Micromechanical Characterization and Testing of Carbon Based Woven Thermal Protection Materials

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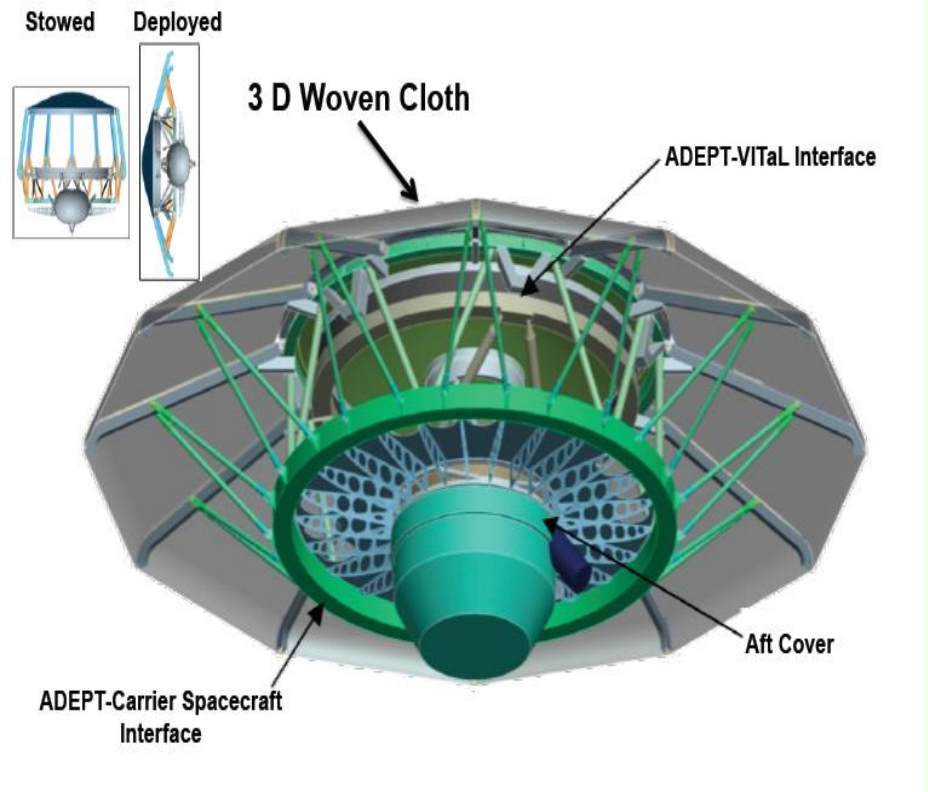
Overview

- **Background**
- **Objectives**
- **Woven carbon fabric**
- **Arcjet tests**
- **SEM observations**
- **Mechanical testing**
- **Conclusions**
- **Recommendations for future work**
- **Acknowledgements**

ADEPT: Background

- **Adaptive Deployable Entry Placement Technology (ADEPT)**
- **Entry system for ADEPT resembles an umbrella, with dry woven carbon cloth skin**
- **Stowed for launch within the rocket's shroud and deployed in deep space, prior to atmospheric entry**
- **Lower ballistic coefficients and heat rates allowing better scientific instruments and efficient TPS**
- **Carbon fabric will experience combination of thermal-mechanical loads**



ADEPT for the Venus Intrepid Tessera Lander (VITaL) Mission[1,2]

1. *Smith et. al.,* "Venus In Situ Explorer Mission Design using a Mechanically Deployed Aerodynamic Decelerator", *Big Sky IEEE Aerospace Conference, Big Sky Montana, March 2-9, 2013.*
2. *Arnold et. al., "Arcjet Testing of Woven Carbon Cloth for Use on Adaptive Deployable Entry Placement Technology", Big Sky IEEE Aerospace Conference, Big Sky Montana, March 2-9, 2013.*

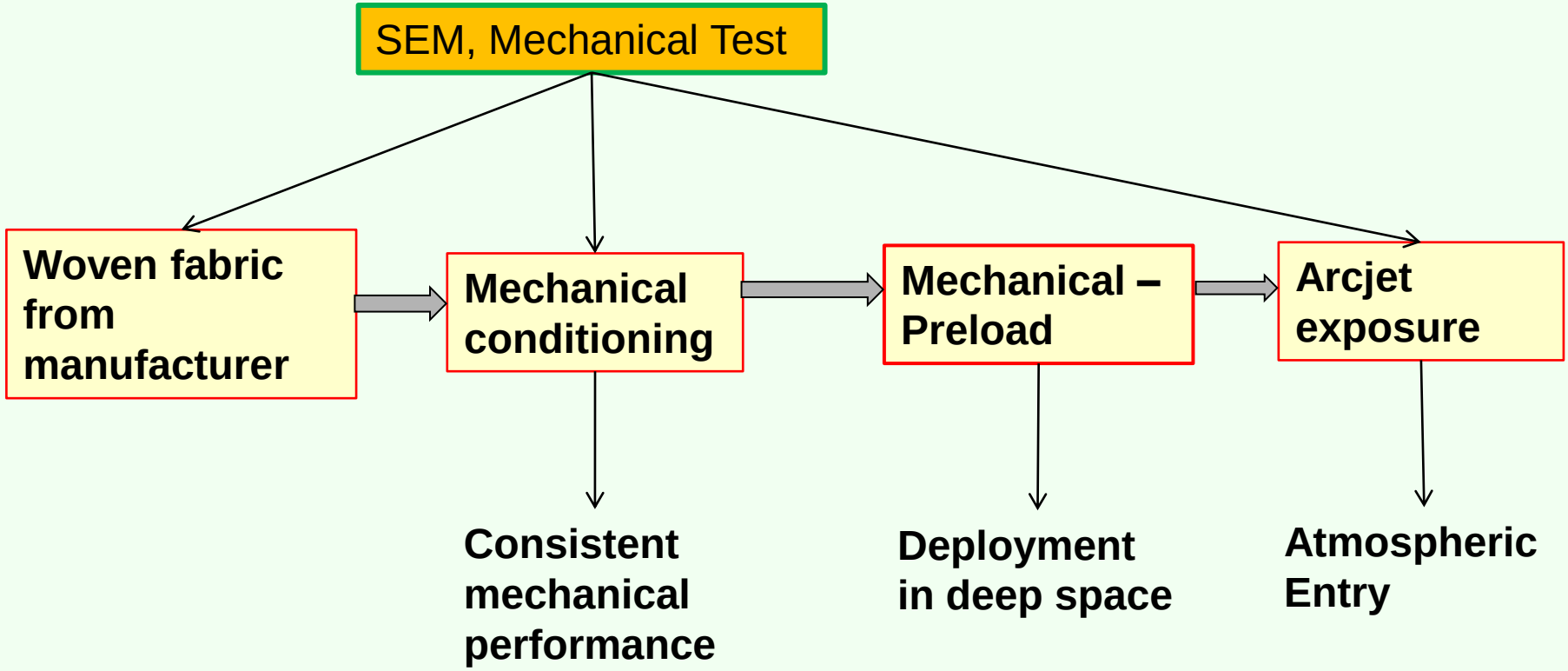
Objectives

- **Investigate micro-structural changes in woven TPS, after exposure to the entry like conditions**
- **Investigate the effects of thermal exposure on mechanical performance of woven TPS**
- **Provide feedback to the design team in order to build a robust system**

Characterization Techniques

- **Scanning Electron Microscopy (SEM) with Energy Dispersive X-ray (EDX)**
  - **Analyze the pre and post arcjet woven TPS at micro-structural scale by examining the top and bottom surface**
  - **Analyze chemical changes due to arcjet exposure**
- **Mechanical Testing**
  - **Obtain load bearing capacity and stiffness for individual yarns (pre and post arcjet)**
  - **Obtain load bearing capacity and stiffness of woven fabric (pre and post arcjet)**
- **Micro CT scan**
  - **Compute layer thickness**
  - **Investigate structural changes**

