Effects of Cooling Holes on SiC/SiC Strength and Durability

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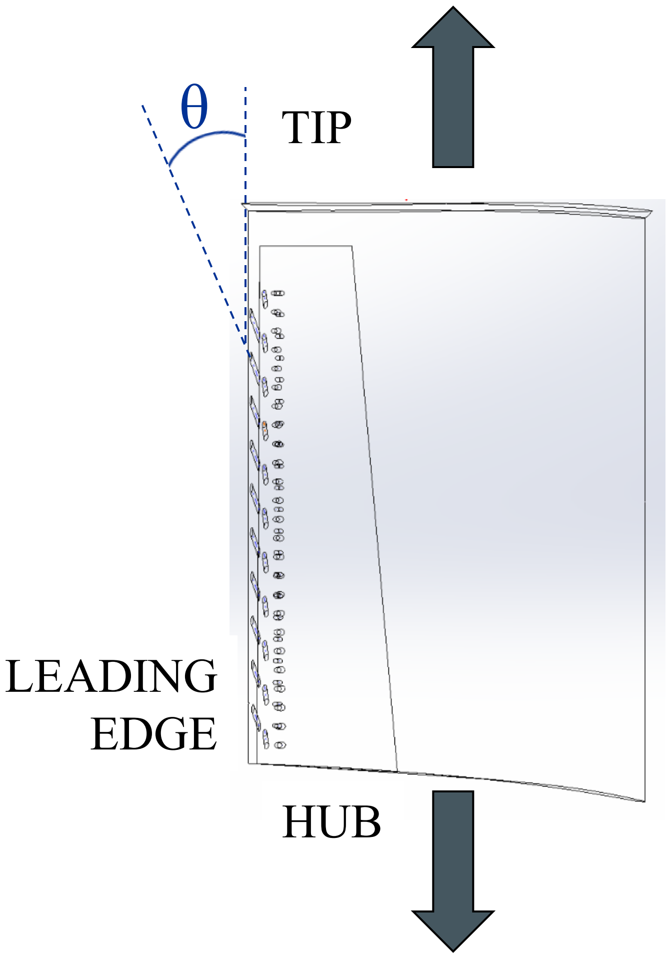
This work was funded by the NASA Advanced Air Transport Technology (AATT) and Hybrid Thermally Efficient Core (HyTEC) Projects

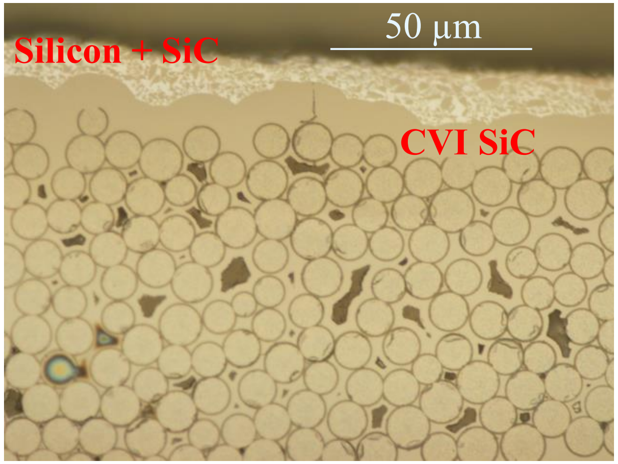
Background



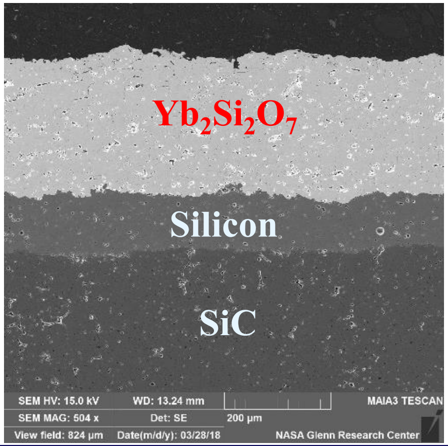
- CMC turbine engine components made from SiC/SiC provide an efficiency increase compared to superalloys, primarily as a result of decreased cooling requirements and decreased density.
- CMC components such as blades may still require film cooling.
- CMCs are known to be notch insensitive.
- The durability of SiC/SiC with cooling hole arrays is not well documented.
- This project seeks to understand the knockdown of matrix cracking strength due to multiple holes.

Materials

- Slurry MI material (NASA N24A) was used in this study
  - 2D woven Sylramic iBN fibers
  - Balanced architecture
  - BN interphase
  - CVI SiC
  - Slurry MI Silicon
  - Made by GE



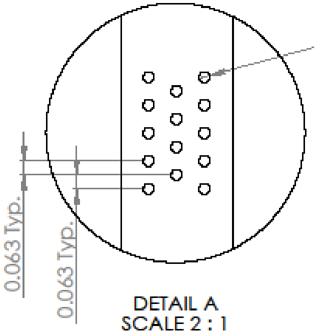
- Some samples were coated with an EBC prior to drilling.
  - Samples were grit blasted prior to coating
  - Silicon bond coat
  - $Yb_2Si_2O_7$ (Gen 2) top coat

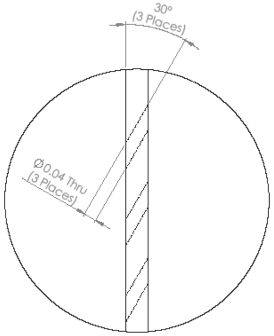


From Kang Lee

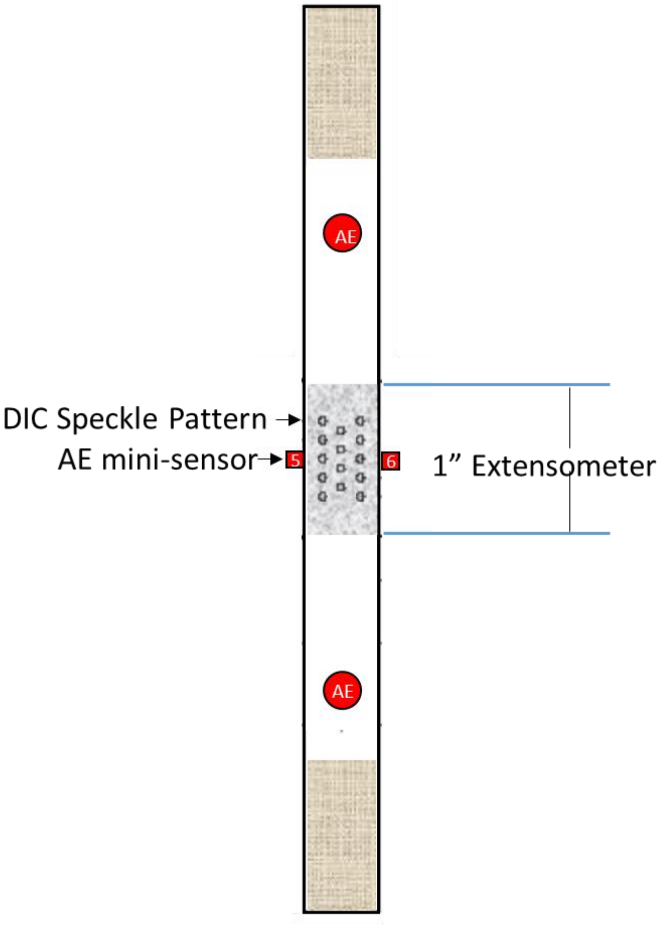
Ultrasonic Drilling

- Holes were machined by ultrasonic drill.
- Drilling was done after depositing EBC
- Diameters were typically 1.1 mm.
- Samples were prepared with holes oriented at either 90° or 30°, relative to the surface.
- 90° Holes were arranged in a 14 hole array.
  - Horizontal & vertical spacing = 3 x Diameter
- 30° Holes were arranged in a 3 hole array.
  - Representative of blade leading edge cooling holes



