e = 0.90
Wake a = 0.922 e = 0.67


GE SiC / HfC
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Reflectance
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)
Pre-flight a = 0.947 e = 0.80
Ram a = 0.945 e = 0.82
Wake a = 0.938 e = 0.80

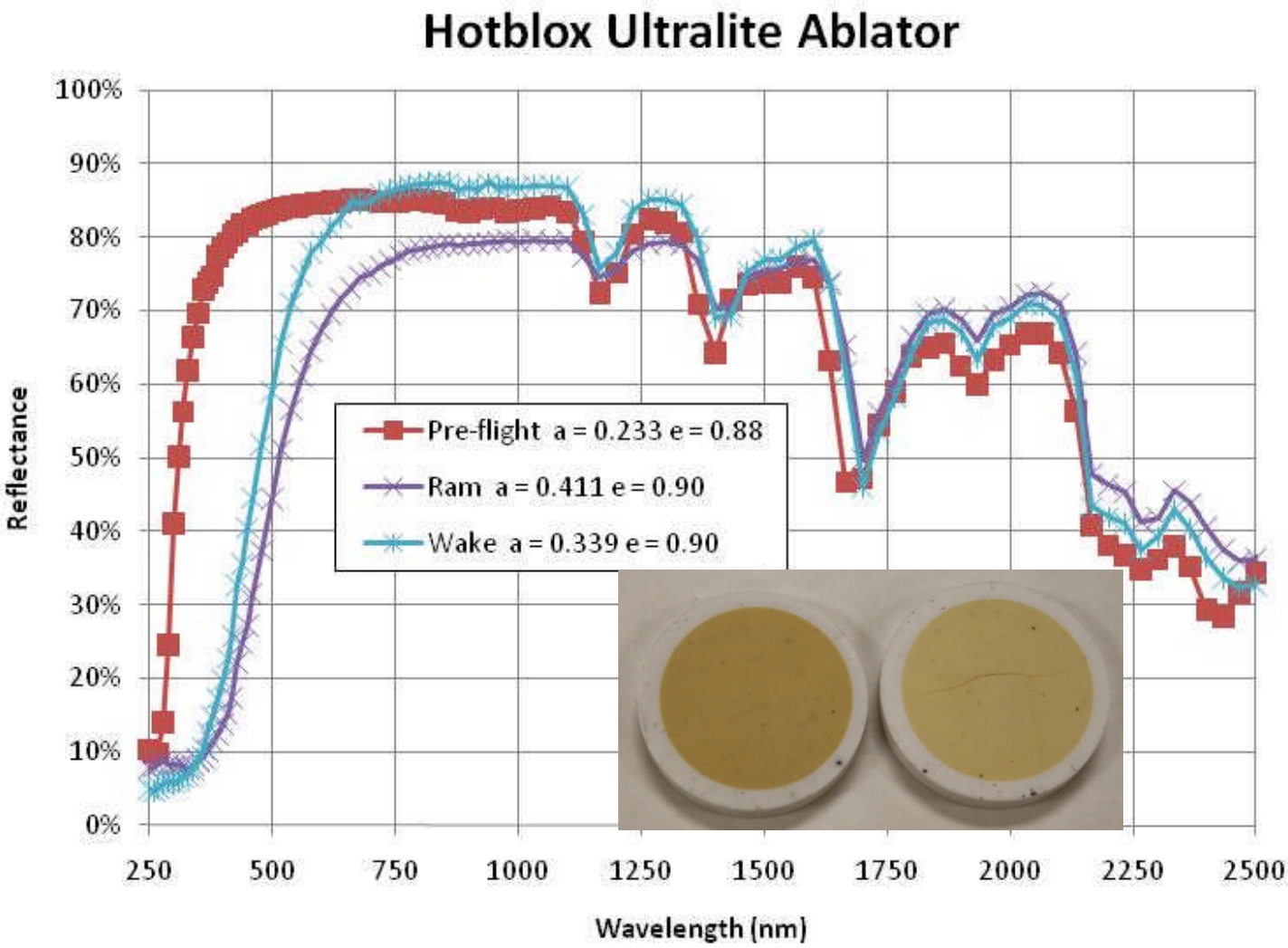

Hypertherm SiC - SiC
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Reflectance
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)
Pre-flight a = 0.871 e = 0.68
Ram a = 0.862 e = 0.69
Wake a = 0.868 e = 0.69