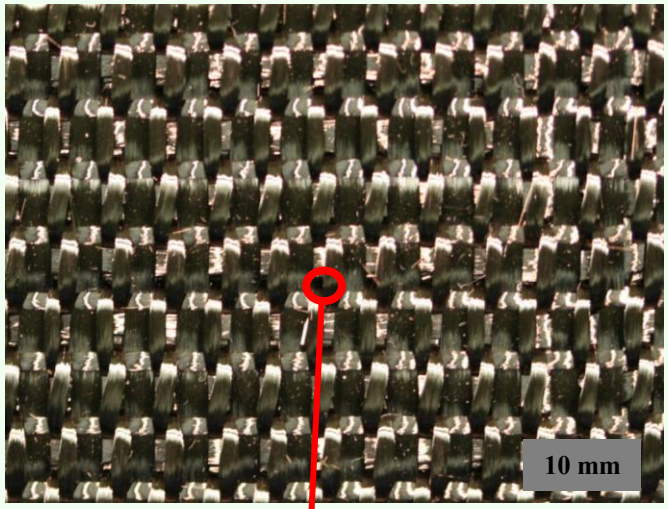
Process Diagram



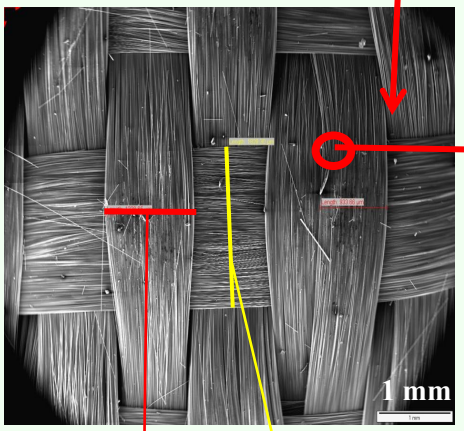
Woven TPS Cloth – Introduction (I)

- **3Dimensional weave with carbon yarns**
- **Multilayer system**
- **Different weave combinations**
- **Yarn width : 1.2 – 1.9 mm**
- **Carbon fiber width: ~5.0 microns**
- **Thin sizing layer is applied to the fabric**

Optical micrograph of carbon fabric

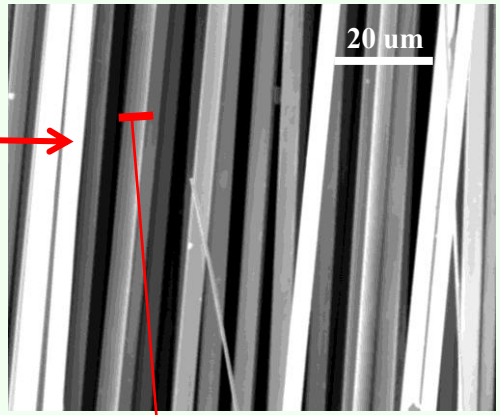


SEM image showing the yarns



1228 um 1829 um

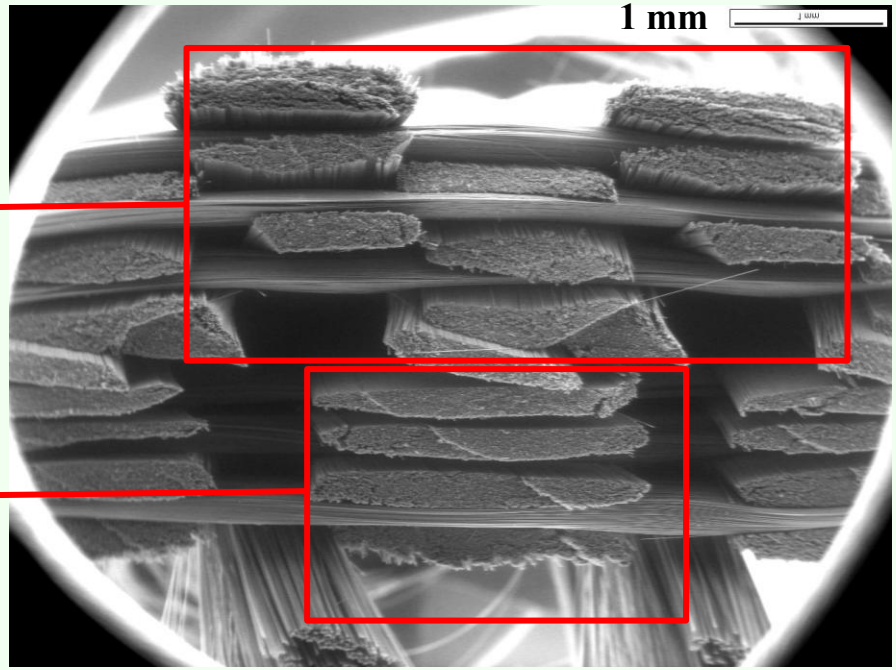
SEM image showing fibers



5 um

Woven TPS Cloth – Introduction (II)

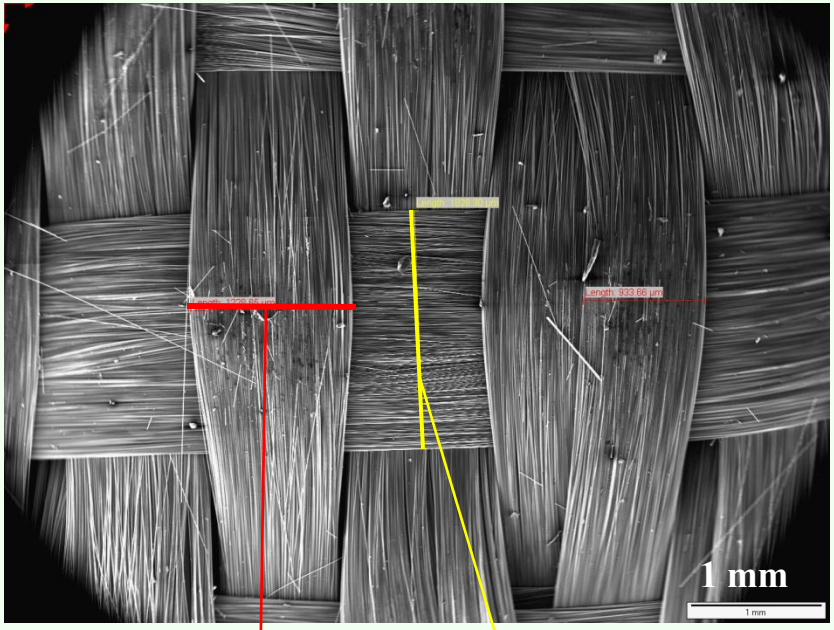
- **Combination of different weaves for different functions**
  - **Top woven layers for optimum thermal performance**
  - **Bottom weave layers for optimum structural performance**
- **Mechanical conditioning (multiple tension cycles) are performed to stabilize the cloth**