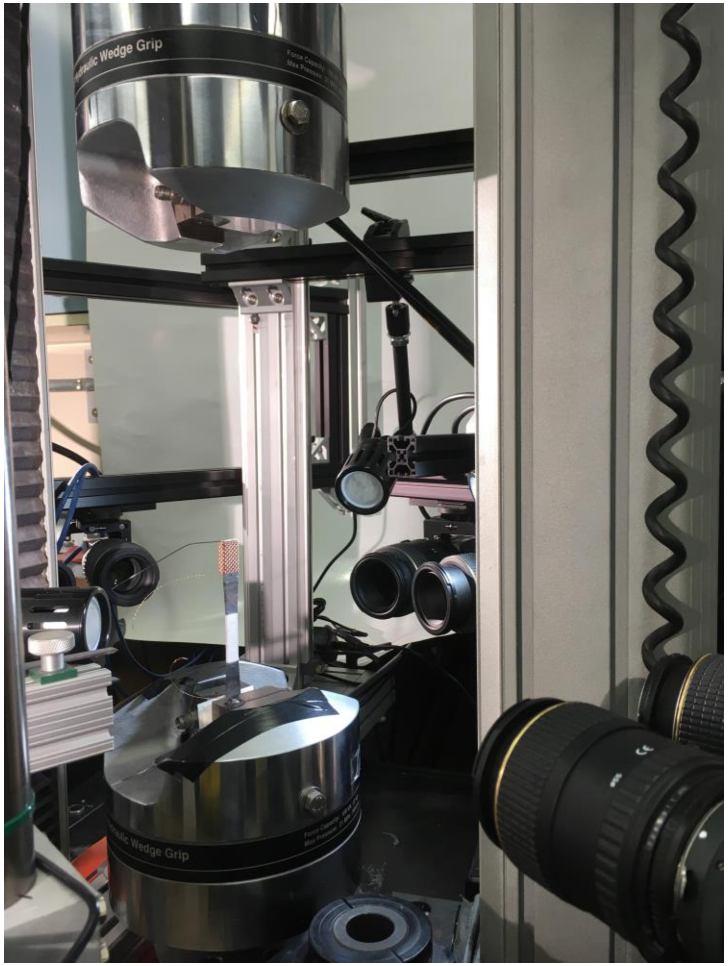


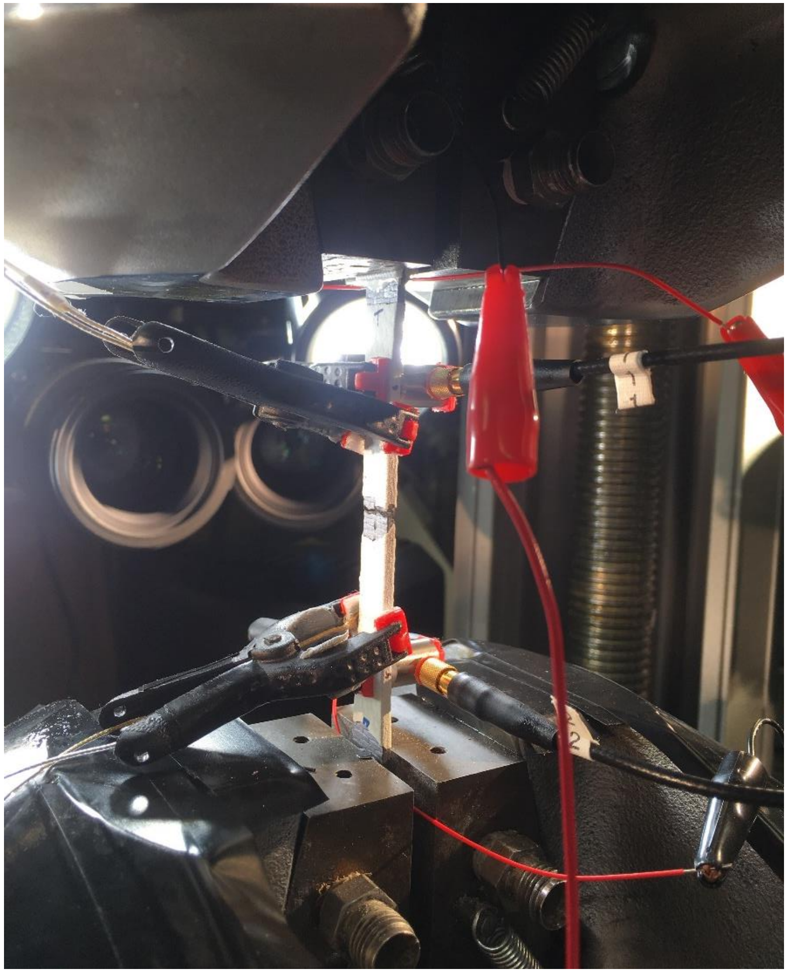
Diagnostic Tools

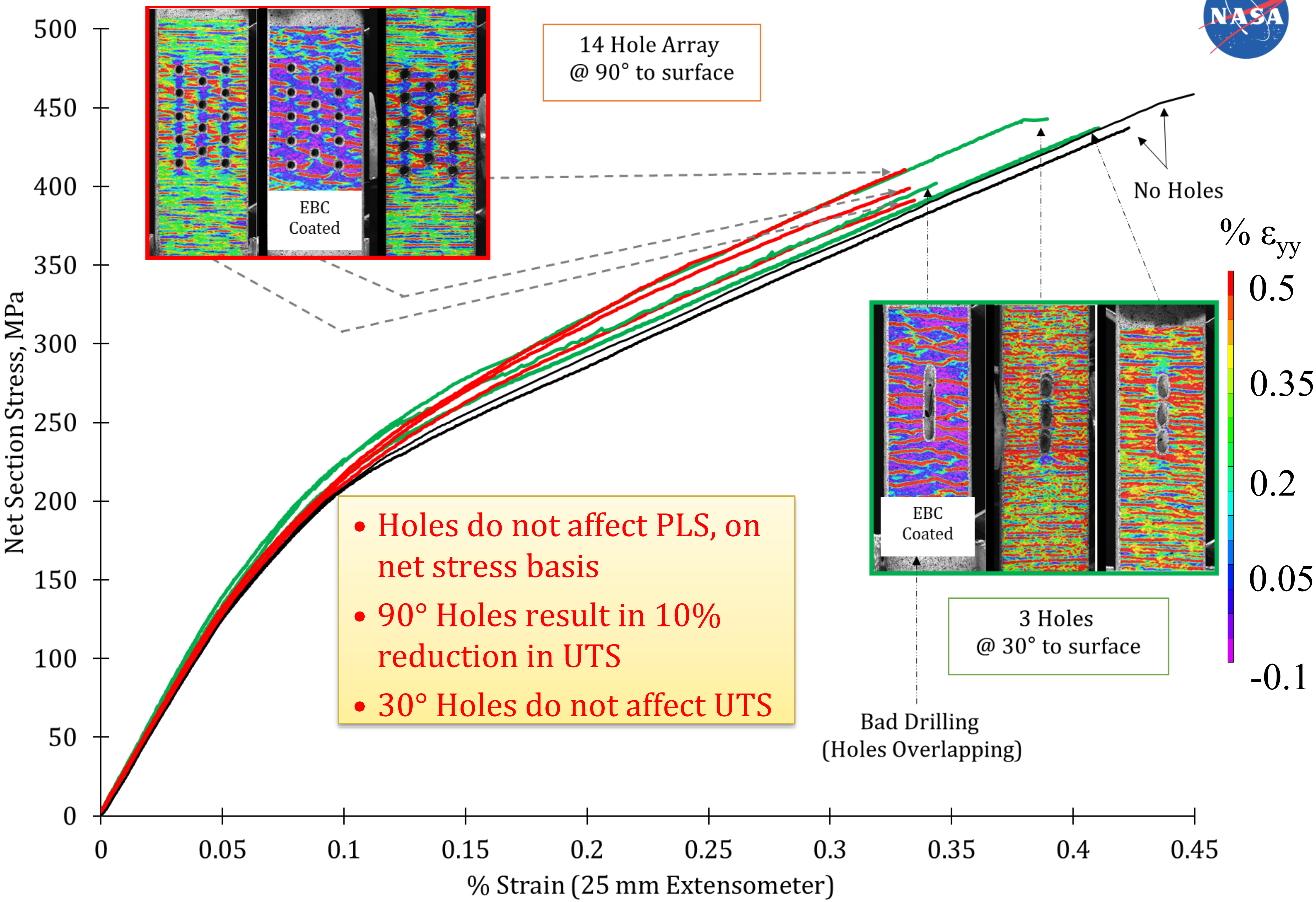


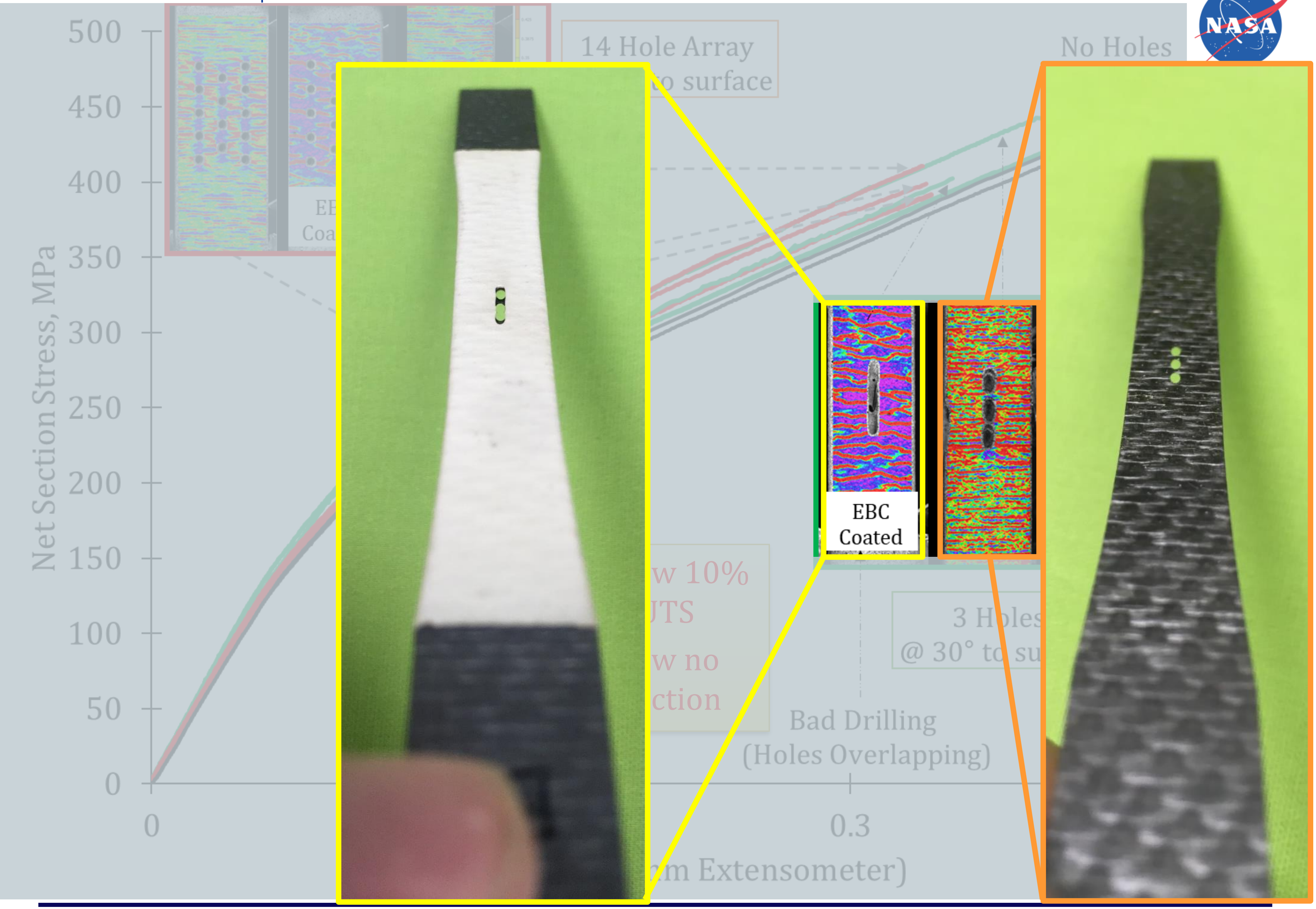
- Acoustic Emission (AE) sensors applied to face and edges
- 3D Digital Image Correlation (DIC)
- 1 inch extensometer on edge

