Space Shuttle Stiffener Ring Foam Failure Analysis, a Non-conventional Approach.

Philip M. Howard
NASA
Kennedy Space Center
Materials Science Division

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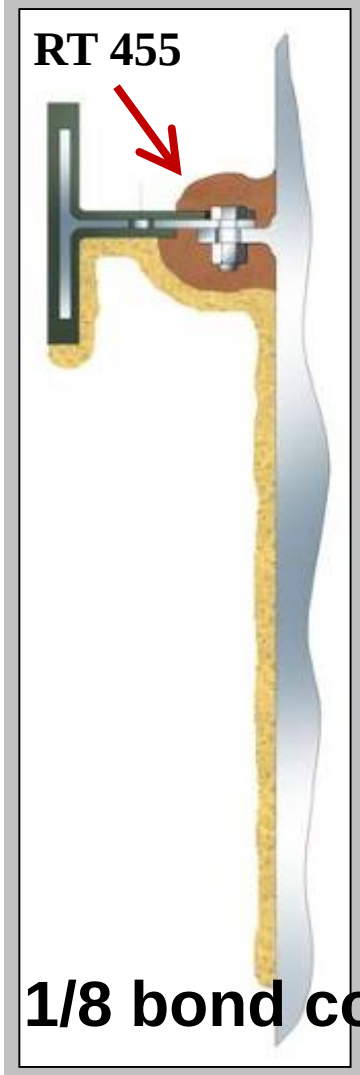
Space Shuttle on Ascent

SRB Recovery

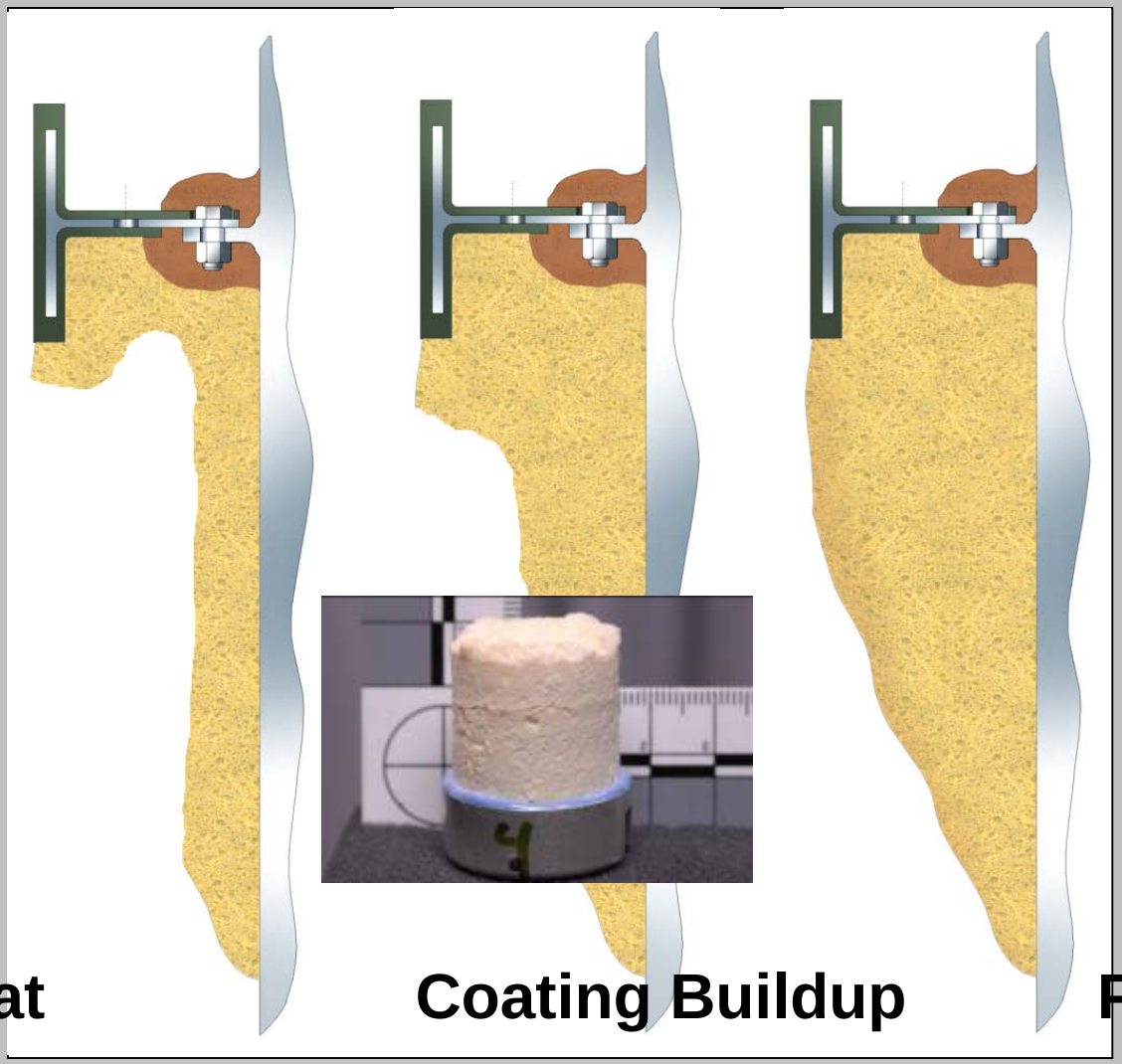
Shuttle Legacy Flight Hardware will Fly on the Space Launch System