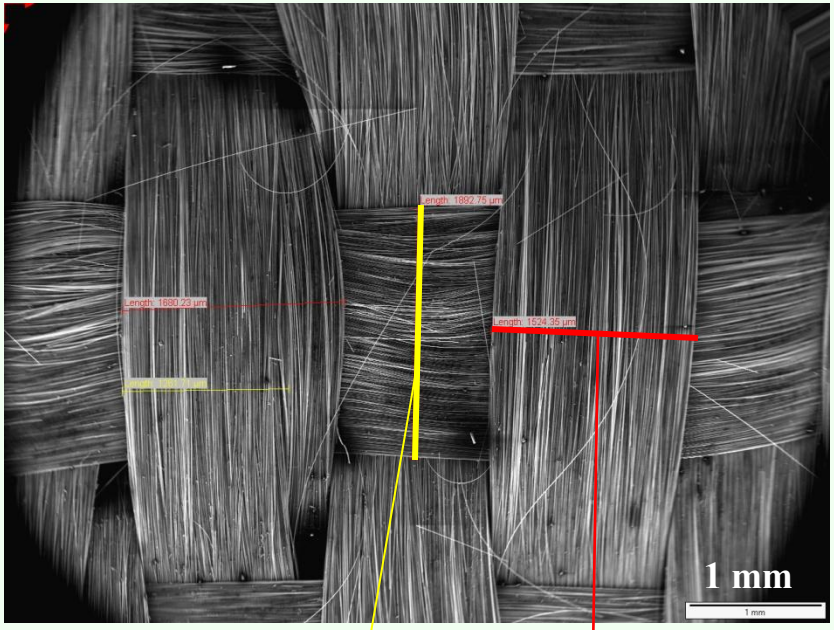
Through the thickness picture

Conditioning Process

Unconditioned

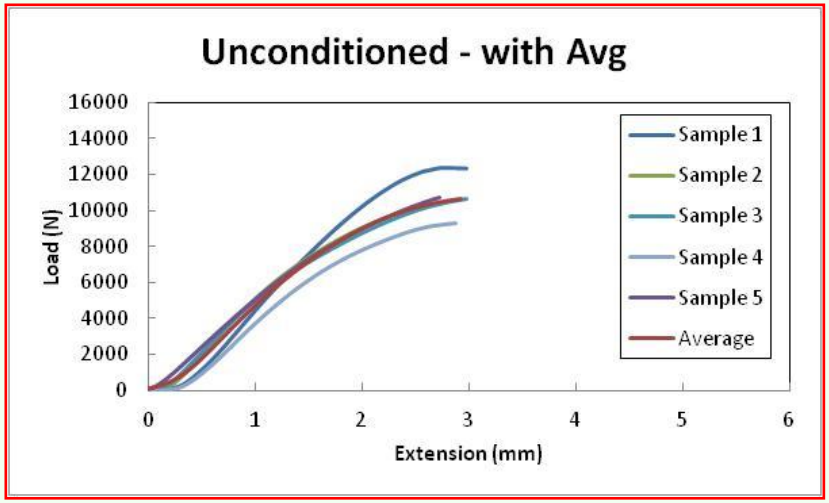


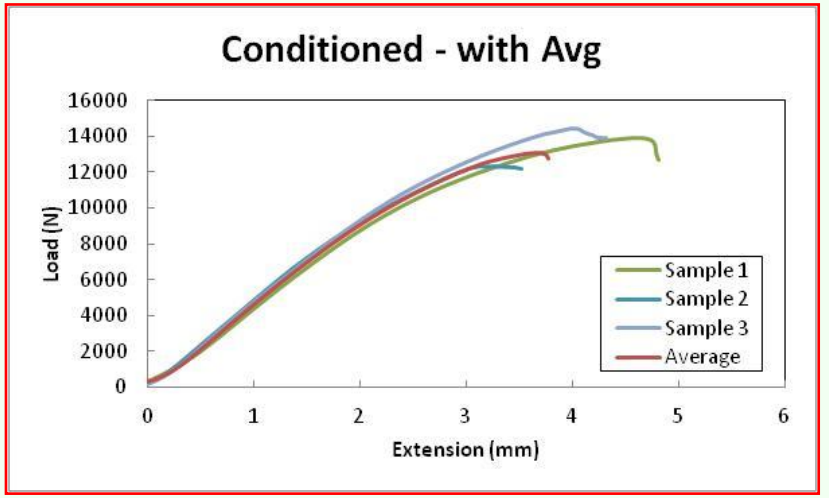
Conditioned



Examination of several unconditioned vs. conditioned zones show that overall yarn width changes as a result of conditioning.

Fabric Test – Pre and Post Conditioning



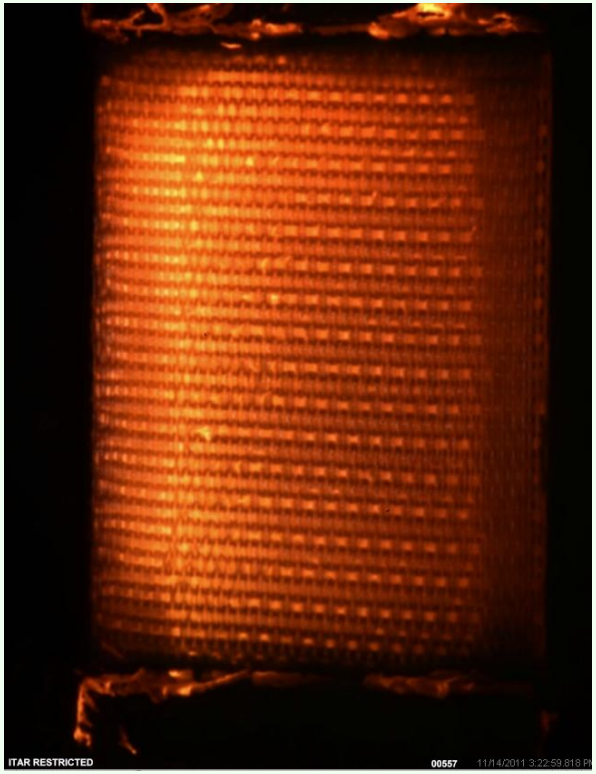


- **Conditioning reduces the variability in the mechanical properties of the fabric.**

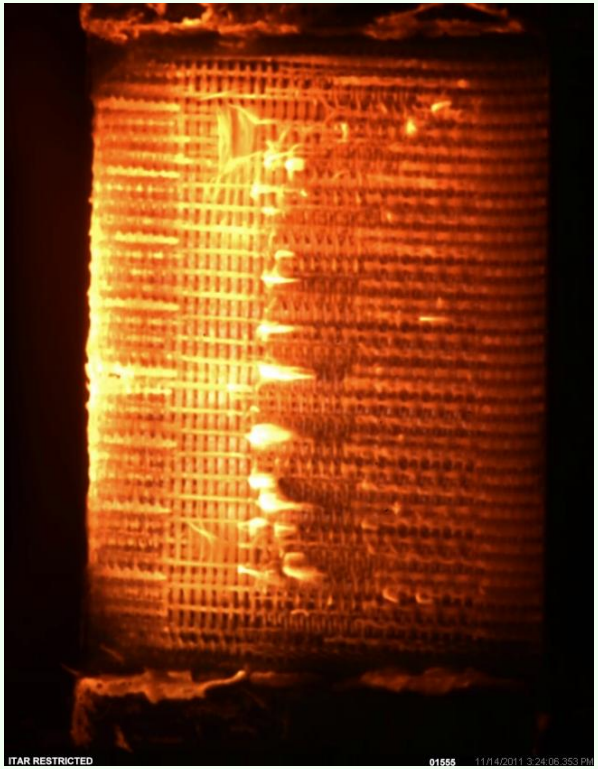
Arcjet Test 1: Wedge Configuration at JSC

- **Test to down-select optimum weave based on aerothermal performance**
- **Two entry conditions representing ADEPT-VITaL mission**
  - **136 W/cm^2 at 3.35 kPa pressure, 86 sec exposure**
  - **246 W/cm^2 at 9.6 kPa pressure**
- **Cloth under uni-axial tension**
- **Surface temperature – 1800^{0}C**
- **Upper layers were burnt through and the structural layers were still remaining.**

JSC Test Results



Shortly after insertion



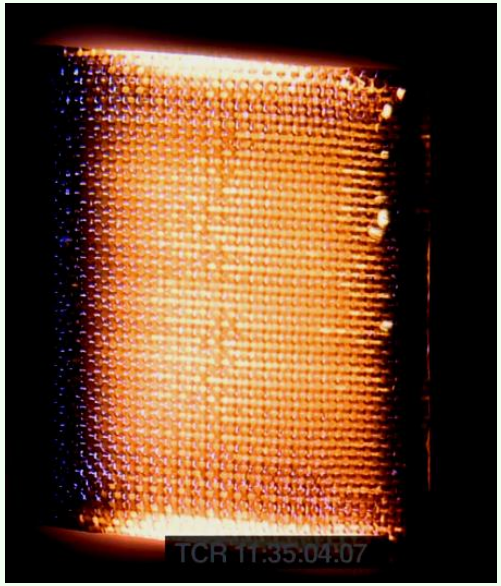
After burn-through to structural layer

This test series resulted in selection of the suitable weave pattern for future development.