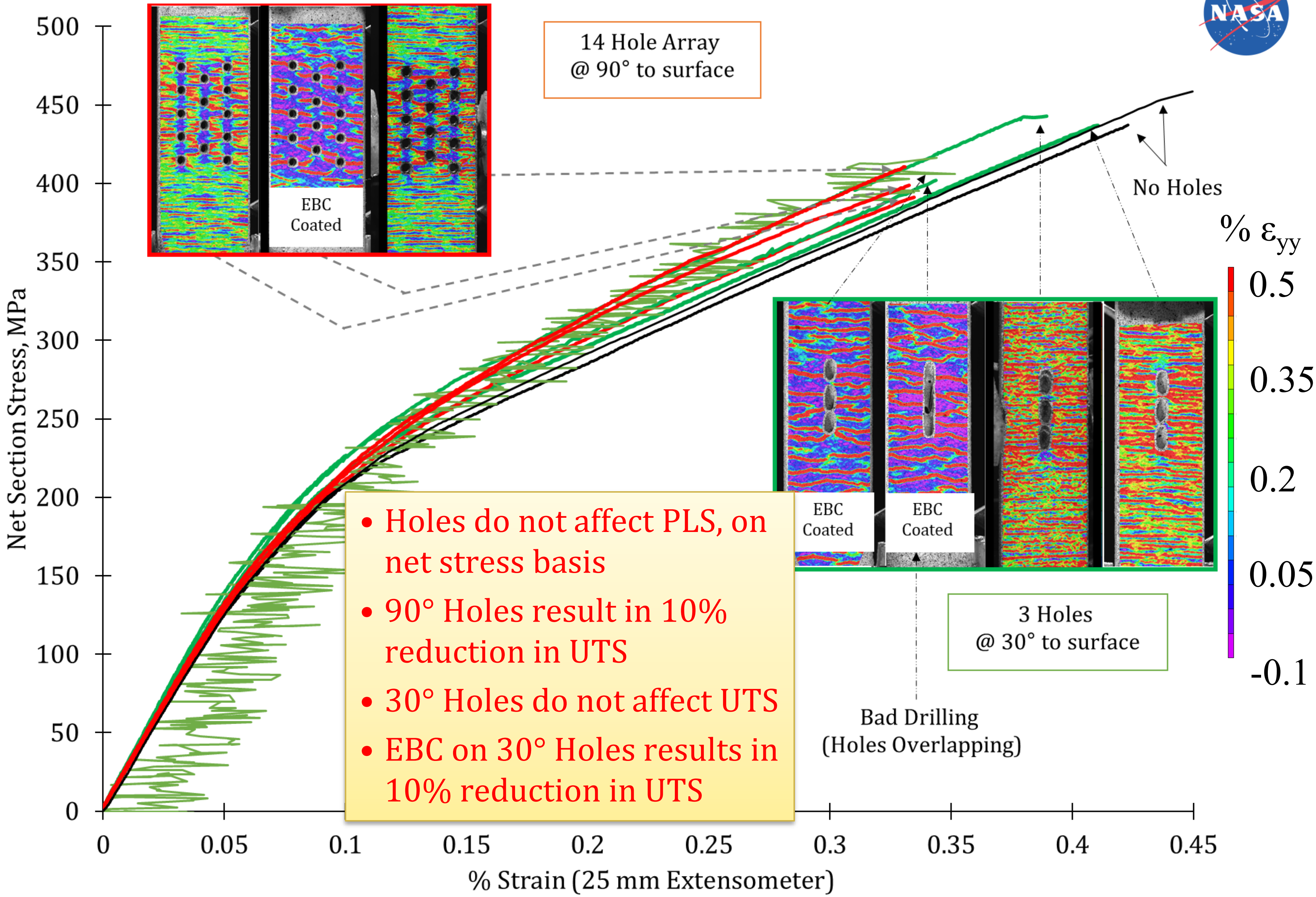
Test Setup





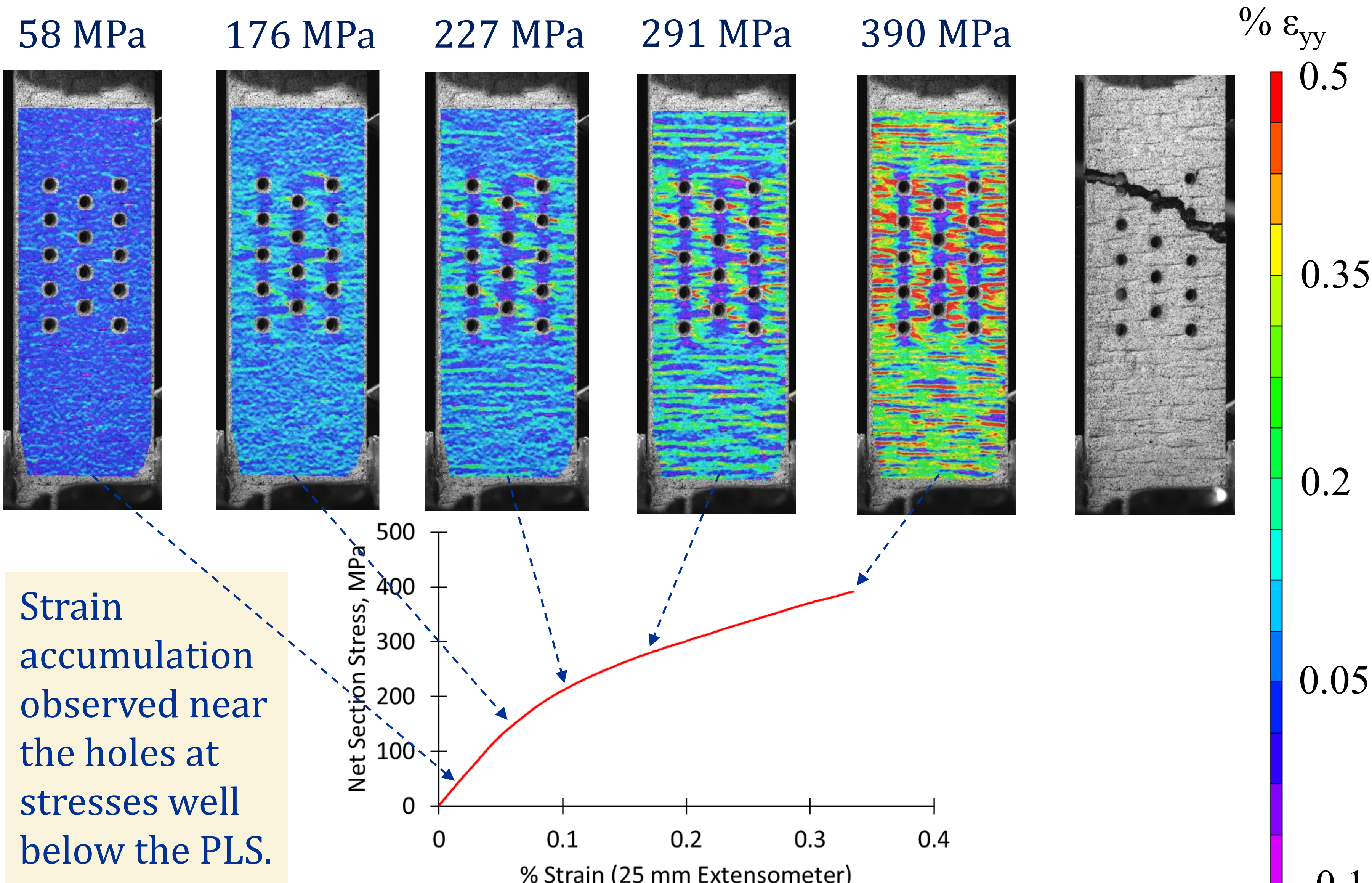

14 Hole Array
@ 90° to surface
EBC
Coated
No Holes
% ε_{yy}
0.5
0.35
0.2
0.05
-0.1
3 Holes
@ 30° to surface
Bad Drilling
(Holes Overlapping)
Net Section Stress, MPa
% Strain (25 mm Extensometer)
0
50
100
150
200
250
300
350
400
450
500
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
• Holes do not affect PLS, on net stress basis
• 90° Holes result in 10% reduction in UTS
• 30° Holes do not affect UTS


Net Section Stress, MPa
500
450
400
350
300
250
200
150
100
50
0
0
0.3
14 Hole Array
No Holes
EBC
Coated
Bad Drilling
(Holes Overlapping)



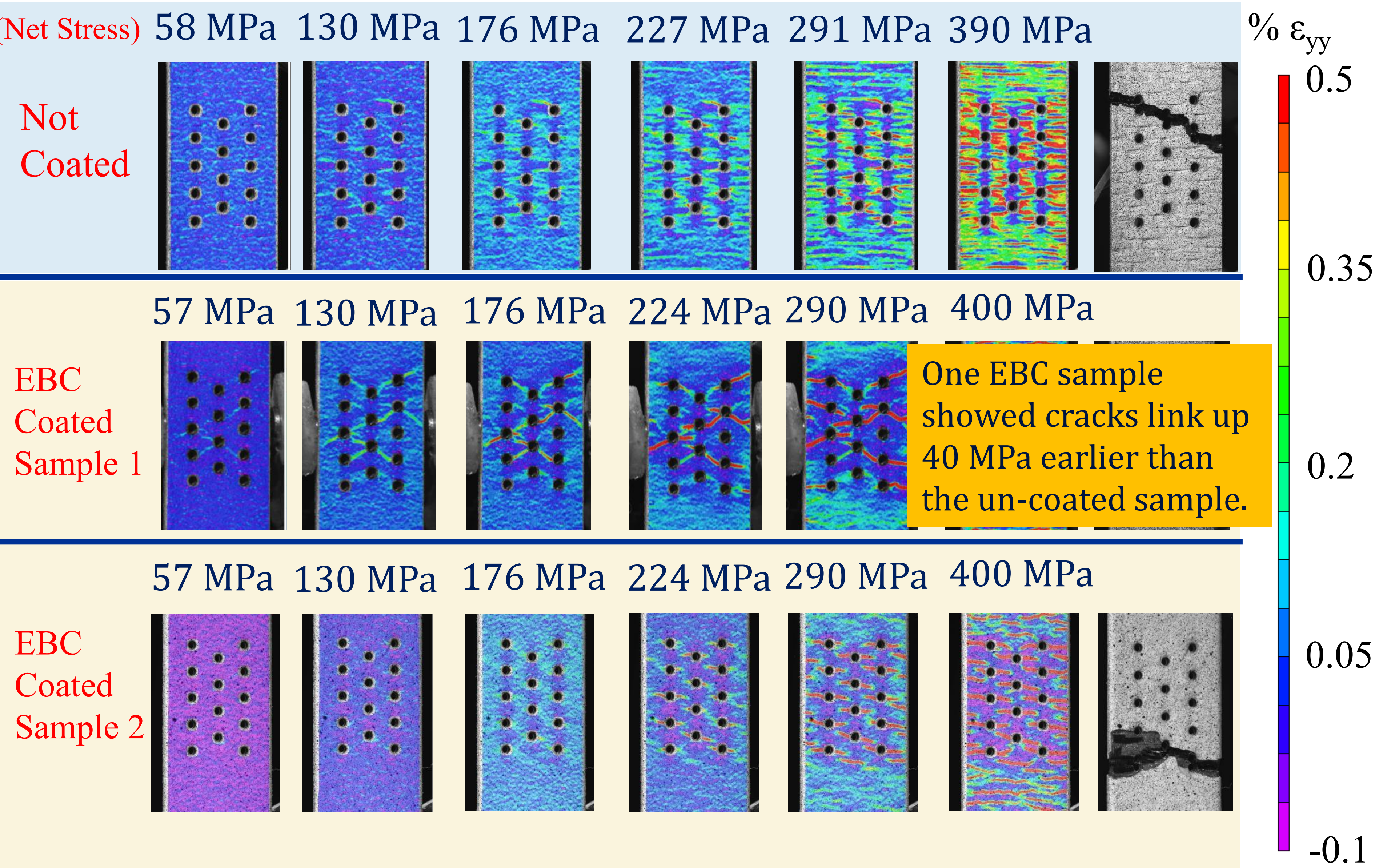
- Holes do not affect PLS, on net stress basis
- 90° Holes result in 10% reduction in UTS
- 30° Holes do not affect UTS
- EBC on 30° Holes results in 10% reduction in UTS