Stiffener Ring

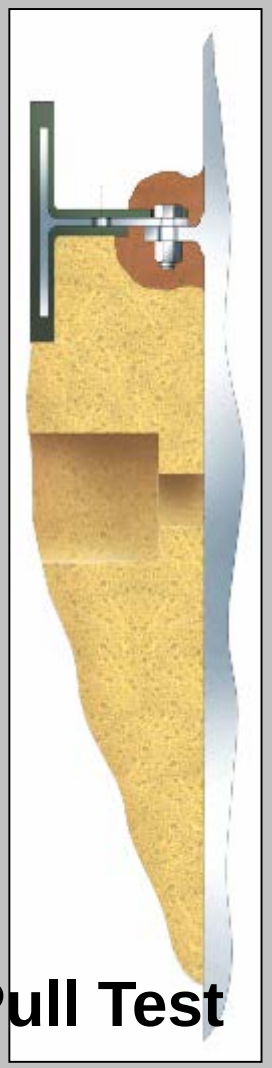
SRB Foam Buildup



1/8 bond coat



Coating Buildup



Pull Test

>20psi

Qualitative Inspection

- ATK define the foam failures qualitatively by visual inspection of the presence or absence of foam residue on the de-bonded surface.

- Foam Failures fall into two categories
  - Adhesive
  - Cohesive
    - Mixture of both

Solid Rocket Booster Stiffener Ring Foam Failure

Solid Rocket Booster Stiffener Ring Foam Failure

The classical methods of analysis failed to provide a root cause into this foam failures for the 25 years.

- Chemistry-extraction of residues
- Bulk property mechanical testing
- Fracture analysis
- No known nondestructive analysis
- 10,000’s of hours testing “process” variables

A new approach was needed

How would a microscopist look at this?

Cell morphology determines the mechanical strength of the foam.

Foam is the ideal media to preserve its own failure.

Cross sectioning to observe the cell morphology.

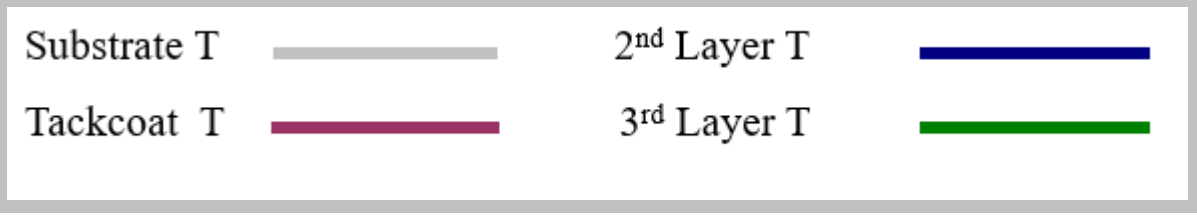
Foam Chemistry

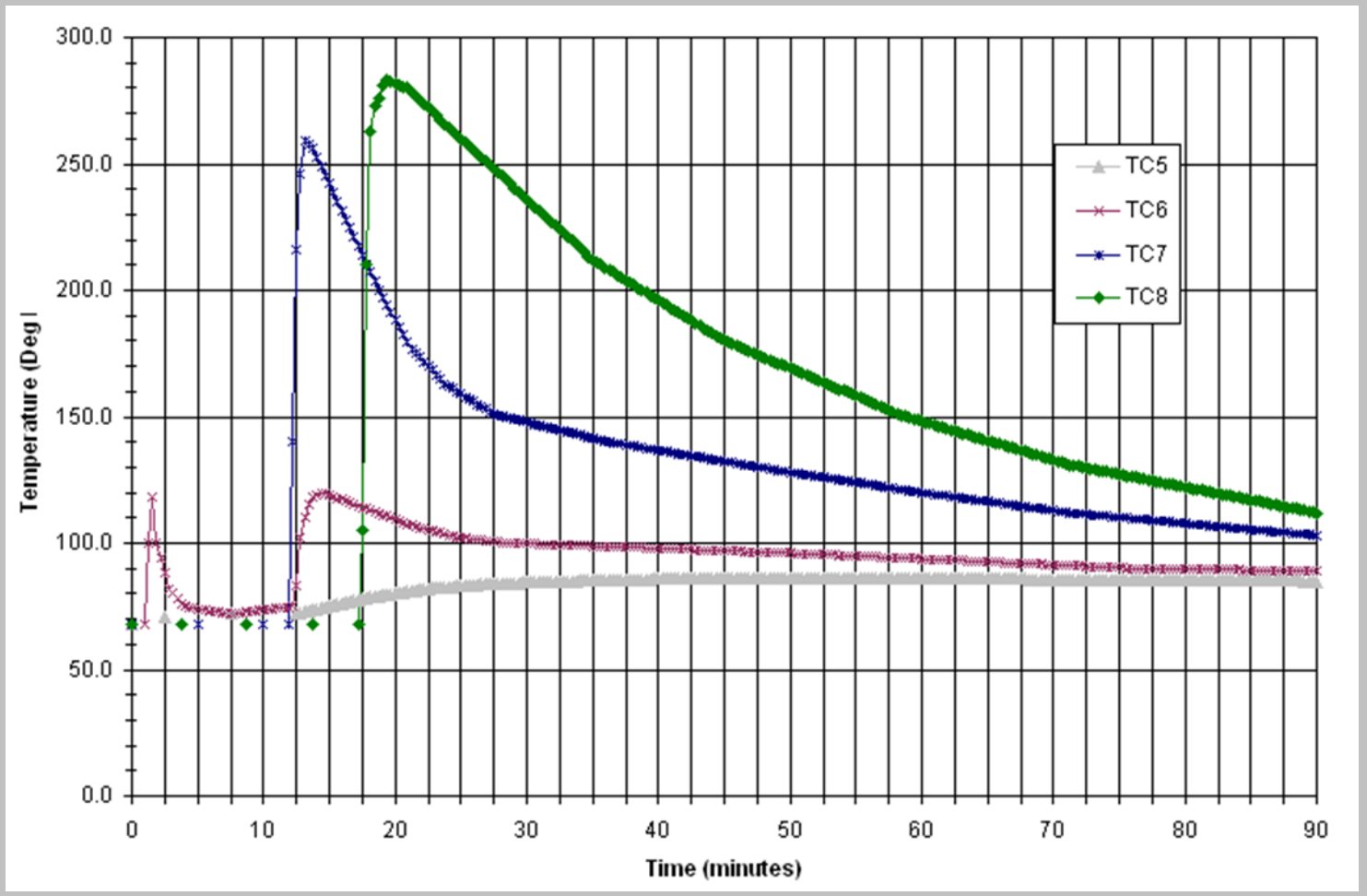
- A/B Ratio- mechanical strength and flexibility
- Blowing agent function of vapor pressure and temperature
- Exothermic reaction –driving the reaction rate
- Moisture