Arcjet Test II : BLAM test at ARC

- **Objectives:**
  - **Evaluate the down selected fabric's ability to maintain structural integrity under combined aerothermal and biaxial loading.**
  - **Evaluate the rate of layer loss as a function of different combined loads.**

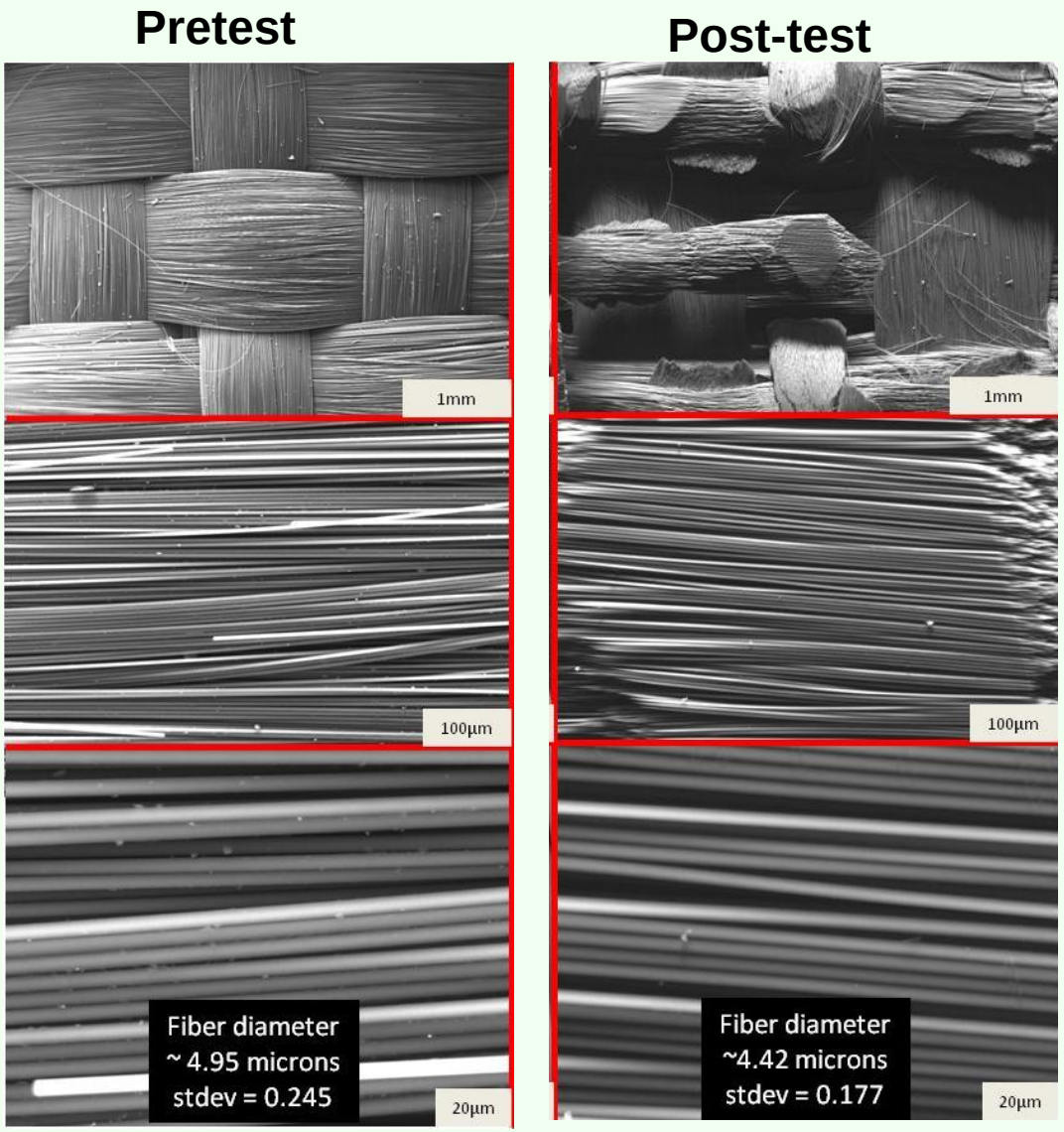
Model	Heat Flux on Fabric (W/cm^2)	Warp Running Load (lbs/in)	Weft Running Load (lbs/in)	Run Time (seconds)
BLAM-B-3	136	750	375	35



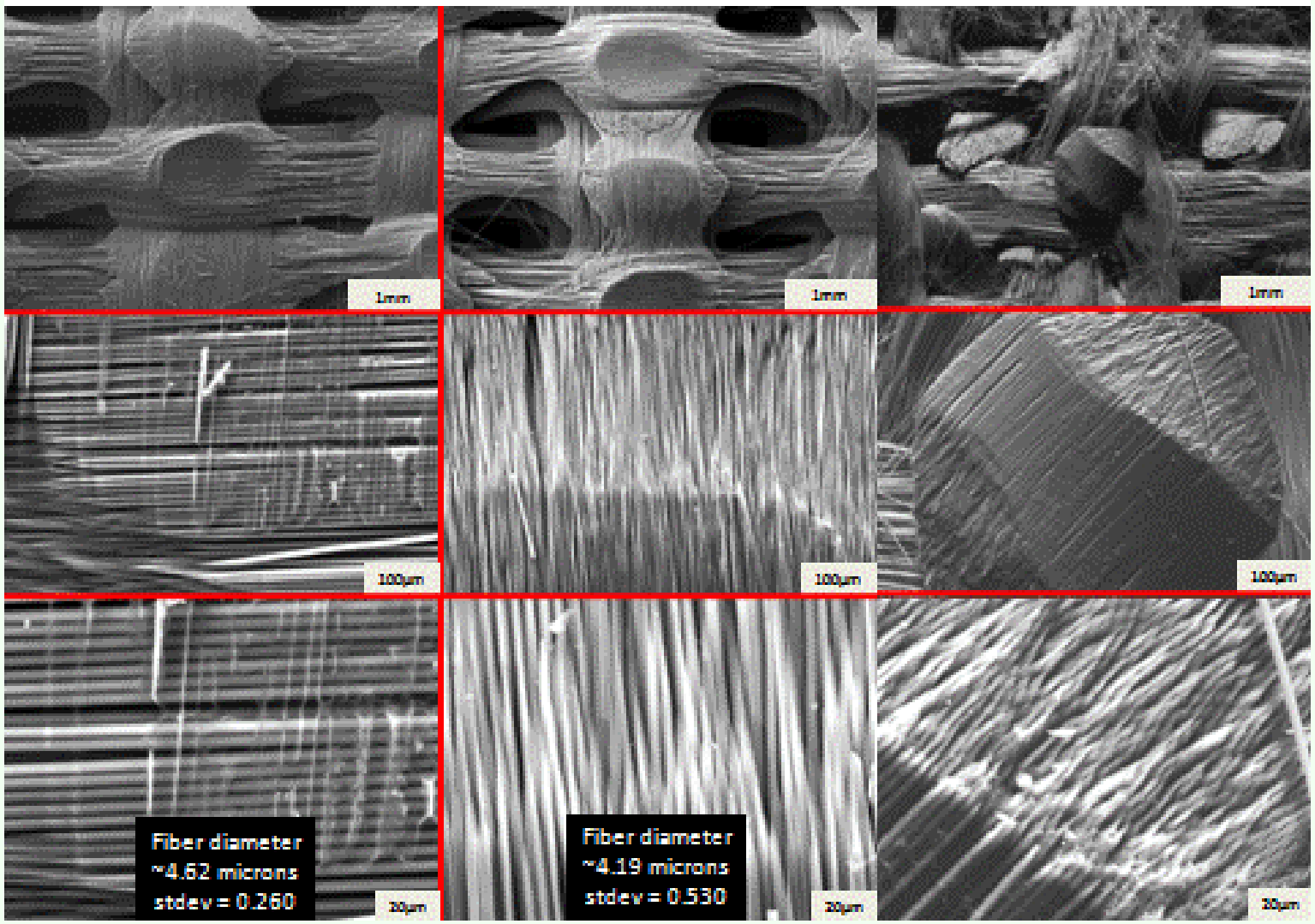
The tests showed that the structural layer continues to bear the mechanical loads after the loss of thermal layers.