DIC Strain of Un-Coated 90° Hole Array Sample

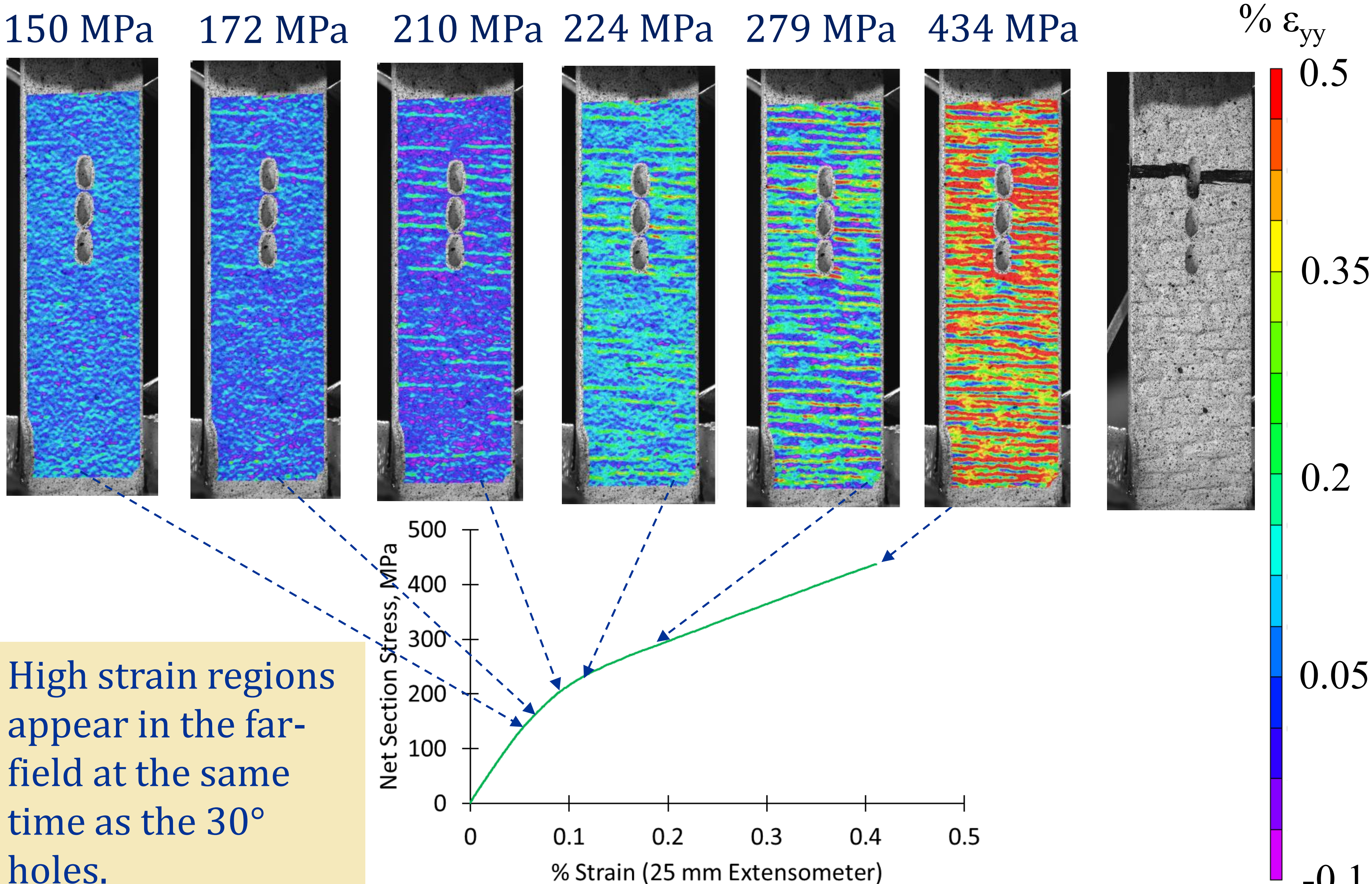


Strain accumulation observed near the holes at stresses well below the PLS.