Application parameters

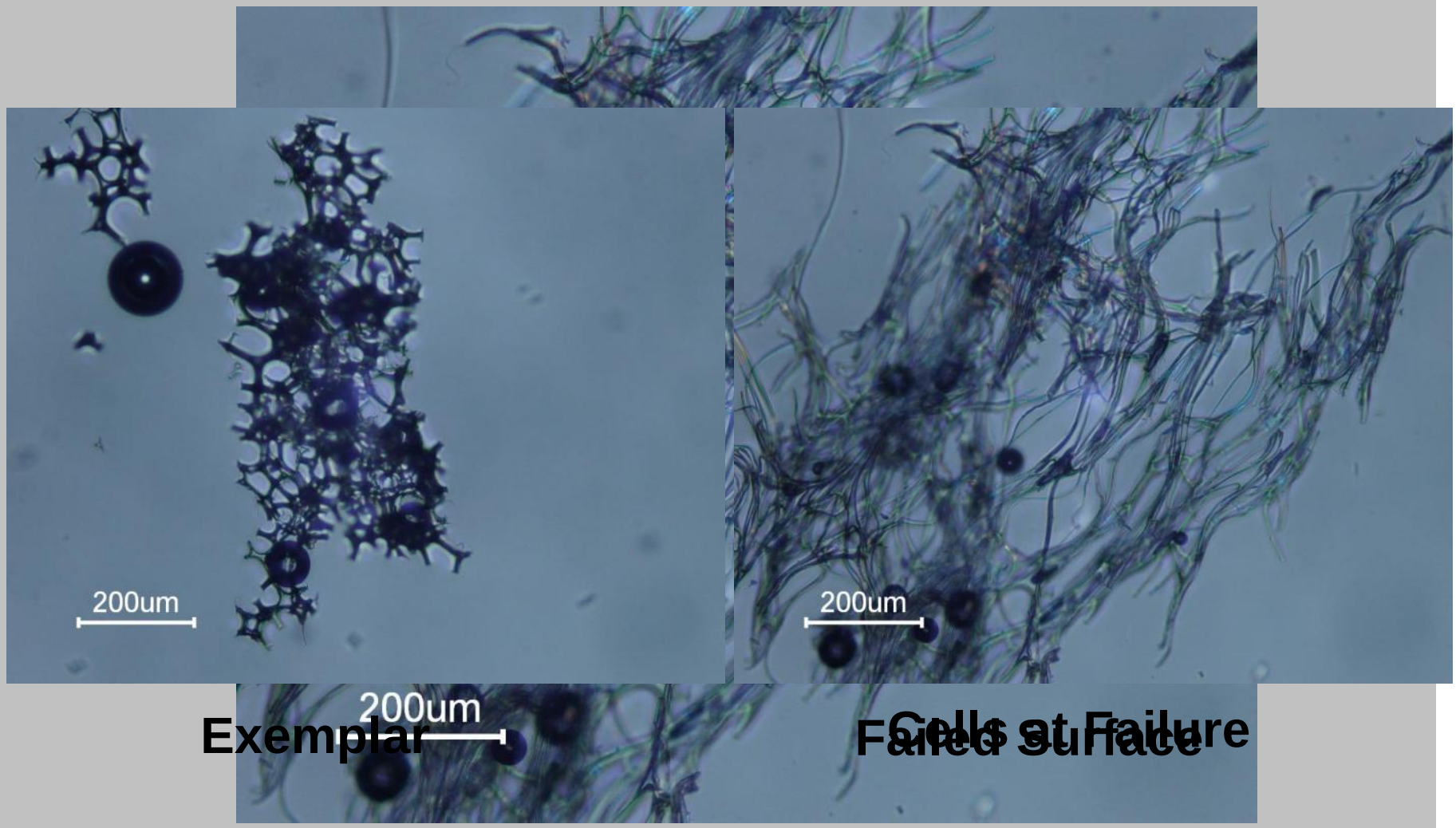
- Optimum two part A/B ratio
  - Viscosities
  - Delivery Pressures
- Temperature
  - Substrate temperature
    - Ambient- outdoor conditions
  - Exothermic reaction ~140 F
- Operator application technique
  - Spray pattern
- Formulation changes
  - Blowing agent
  - Catalyst
- Humidity-dew point
  - Cure rate
  - Condensation on substrate