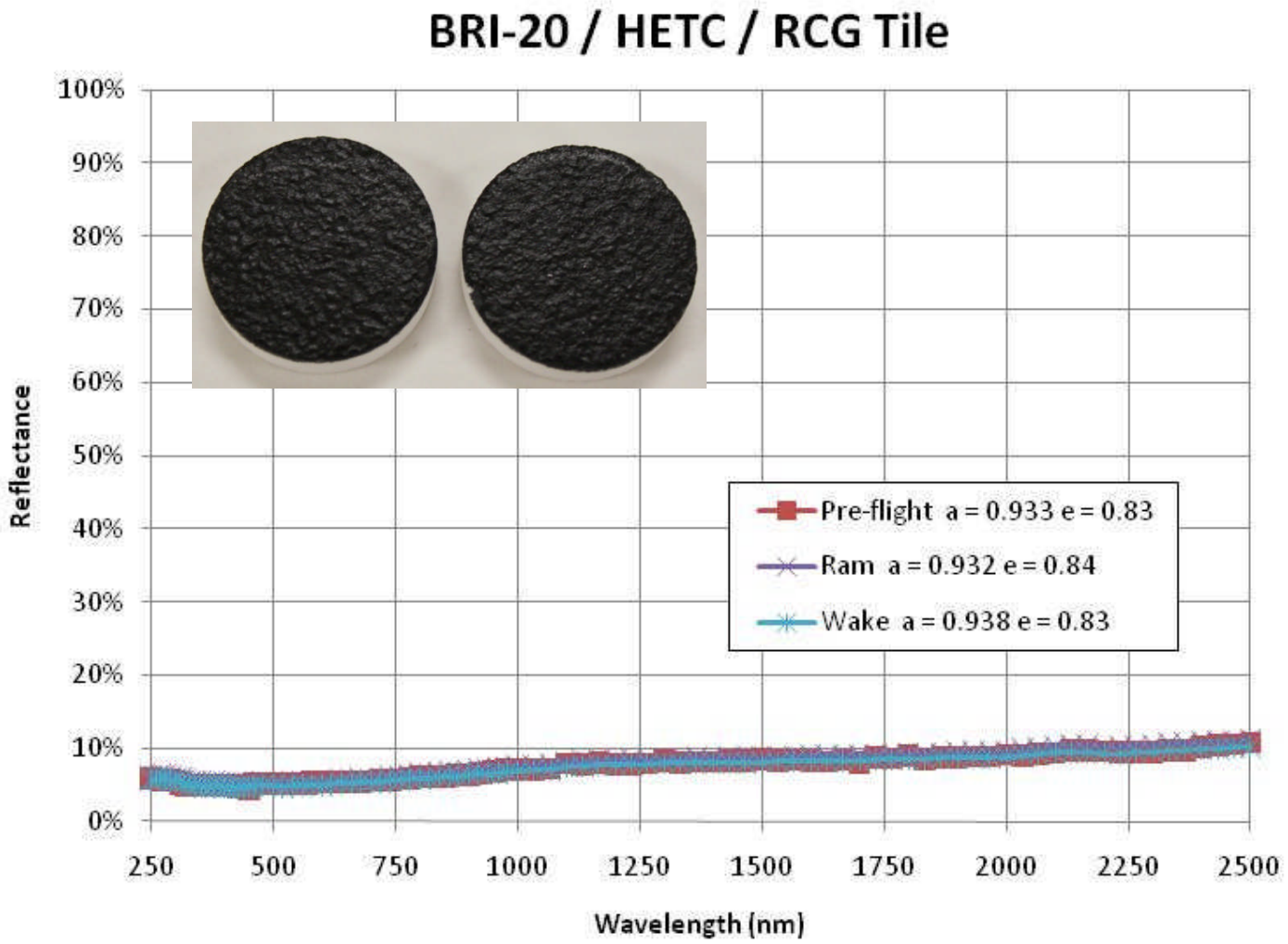

Hotblox Ablator
Reflectance
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)
Pre-flight a = 0.378 e = 0.85
Ram a = 0.463 e = 0.85
Wake a = 0.450 e = 0.86