DIC Strain of Un-Coated & EBC Coated 90° Hole Array Sample

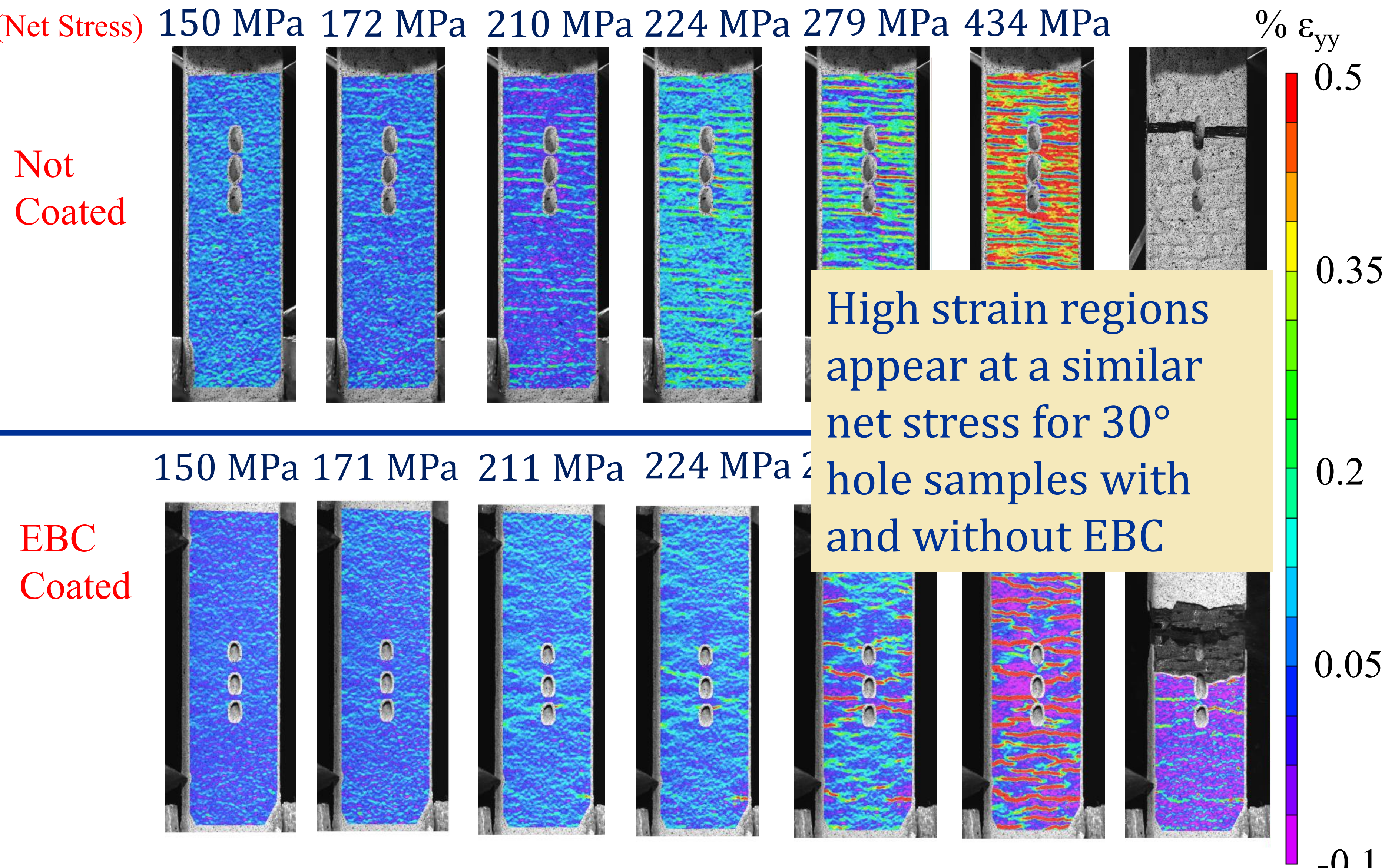


DIC Strain of Un-Coated 30° Hole Sample



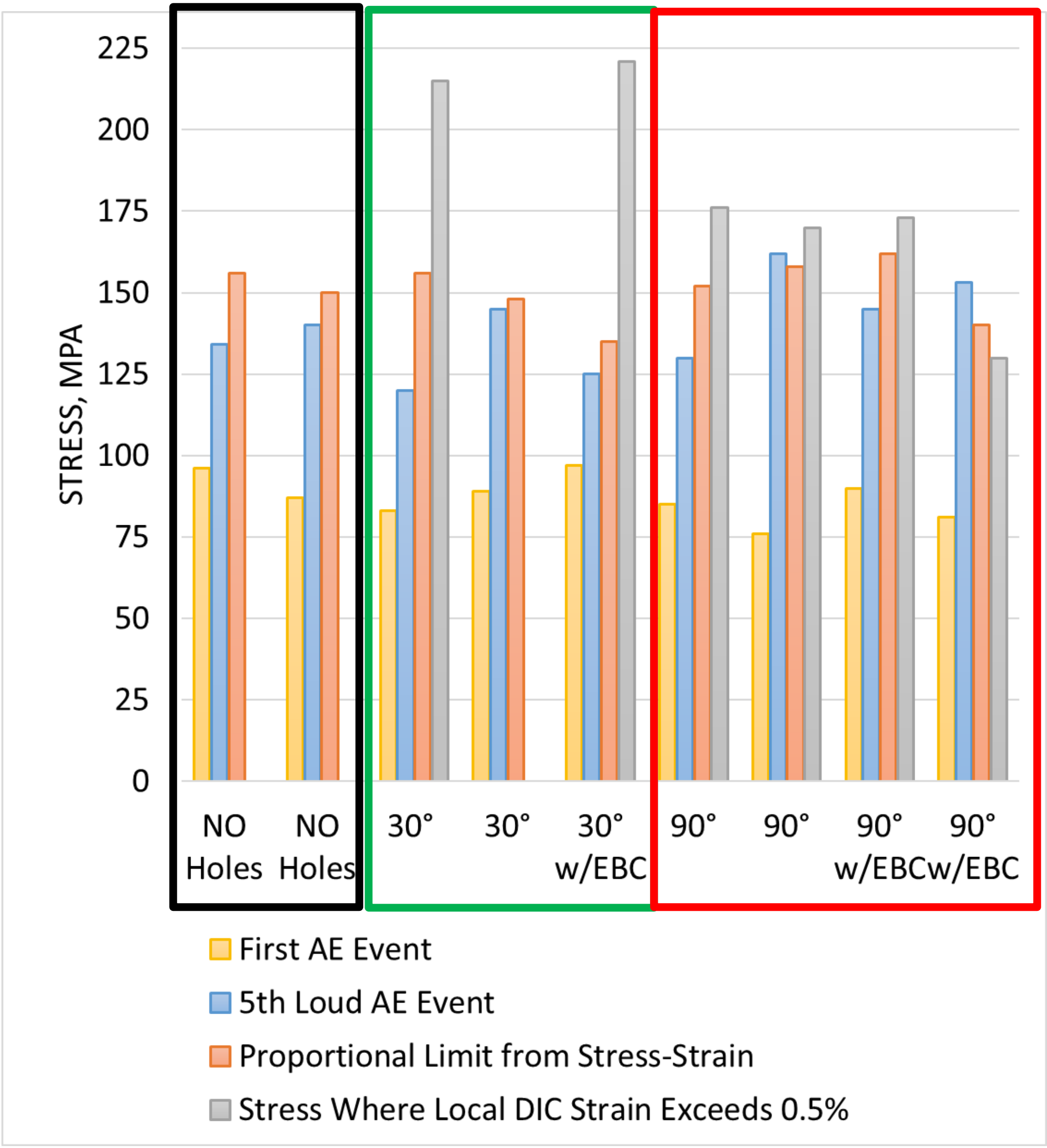
High strain regions appear in the far-field at the same time as the 30° holes.

DIC Strain of Un-Coated & Coated 30° Hole Sample



High strain regions appear at a similar net stress for 30° hole samples with and without EBC

Comparing the Beginning of Cracking



- All samples have similar PL and beginning of AE activity
- 90° samples reach local DIC strains of 0.5% at ~50 MPa lower stress than 30° samples

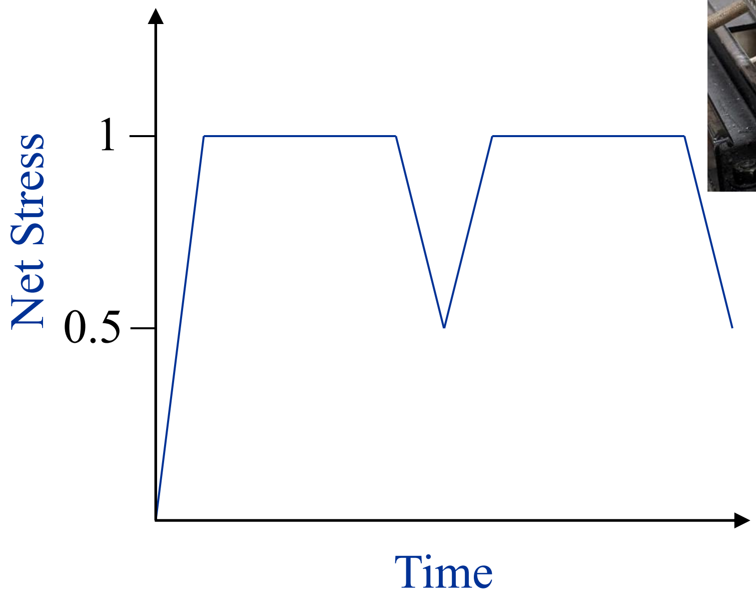
Room Temperature Results

- Holes do not affect proportional limit stress, on a net stress basis
  - DIC does show strain accumulation near 90° holes below the PLS
- Ultimate tensile strength is affected by hole angle
  - 90° Holes cause a 10% reduction in UTS
  - 30° Holes do not affect UTS
  - However, 30° Holes with EBC cause a 10% reduction in UTS