Foam Curing ΔT

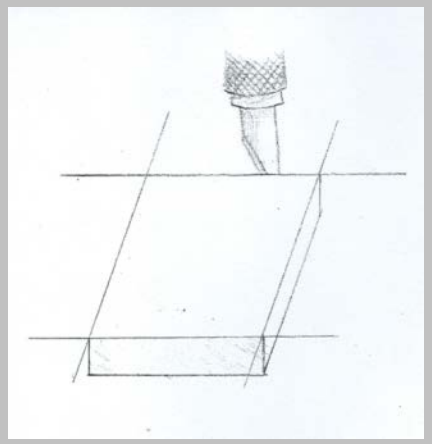


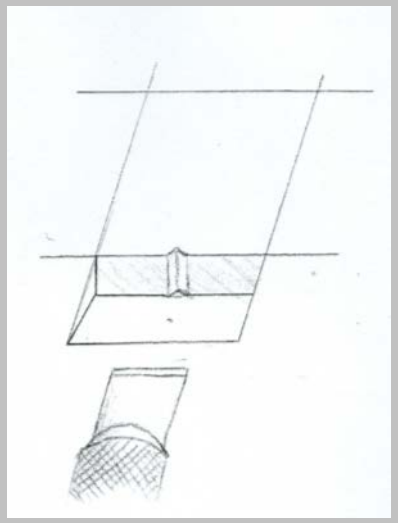


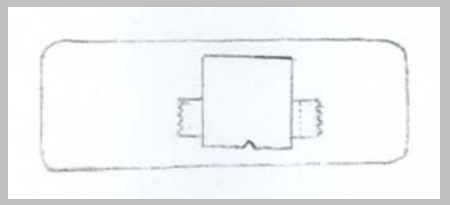
PLM of SRB Foam Failure



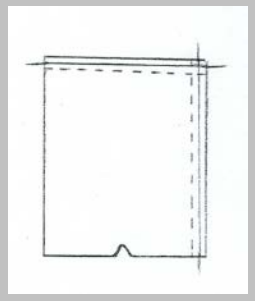
Cross Sectioning of Foam



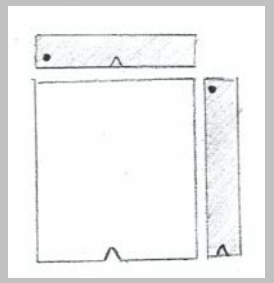




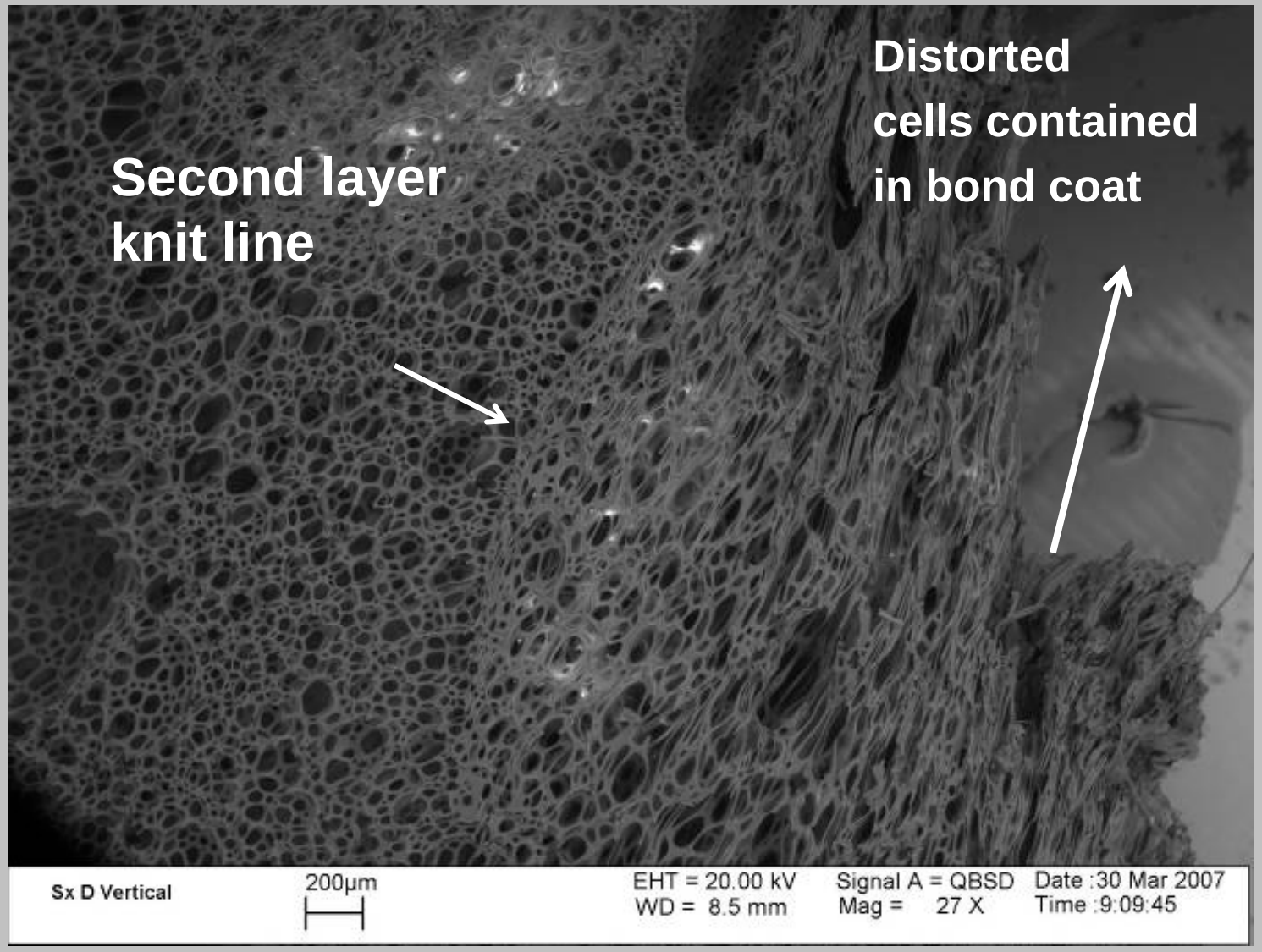
- Plastic slide with double
- sided tape