JSC Arcjet Test SEM: Top Surface

- **The top thermal layers were oxidized due to extended exposure.**
- **The bottom structural layers were exposed to plasma.**
- **Significant fiber thinning observed due to oxidation.**



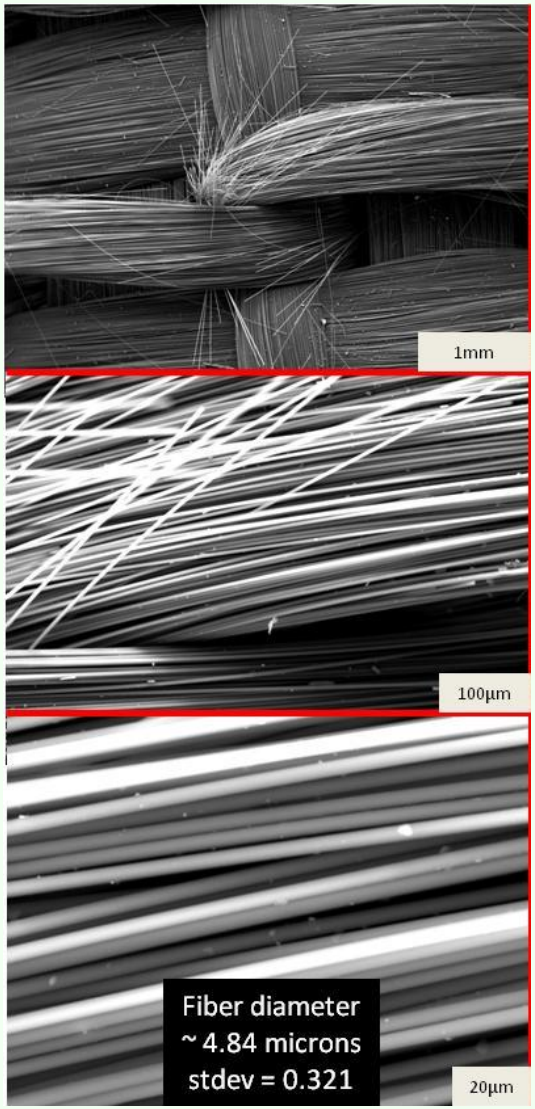
Post JSC Arcjet Test SEM: Top Surface (II)



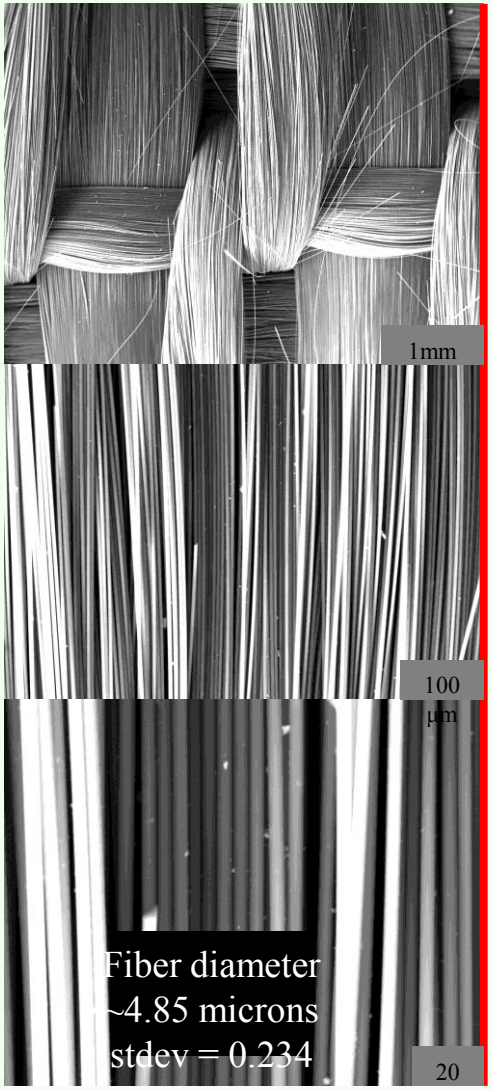
Post JSC Arcjet Test SEM: Bottom Surface

- **No apparent significant change was observed at the bottom surface.**
- **However it is hard to predict to what depth (layer thickness) the oxidation affected the fabric.**