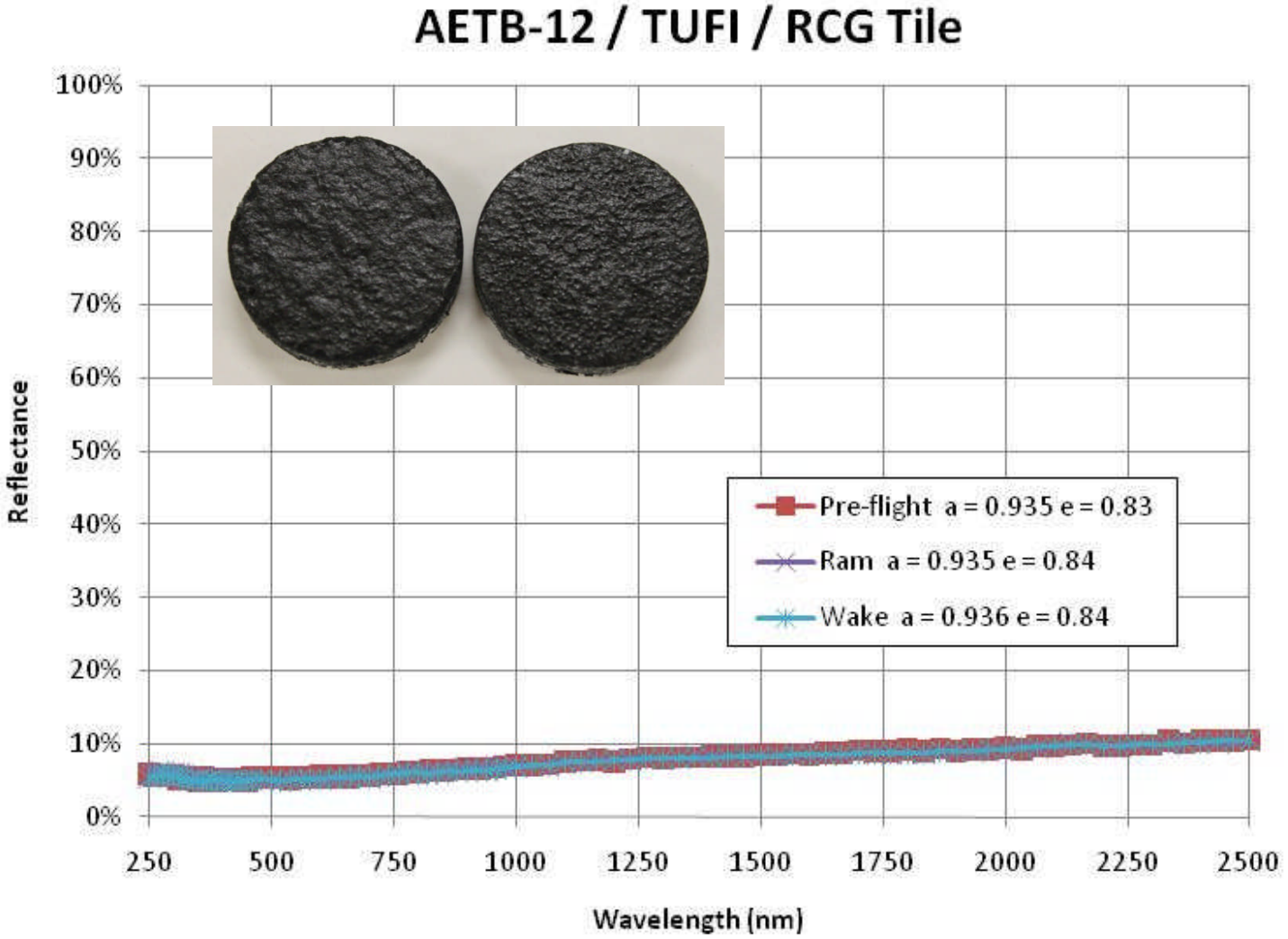

Hotblox Lite Ablator
Reflectance
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)
Pre-flight a = 0.195 e = 0.84
Ram a = 0.188 e = 0.86
Wake a = 0.189 e = 0.86

Atomic oxygen stimulated fluorescence

- LDEF experiment A0034 showed that AO can change fluorescence of materials
- Both ram and wake Hotblox Lite more reflective in UV wavelengths, proportional to AO exposure
- Concurs with post-flight fluorescence under black light