- 1st cut 1 mm section single edge razor
- 2nd cut 0.5-1mm section double edge razor

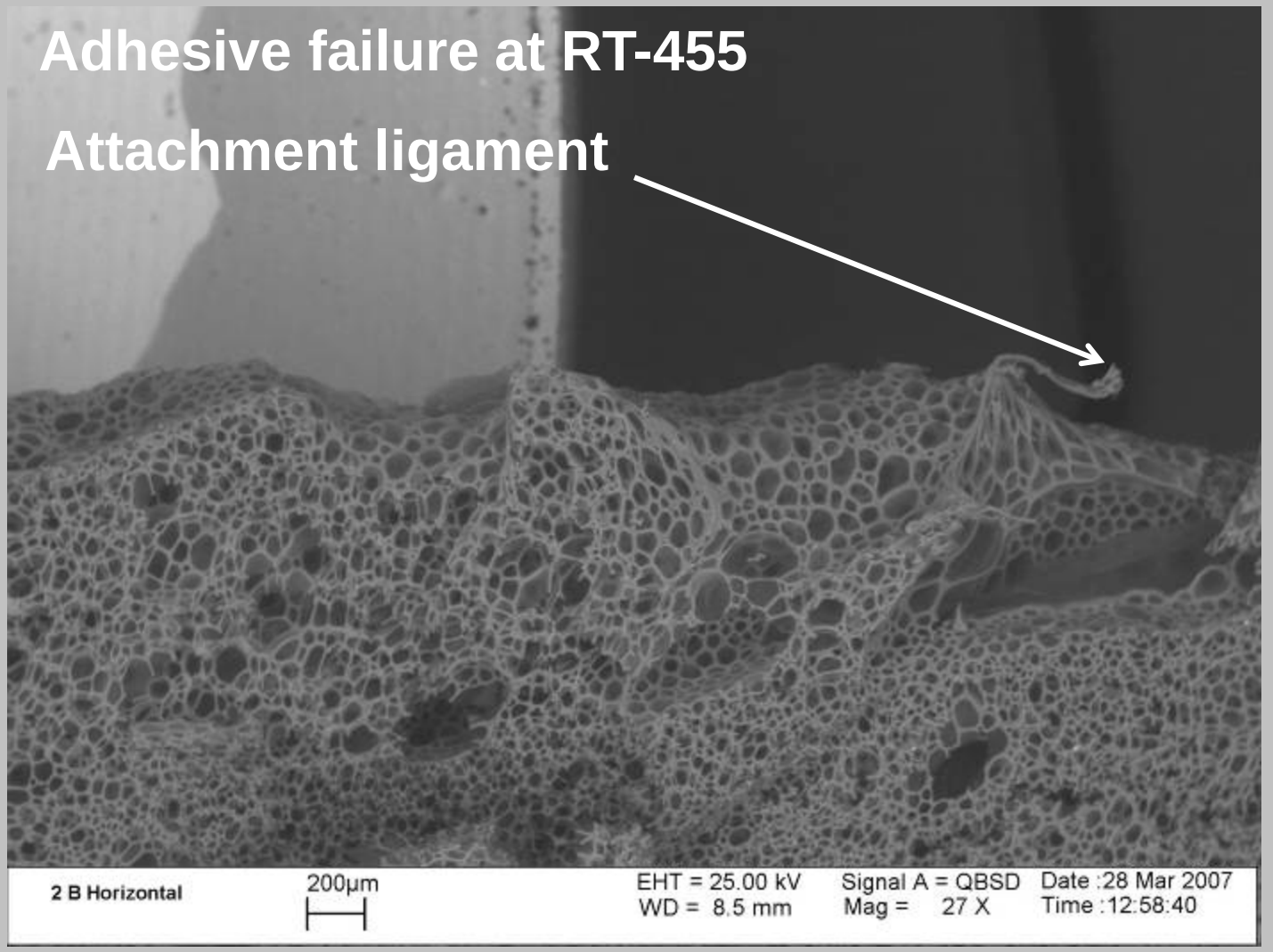


Cross Section of SRB Foam Failure

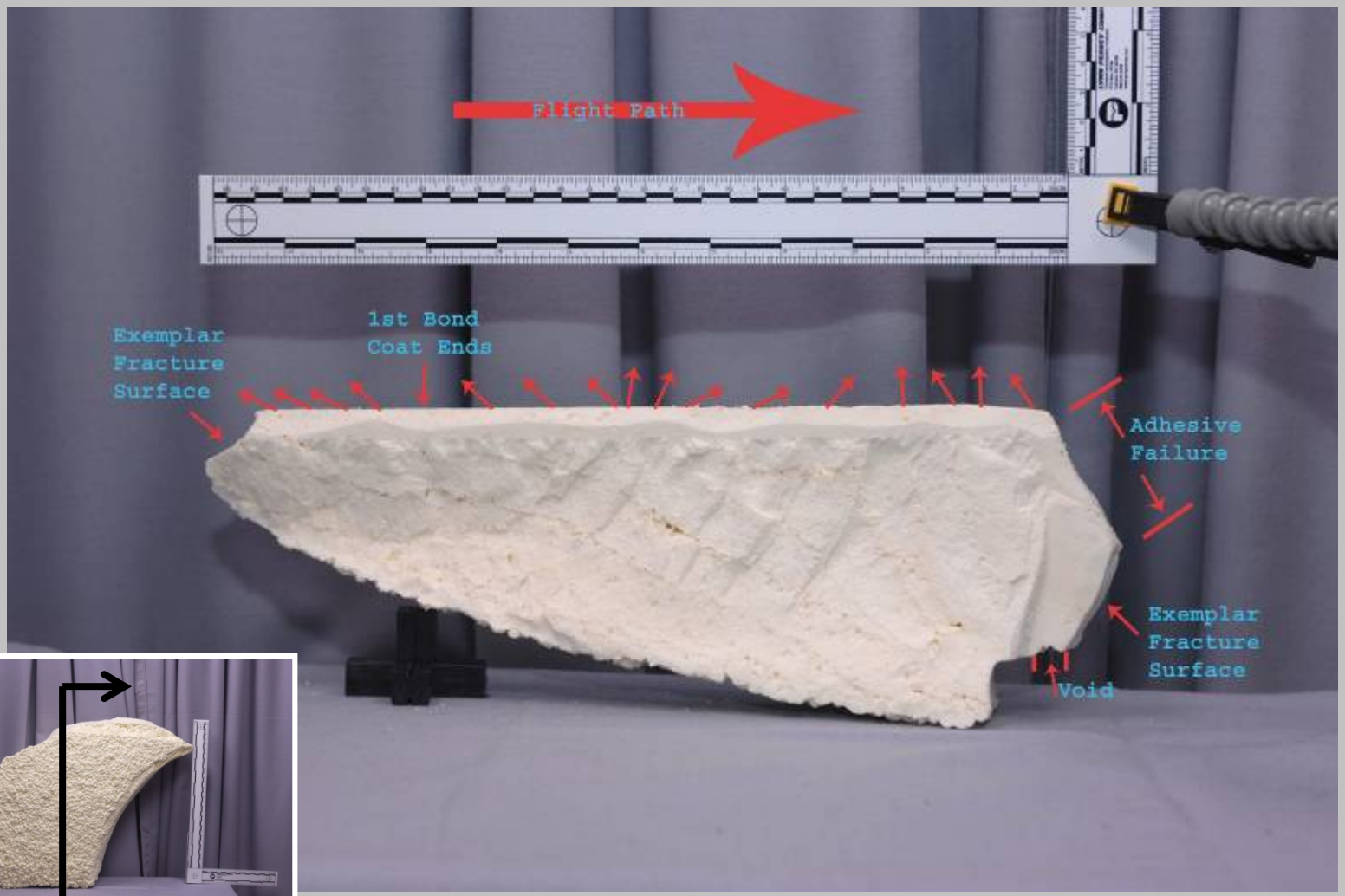


Chief SRB Engineer –we have never looked at foam like this

SRB Foam Failure



SRB Foam Failure



SRB Foam Failure

>80 percent application failed

The foam bond coat displayed two modes of failure:

- Cohesive failure was observed due to severely deformed foam cells in the bond coat
- Adhesive failure was observed at the RT-455 Epoxy interface.

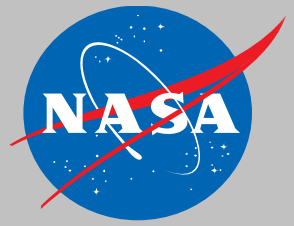
The observed morphology indicates that the bond coat was not fully cured before other forces were applied, e.g. the expansion forces of the second coat distorted the bonding cells.

Process Changes

- Substrate as an infinite heat sink
- Develop spray hardware to apply micro bond layers
  << 1/8” layers
- Primer (polyurethane)
- The bond coat should be allowed to completely dry/cure
  - Never apply over wet uncured layers