Pretest

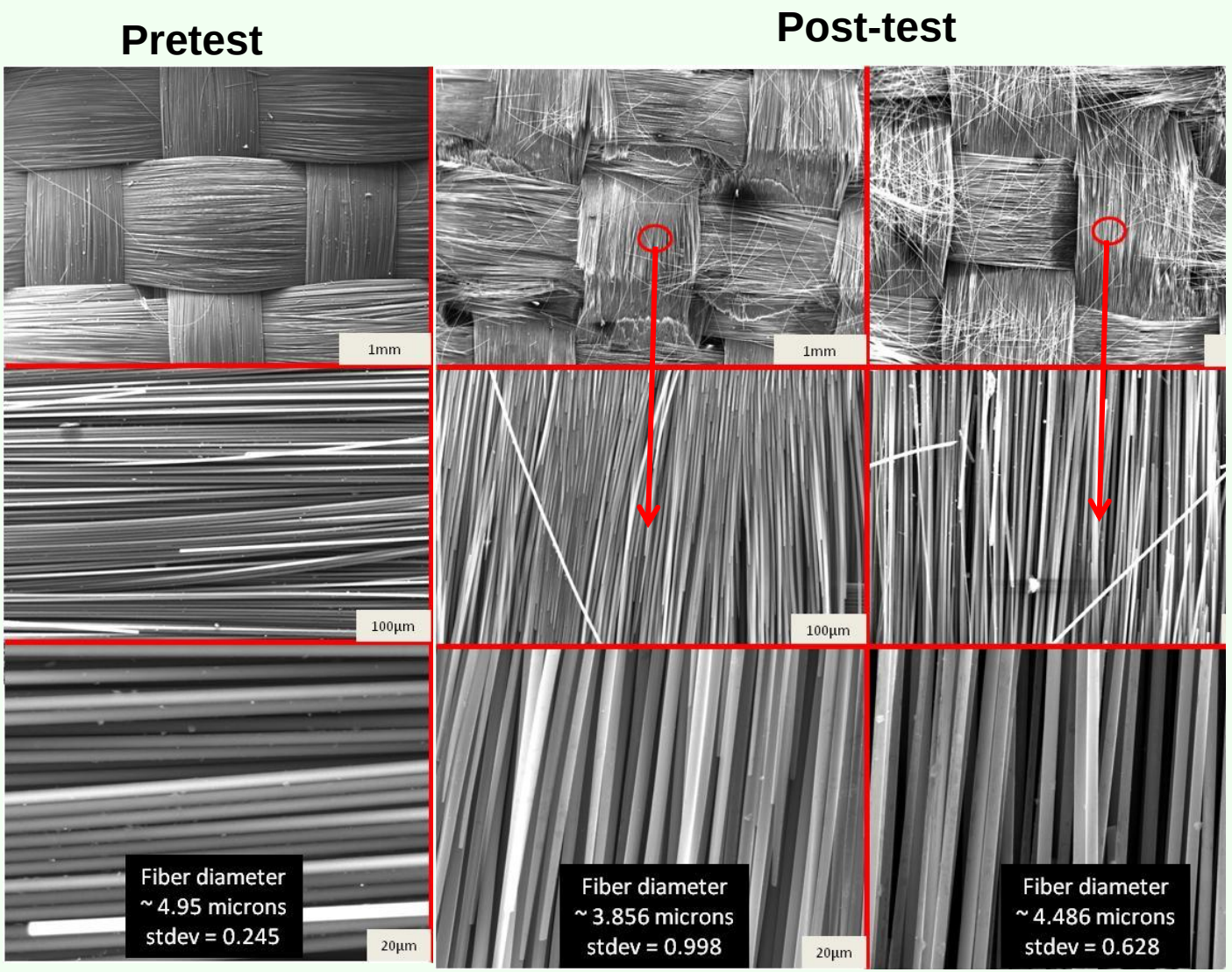


Post-test



Post ARC BLAM-test SEM – Top surface

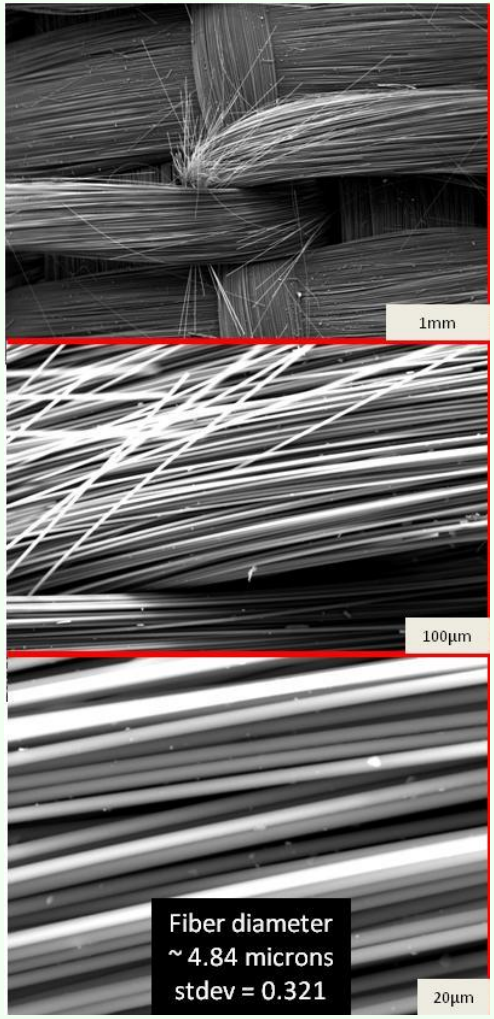
- **Oxidation and fiber thinning was observed in post arcjet cloth.**
- **Due to smaller exposure time not all the top layers were burnt and the bottom ortho layers were not directly exposed to plasma.**



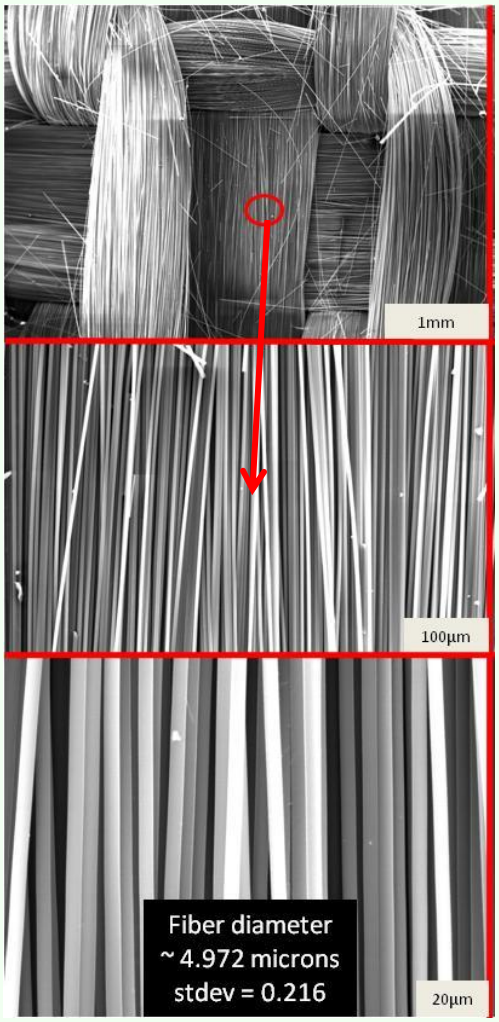
Post Arcjet BLAM-test SEM – Bottom Surface

- **Similar to JSC tests no apparent significant change was observed at the bottom surface.**
- **Again the in-depth oxidation is cannot be predicted and more analysis will be performed to understand the extent of in-depth oxidation and fiber thinning.**

Pretest

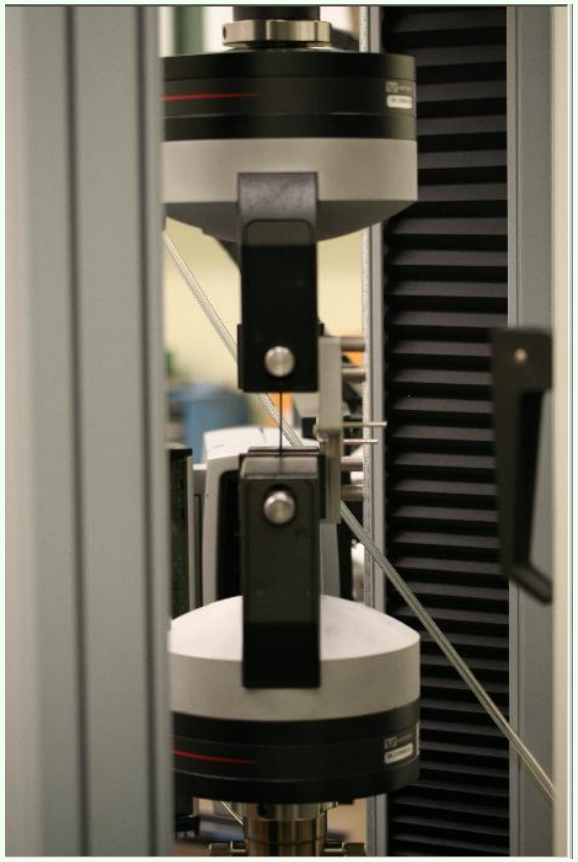


Post-test

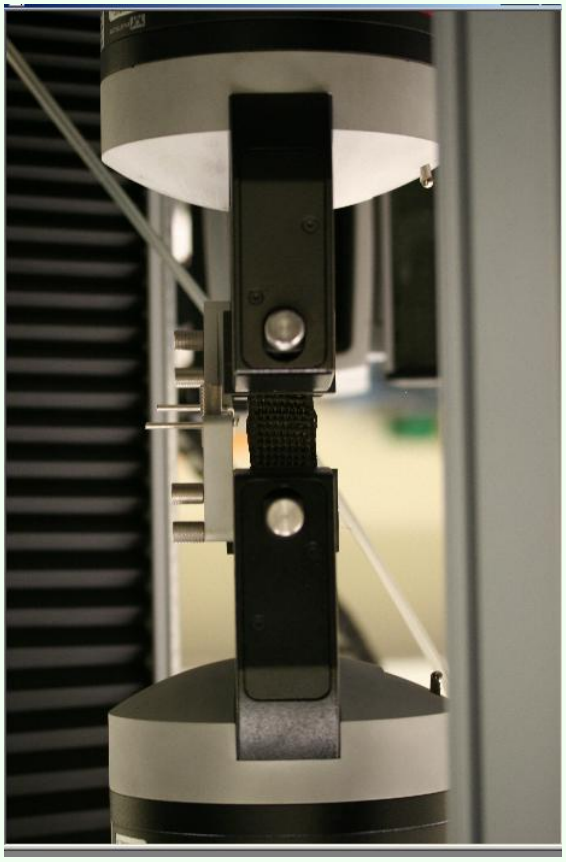


Mechanical Testing of Woven TPS

- **Uni-axial tension tests**
- **Instron 5569 load cell with variable load capacity**
- **Pneumatic grips with significant pressure (avoid slipping)**
- **Pre and post arcjet tests of individual yarns (tow) and woven cloth**