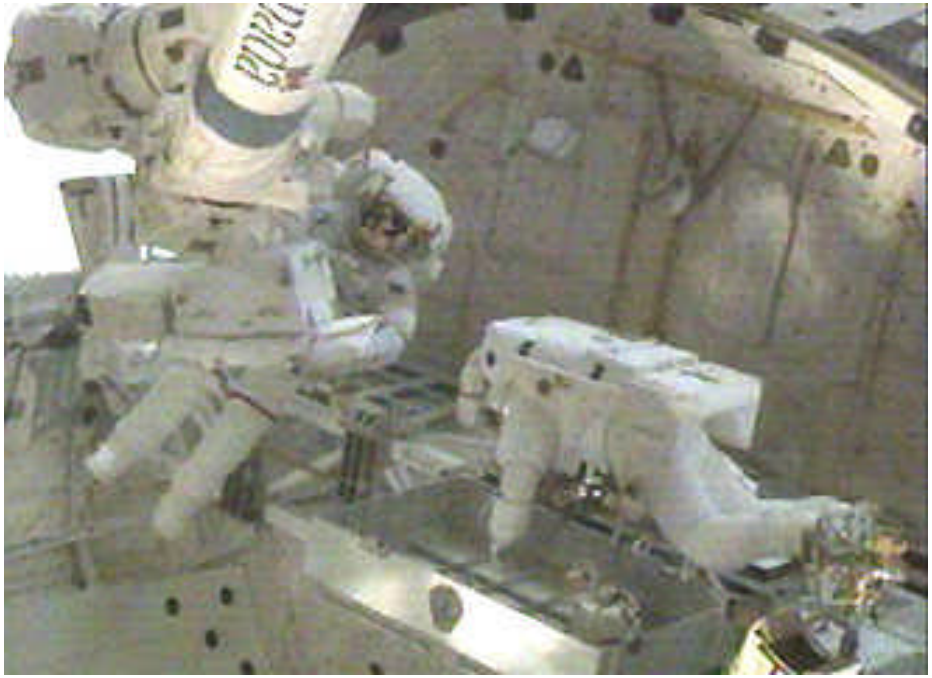

Hotblox Ultralite Ablator
Reflectance
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)
Pre-flight a = 0.233 e = 0.88
Ram a = 0.411 e = 0.90
Wake a = 0.339 e = 0.90

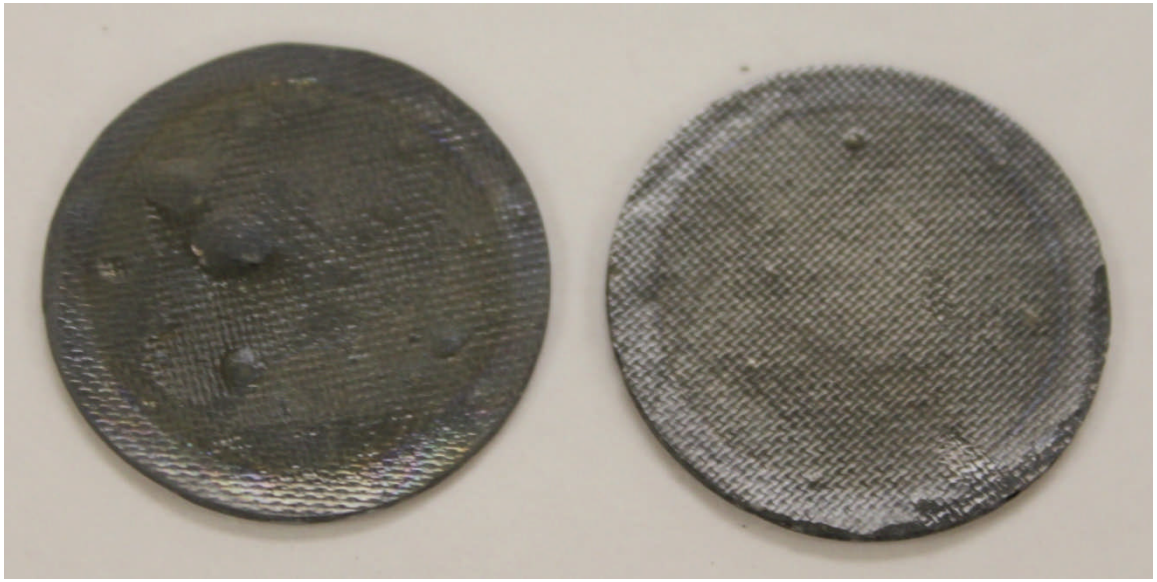

BRI-20 / HETC / RCG Tile
Reflectance
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)
Pre-flight a = 0.933 e = 0.83
Ram a = 0.932 e = 0.84
Wake a = 0.938 e = 0.83


AETB-12 / TUFI / RCG Tile
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Reflectance
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)
Pre-flight a = 0.935 e = 0.83
Ram a = 0.935 e = 0.84
Wake a = 0.936 e = 0.84

Additional material from Marshall

- NOAX-D (non-oxide adhesive experimental) from Andy Hodge





NOAX-D	Solar Absorptance	Infrared Emittance
Pre-flight	0.855	0.86
Post-flight Ram	0.882	0.84
Post-flight Wake	0.871	0.86

Mass Changes

- Slight increase in mass for plain Hotblox, PSI SiC C-C
- No significant change in mass
  - Tile materials
  - Hotblox Lite
  - Hyper-Therm SiC – SiC
  - NOAX-D
- Slight decrease in mass
  - Hotblox Ultralite
  - C-CAT ACC-6
- Significant AO erosion of SiC / HfC materials

In conclusion:

MISSE-6 contributed to advancing the TRL of these materials.

Synergistic effects between AO, UV, and vacuum not easy to reproduce on the ground.

Further details of the LNTPMT program can be found –

- MSFC-RPT-3493: TPS Materials Properties Testing and Evaluation ---Integrated Test Plan and Report
- MSFC-RPT-3486: Effects of Space and Planetary Environments on TPS Materials --- Integrated Test Report