Sunset on International Space Station Expedition 15

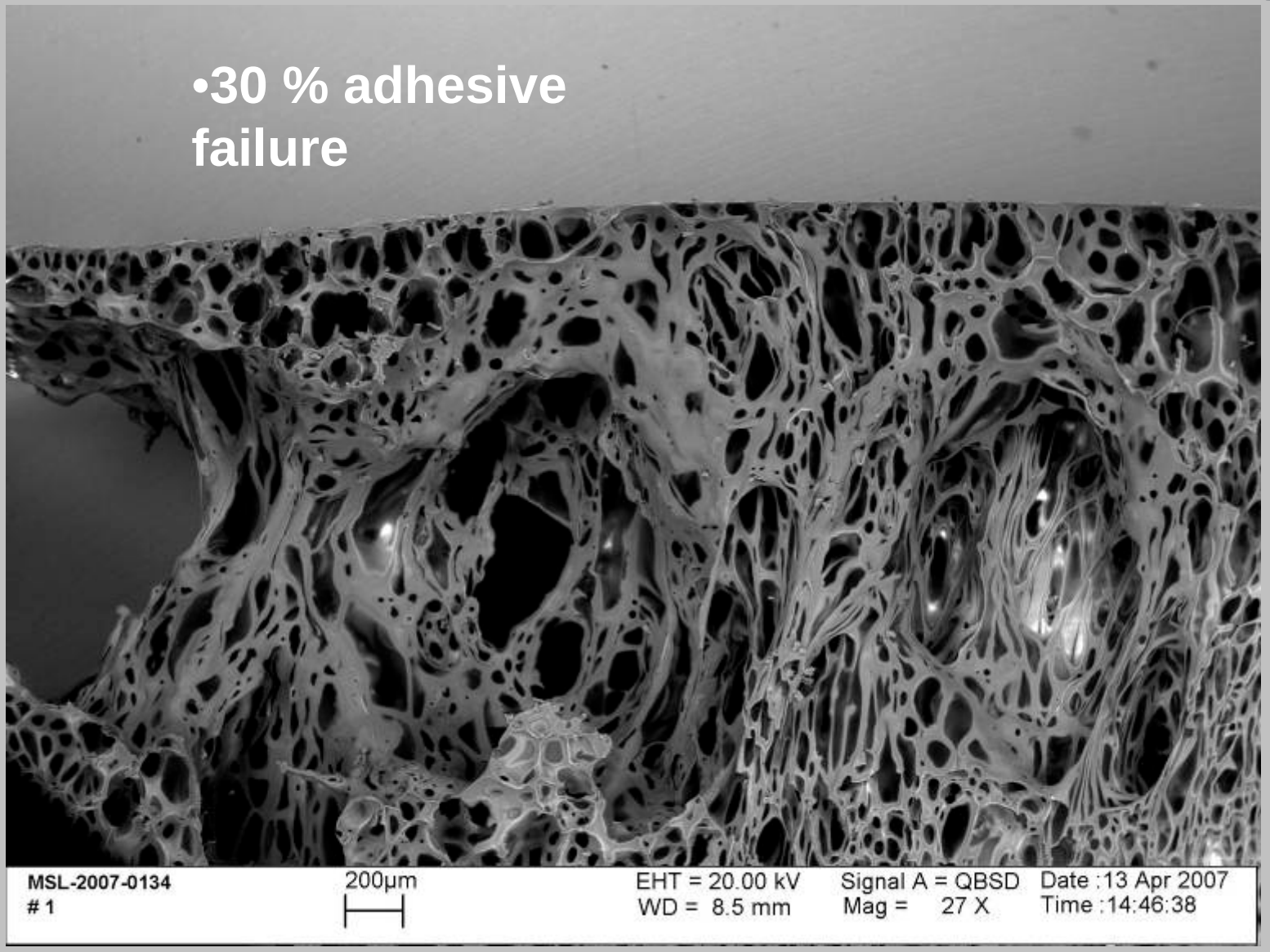
ISS015E10469


NASA

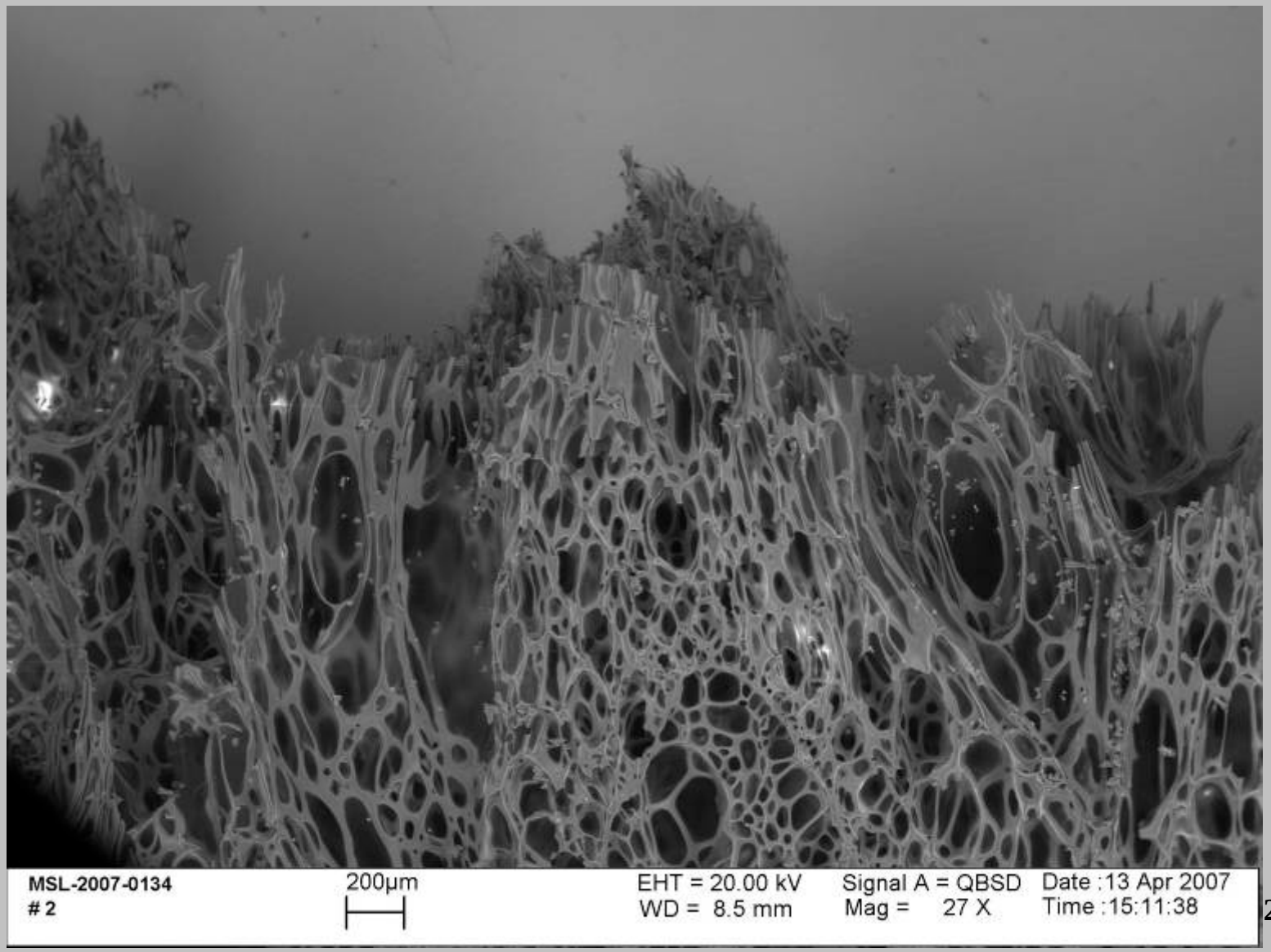
A View from Above!