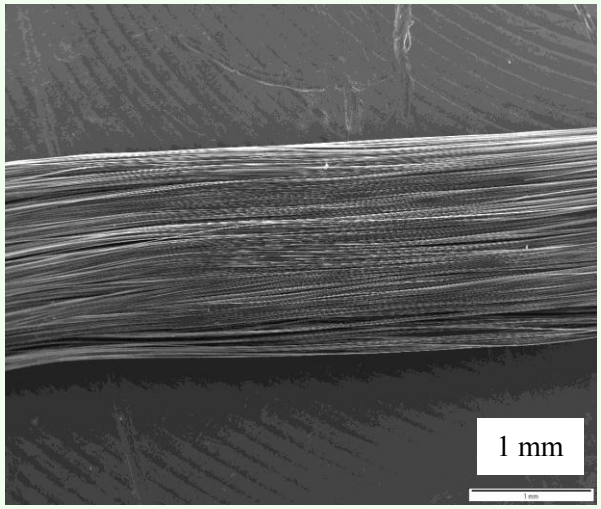
Yarn test

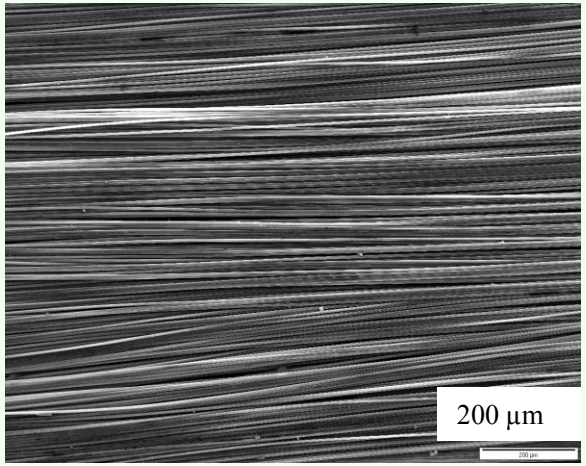


Fabric test

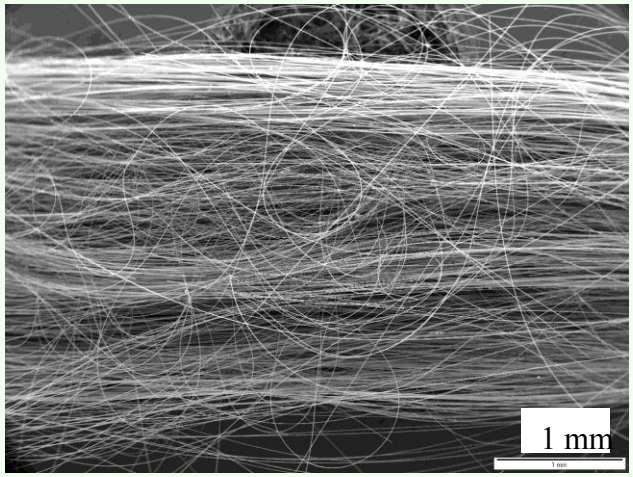
SEM Observation of Yarns

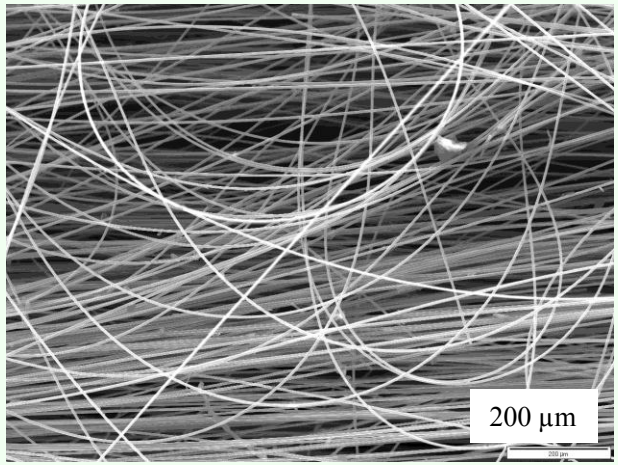
Pre-test





Post-test

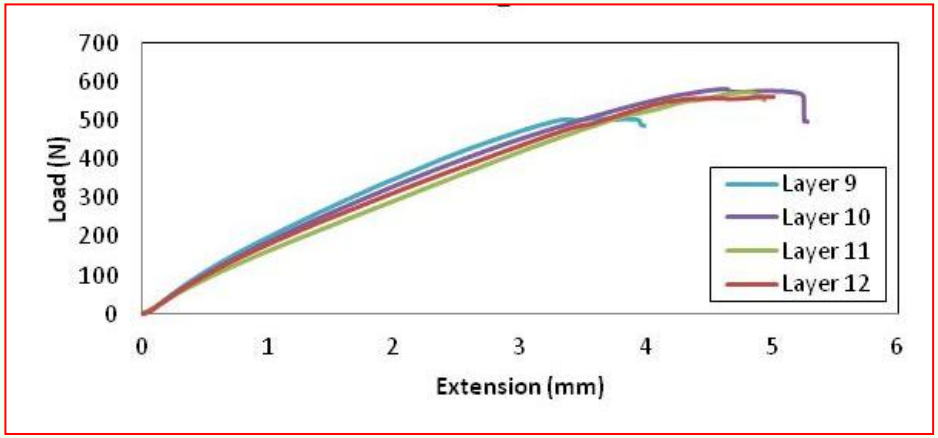




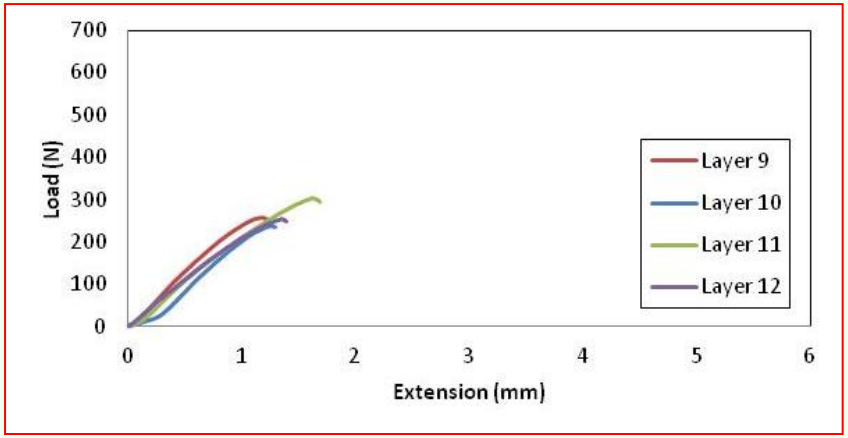
- **The fibers in the yarns become loose after failure**