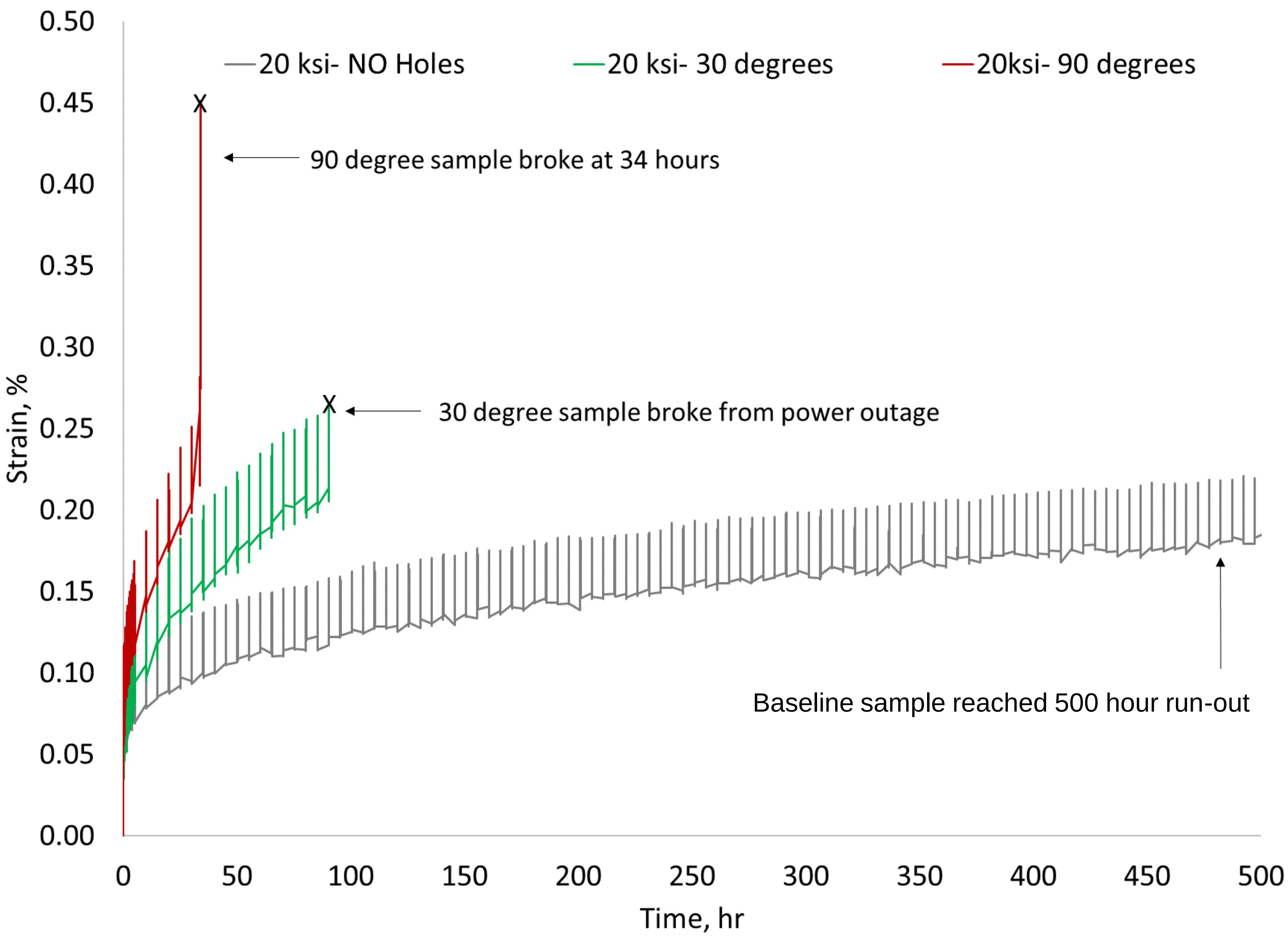
Durability Testing

Sustained Peak Low Cycle Fatigue Tests (SPLCF) were done in air

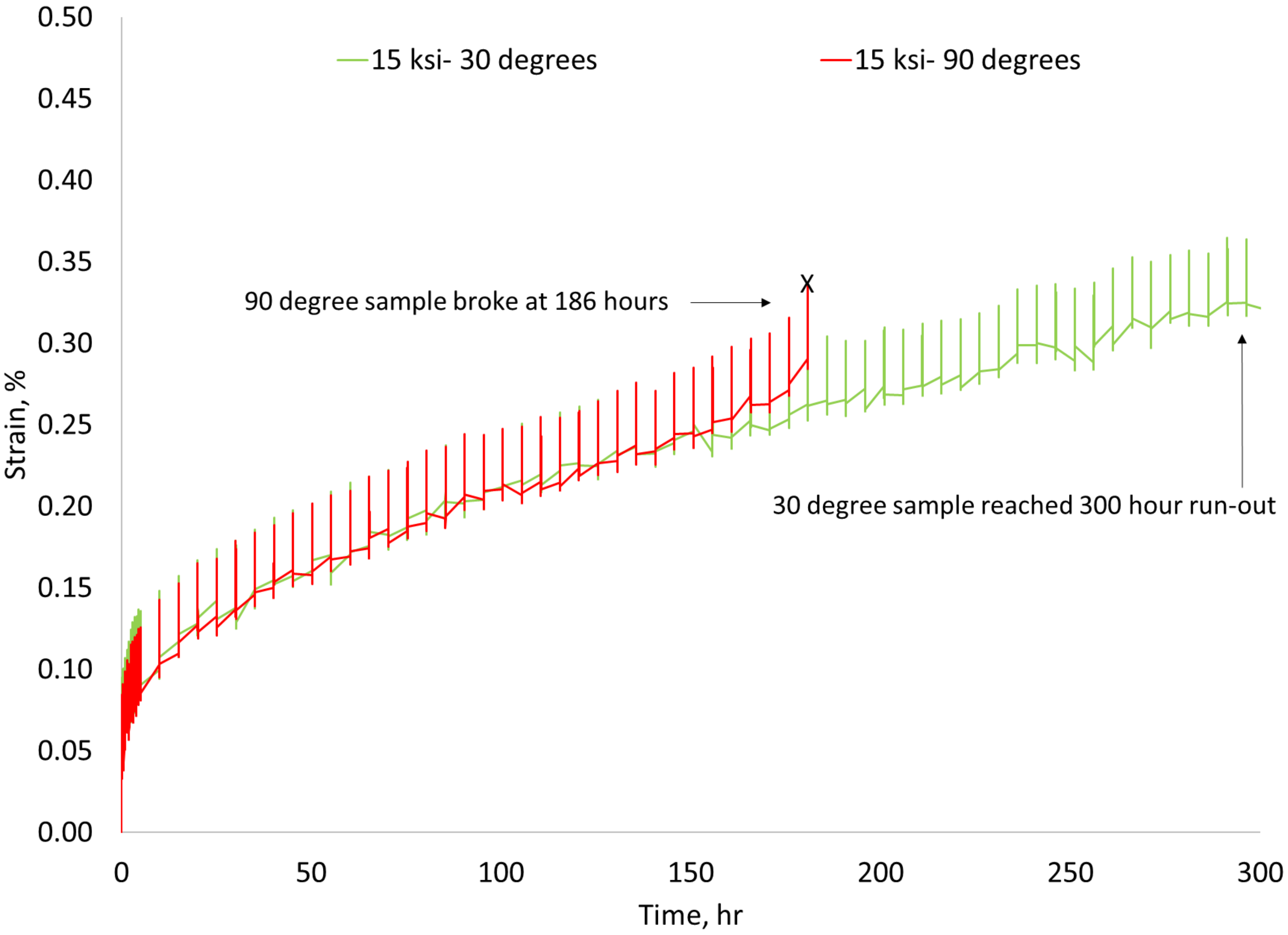
- 1315°C
- R=0.5
- 30 second ramp
- 2-minute dwell