ISS007E07306

25 PSI


•30 % adhesive failure
MSL-2007-0134
1
200µm
EHT = 20.00 kV
WD = 8.5 mm
Signal A = QBSD
Mag = 27 X
Date :13 Apr 2007
Time :14:46:38

50 PSI


MSL-2007-0134
2
200µm
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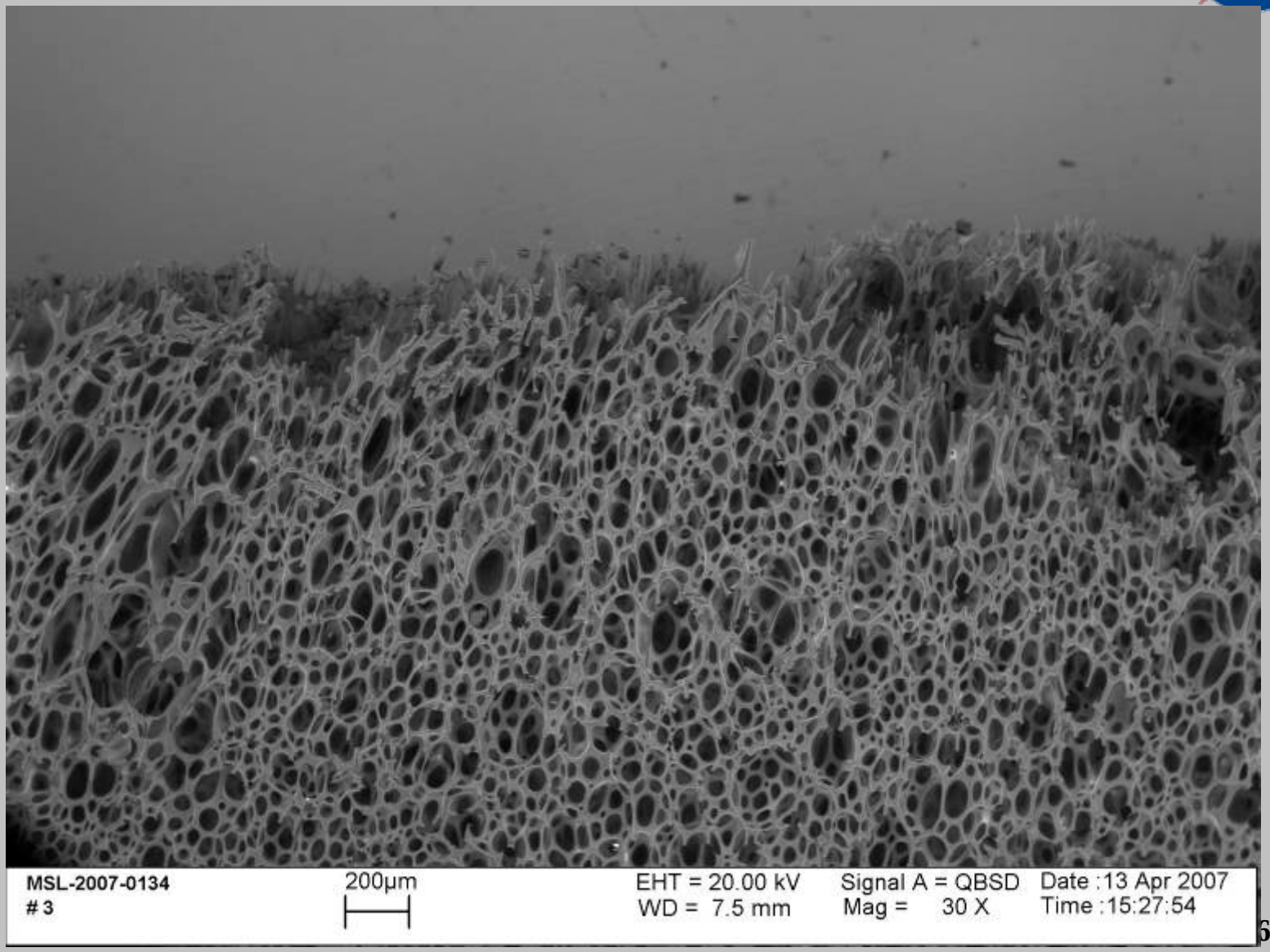
78 PSI


MSL-2007-0134
3
200µm
EHT = 20.00 kV
WD = 7.5 mm
Signal A = QBSD
Mag = 30 X
Date :13 Apr 2007
Time :15:27:54

Foam Mechanics

- Mixing of part A and B
- Evaporation of blowing agent-bubble formation
- Catalyst initiate cure
- Exothermic reaction