Yarn Test – Pre and Post BLAM Exposure

Yarns from unexposed fabric

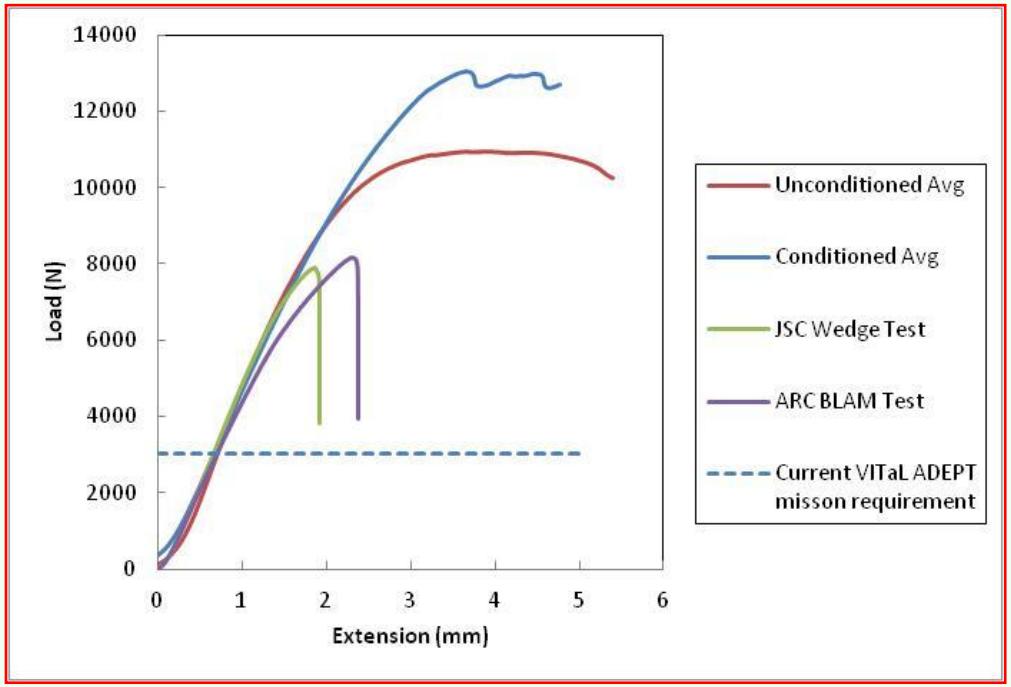


Yarns from post arcjet fabric



- **Individual yarns from the bottom structural layer were carefully extracted and mechanically tested.**
- **~ 50% reduction in strength of yarns (in the structural layer) due to arcjet exposure.**

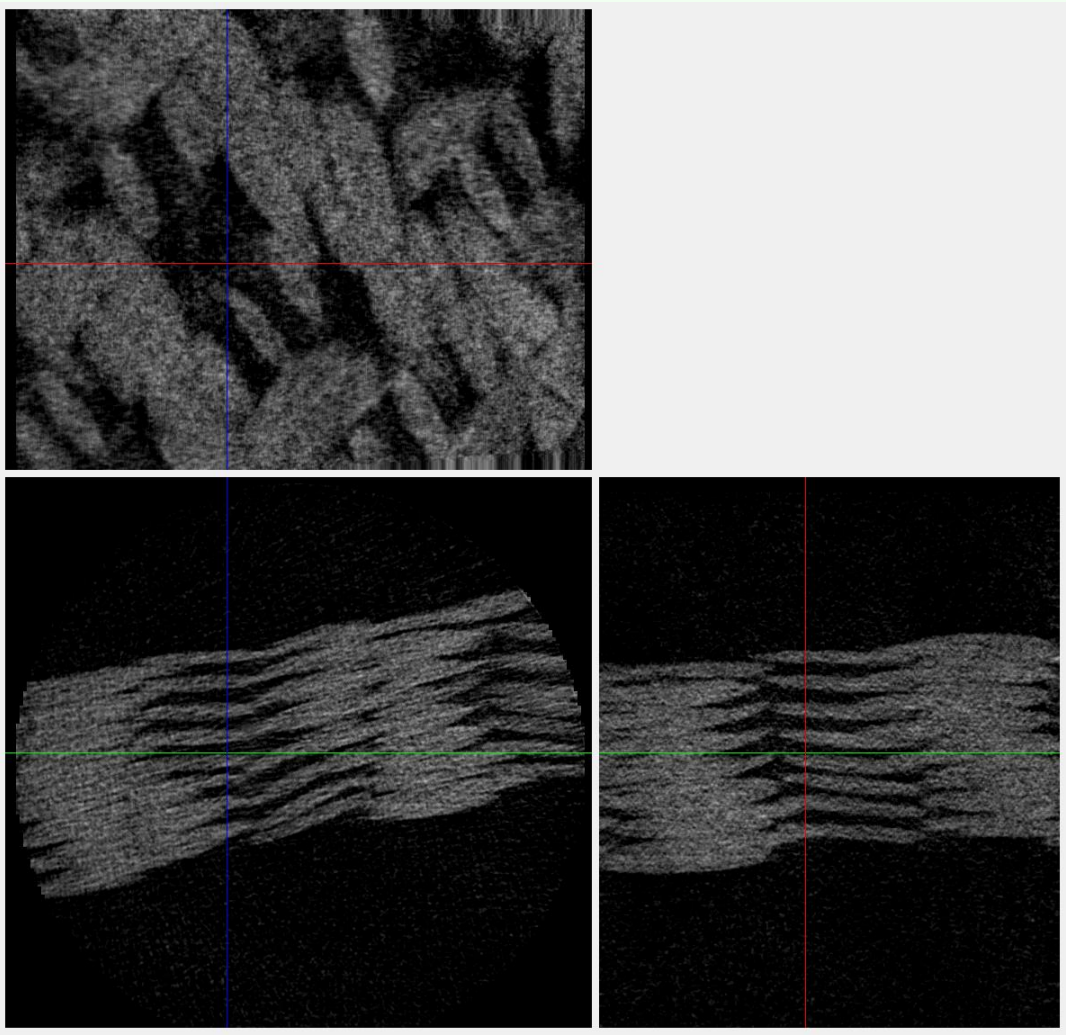
Fabric Test – Pre and Post Arcjet Exposure



- **Preliminary experiment indicate ~ 40% reduction in load bearing capacity of woven cloth due to arcjet exposure**
- **A brittle failure (post exposure) as opposed to slow reduction in strength for pre-exposure cloth.**
- **The cause of embrittlement needs to be investigated.**

Micro CT Scan Capability

- **The micro CT scans of selected woven will be performed to investigate thickness of post arcjet woven cloth and weave conditions after the exposure.**



Conclusions

- **SEM observations of post arcjet cloth shows fiber thinning on the top surface due to oxidation. However, the bottom surface does not show any changes.**
- **Mechanical testing of woven cloth and tows, pre and post arcjet was successfully performed.**
- **The yarn testing shows reduction in tensile strength due to arcjet exposure even for the bottom most structural layer, that didn't show thinning.**
- **The reduction in yarn strength after the arcjet exposure correlates with the reduction in load bearing capacity of the cloth.**
- **These observations of yarn and fabric characteristics will help guide the design of woven carbon fabric for TPS applications.**

Work in- Progress

- **More SEM scans and mechanical testing of carbon clothes and yarns with various arcjet exposure durations are in progress.**
- **Mechanical performance testing of fabric after being subjected to extended mechanical loading will be performed to understand whether preloading affected the reduction in load bearing capacity.**
- **A sample carbon fabric after being subjected to thermal heating to remove sizing will also be tested to understand any contributions coming from sizing (chemical coating of the yarns.)**
- **Micro CT scans will be performed pre and post arcjet exposure to investigate changes in weave and layer thickness after the arcjet exposure.**
- **The results and recommendations from above work will be communicated to the design team to build a robust architecture for future missions.**

Acknowledgements

- **ADEPT Project**
  - **Paul Wercinski**
  - **Peter Gage**
- **Equipment Support**
  - **Josh Alwood (CT Scan)**
  - **Quy Doan (SEM and Instron)**
  - **Jerry Ridge (Instron)**
  - **Jose Chavez (SEM)**

APPENDIX

Yarn Test - Video

Structural Layer Extraction

- **Micro-precision tool and magnifying lens utilized to systematically extract structural yarns, layer by layer**
- **Cloth and surrounding yarns remain intact**
- **Extraction of first two layers imaged below**