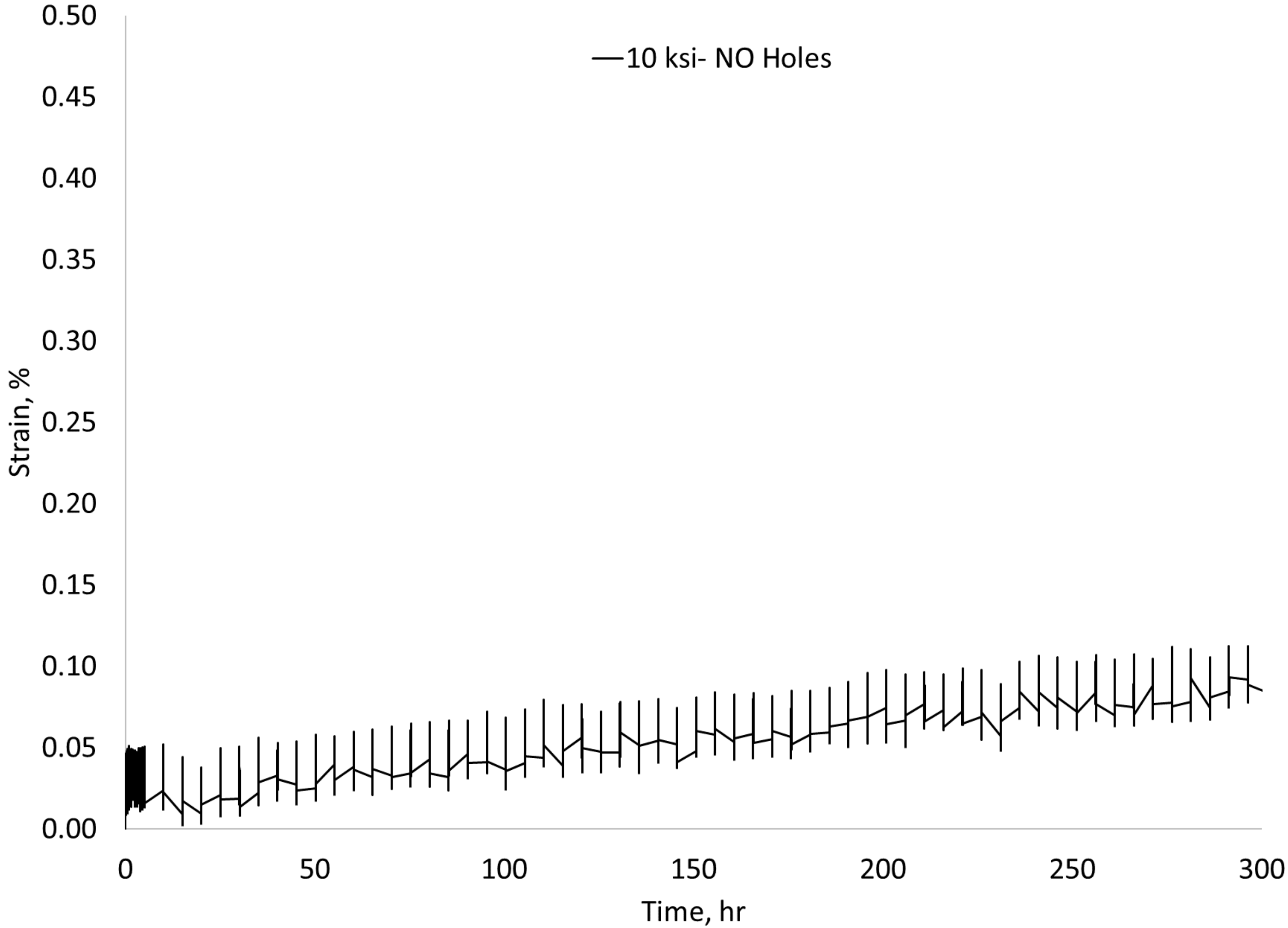
SPLCF Testing – 20 ksi (138 MPa) Dwell



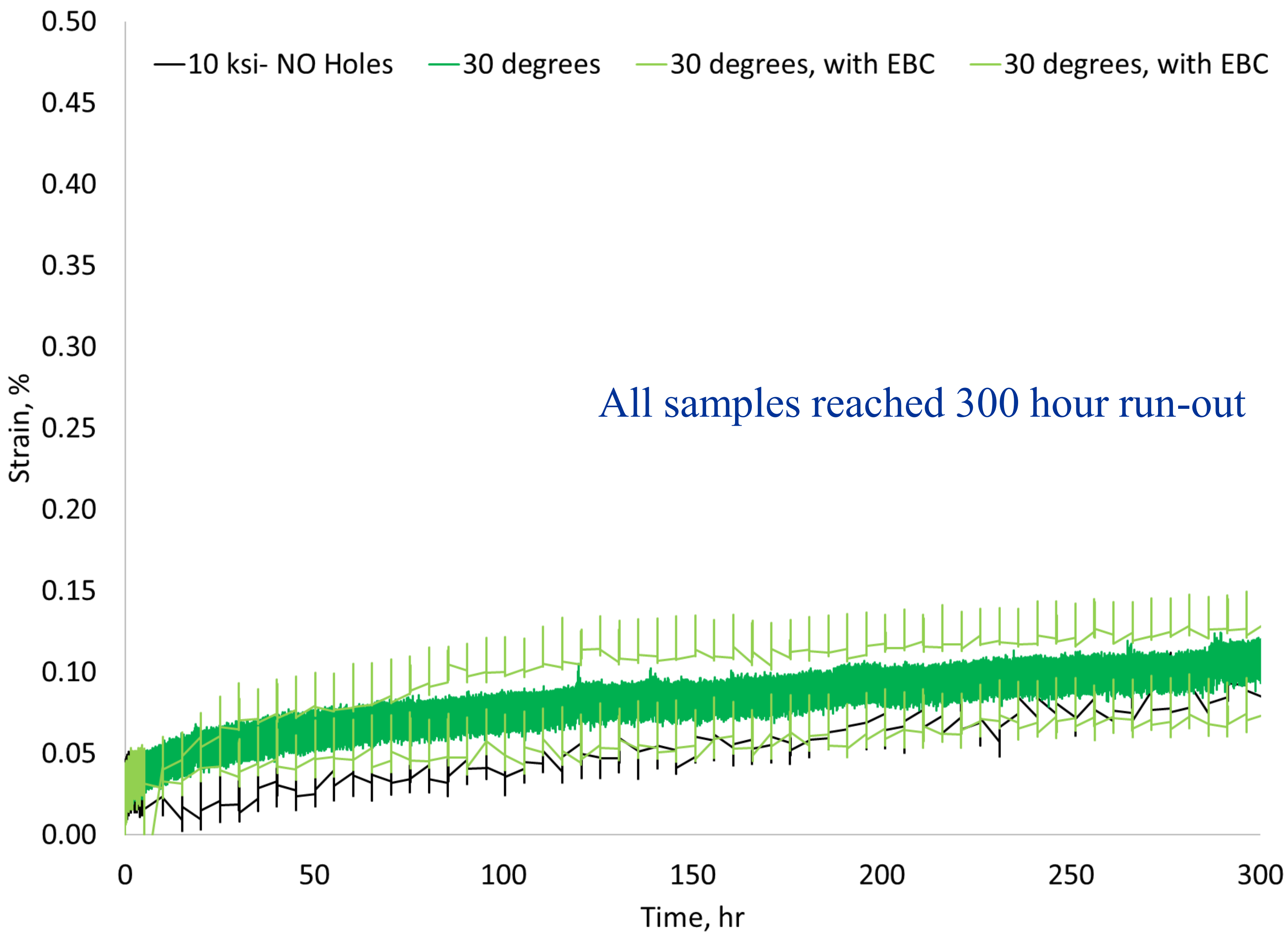
SPLCF Testing – 15 ksi (103 MPa) Dwell



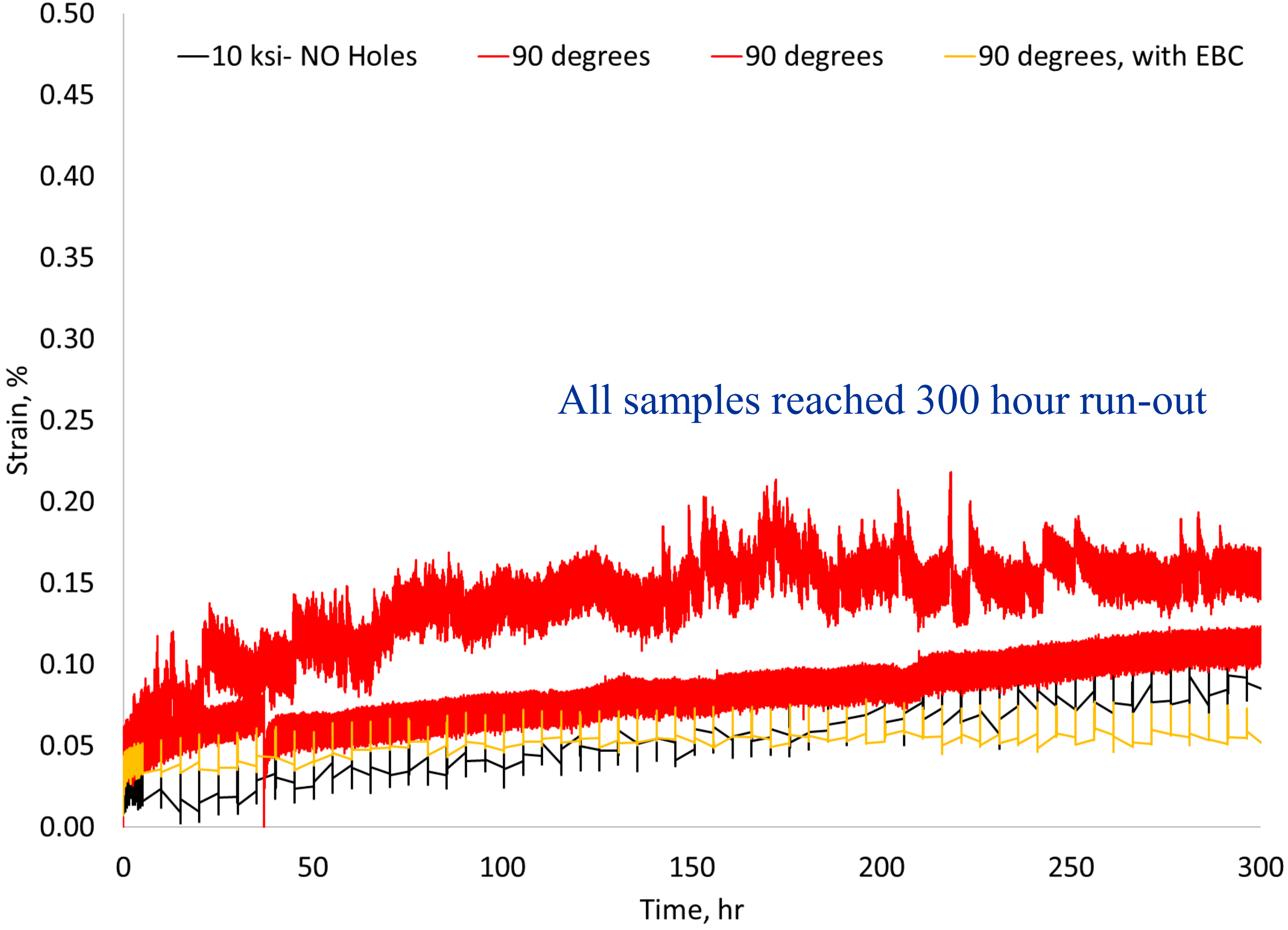
SPLCF Testing – 10 ksi (69 MPa) Dwell



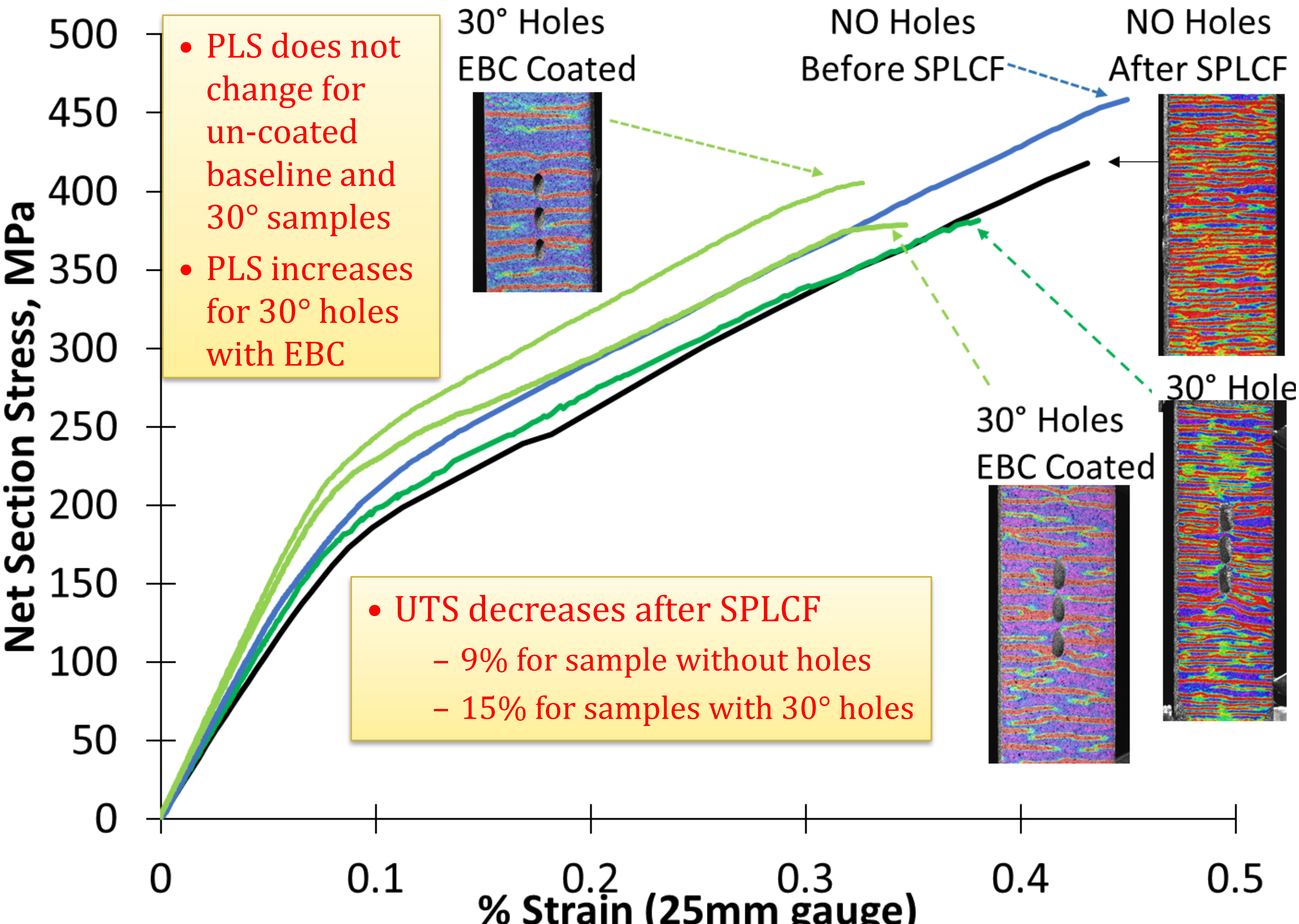
SPLCF Testing – 10 ksi (69 MPa) Dwell



SPLCF Testing – 10 ksi (69 MPa) Dwell



Retained Strength after SPLCF Testing at 69 MPa Dwell

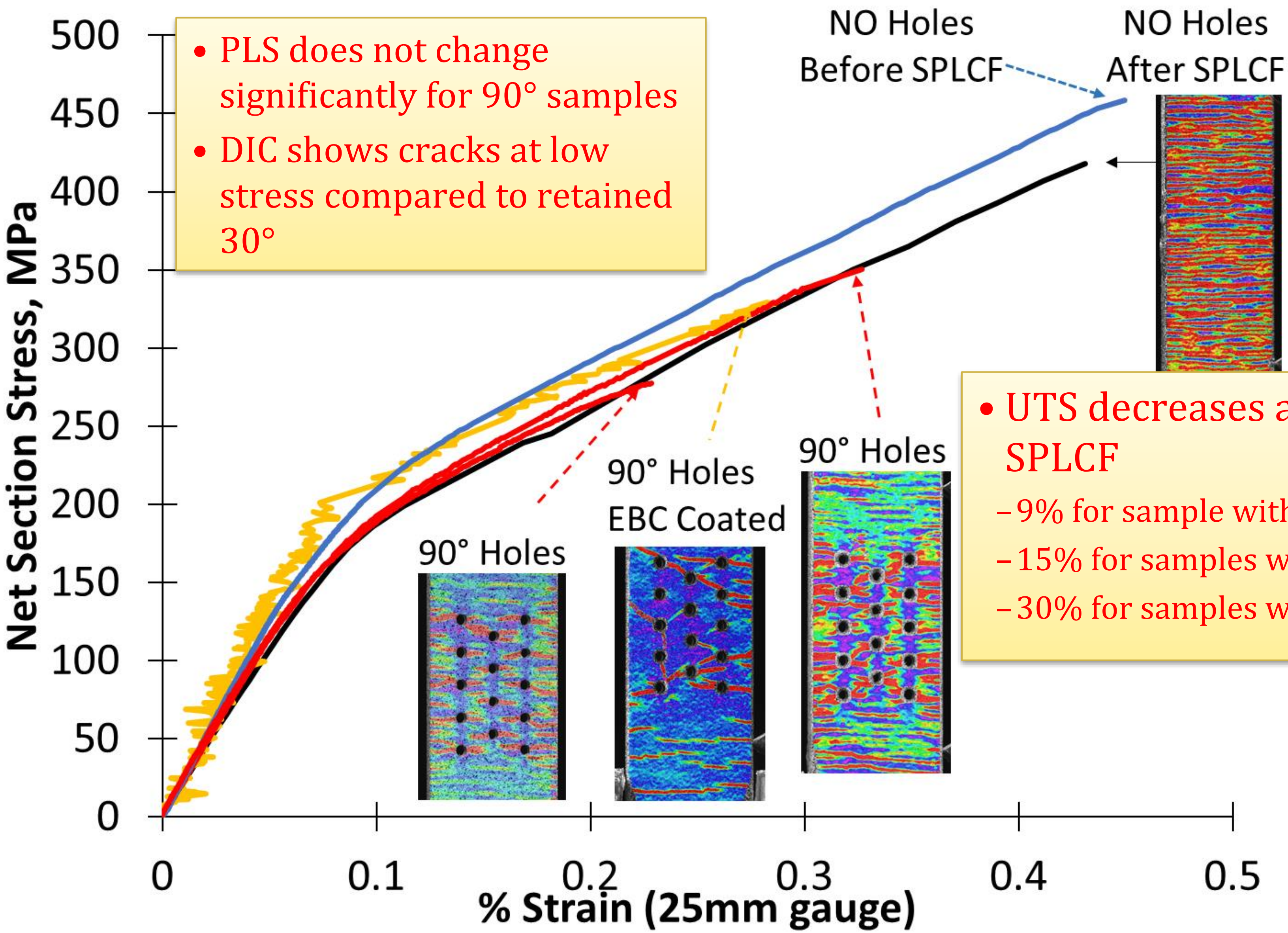


- PLS does not change for un-coated baseline and 30° samples
- PLS increases for 30° holes with EBC

- UTS decreases after SPLCF
  - 9% for sample without holes
  - 15% for samples with 30° holes

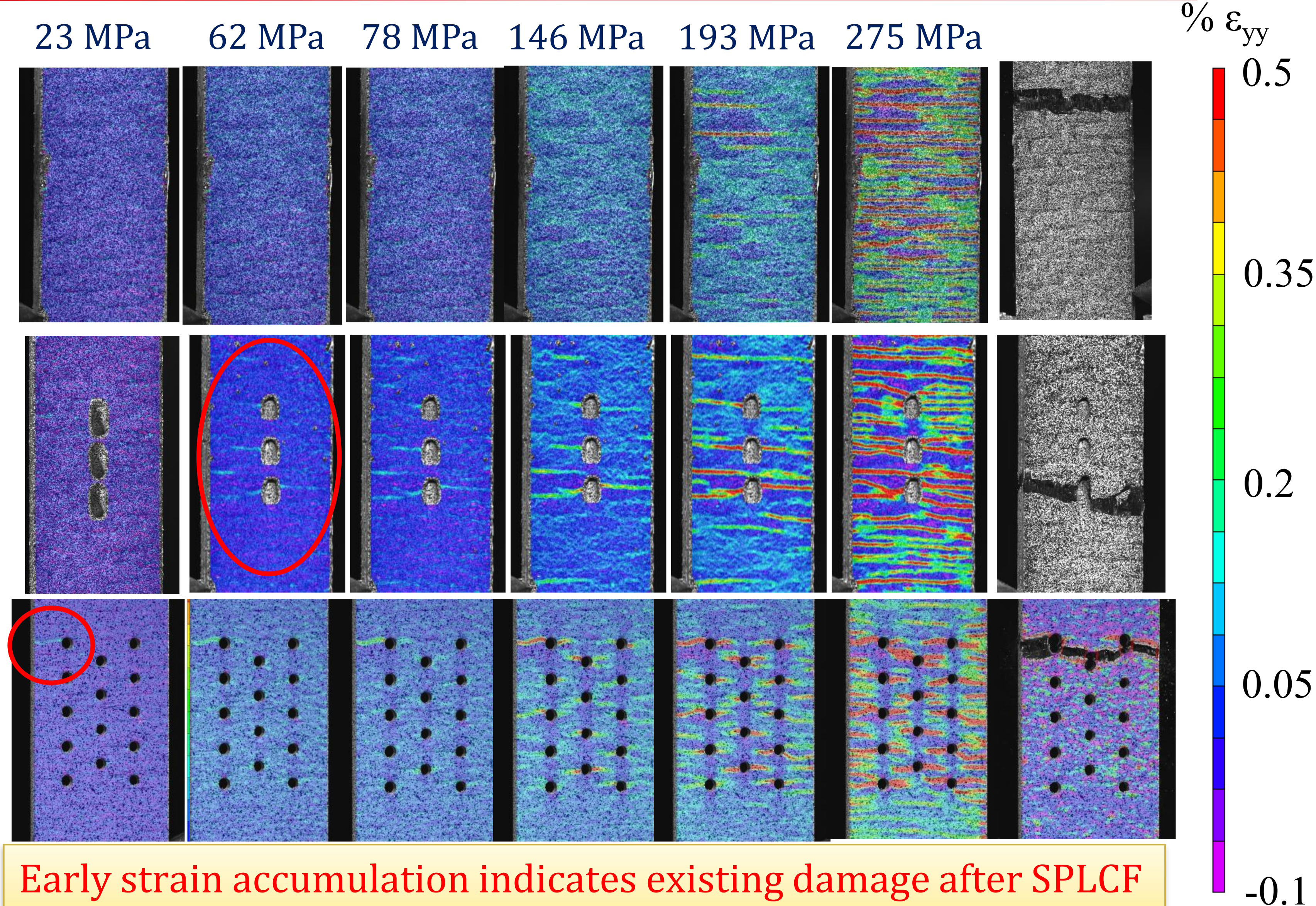
Retained Strength after SPLCF Testing at 69 MPa Dwell

- PLS does not change significantly for 90° samples
- DIC shows cracks at low stress compared to retained 30°



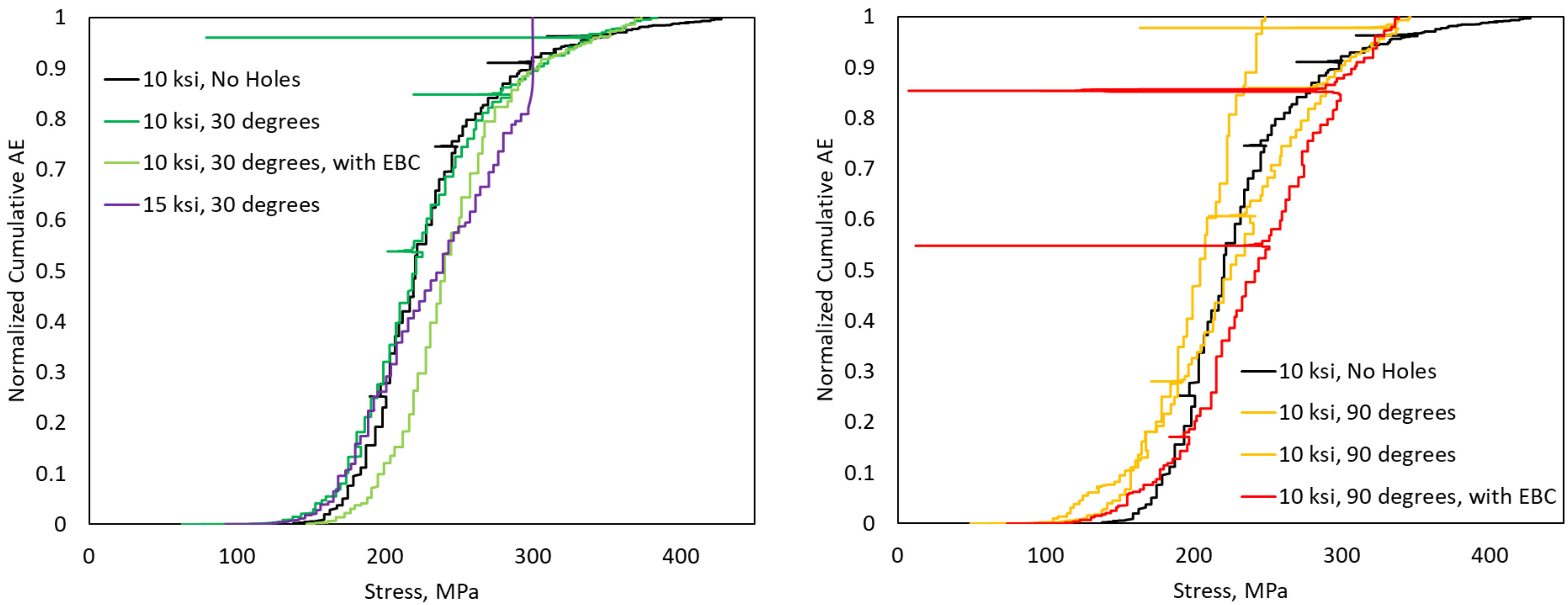
- UTS decreases after SPLCF
  - 9% for sample without holes
  - 15% for samples with 30° holes
  - 30% for samples with 90° holes

DIC Strain of Un-Coated Samples after 69 MPa SPLCF



Early strain accumulation indicates existing damage after SPLCF

Acoustic Emission after 10 ksi (69 MPa) SPLCF



90° samples start cracking at lower stress

Summary

- MI SiC/SiC samples with multiple holes were tensile tested.

- Room Temperature Results:
  - Holes do not affect proportional limit stress, on a net stress basis
    - DIC does show strain accumulation near 90° holes below the PLS
  - Ultimate Tensile Strength is affected by hole angle
    - Zero Reduction for 30° holes
    - 10% Reduction for 90° holes
    - However, 30° Holes with EBC cause a 10% reduction in UTS

- SPLCF Results:
  - 90° Holes lead to reduced life compared to 30° Holes or baseline samples
  - Proportional Limit Stress is largely unaffected by holes
    - EBC on 30° holes led to an increase in PLS after SPLCF
  - Ultimate Tensile Strength decreases after 300-hour SPLCF at 69 MPa
    - 9% Reduction for the sample without holes
    - 15% Reduction for samples with 30° holes
    - 30% Reduction for samples with 90° holes

Acknowledgements

- Kang Lee, NASA GRC
- Dan Gorican, HX5 LLC