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In-situ Observations and Measurements of Thread Failure in Thin Walled Aluminum Alloy Joints

Bonnie R. Antoun[1]
Gerald W. Wellman[2]
J. Franklin Dempsey[2]
Spencer Grange[2]
Kevin Connelly[1]
Helena Jin[1]
John S. Korellis[1]

[1]Sandia National Laboratories, Livermore, CA
[2]Sandia National Laboratories, Albuquerque, NM

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Motivation

- **Large diameter shallow engagement threads in thin walled assemblies present failure modes considerably different than typical fastener threads.**

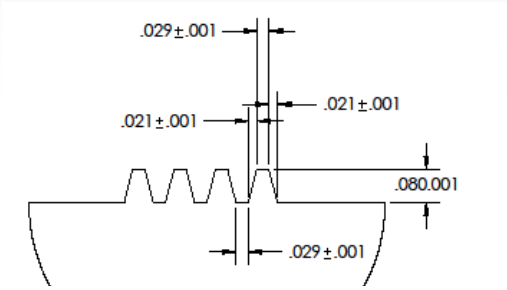
- **Developing an understanding of the mechanics of this type thread deformation leading to threaded joint failure is critically needed.**

Example dimensions:

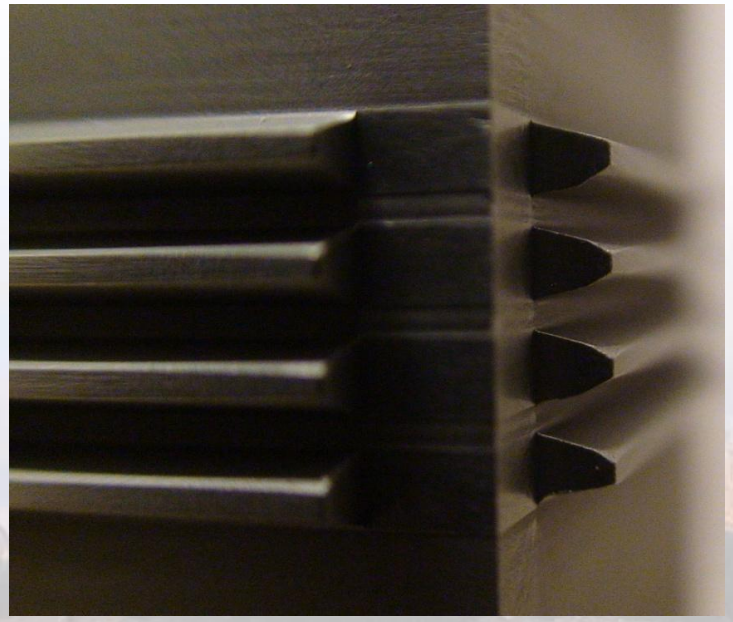
- **13” DIA, nominally**
- **10 threads/inch**
- **0.04” thread height**

Linear Thread Specimen Design

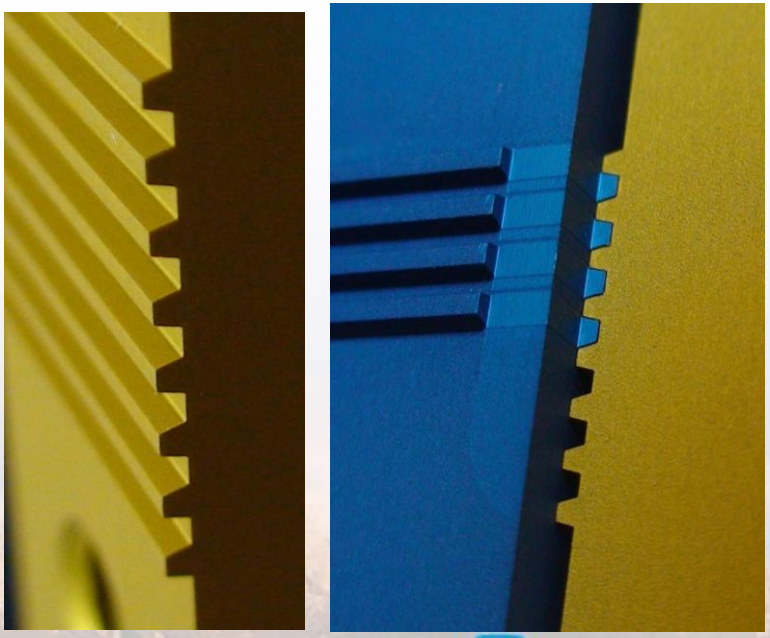
- ACME type threads were studied using three material pairing combinations of 7050-T74 and 7075-T651 aluminum alloys
- Two thread geometries (heights) studied to assess failure mode dependence.
- Different geometries may have different failure modes, increasing what we can learn about thread failure.



0.080” thread height (w/clear anodize)

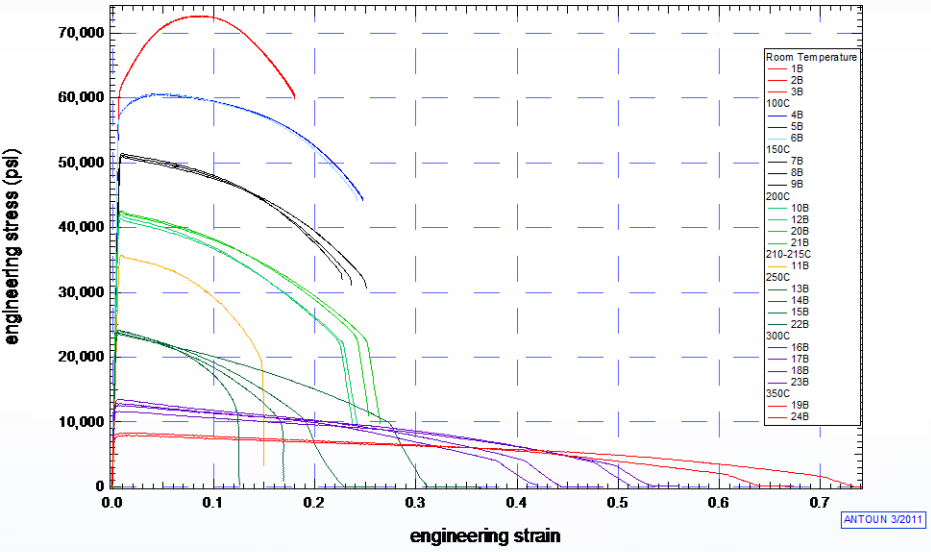


0.040” thread height (w/blue/gold anodize)

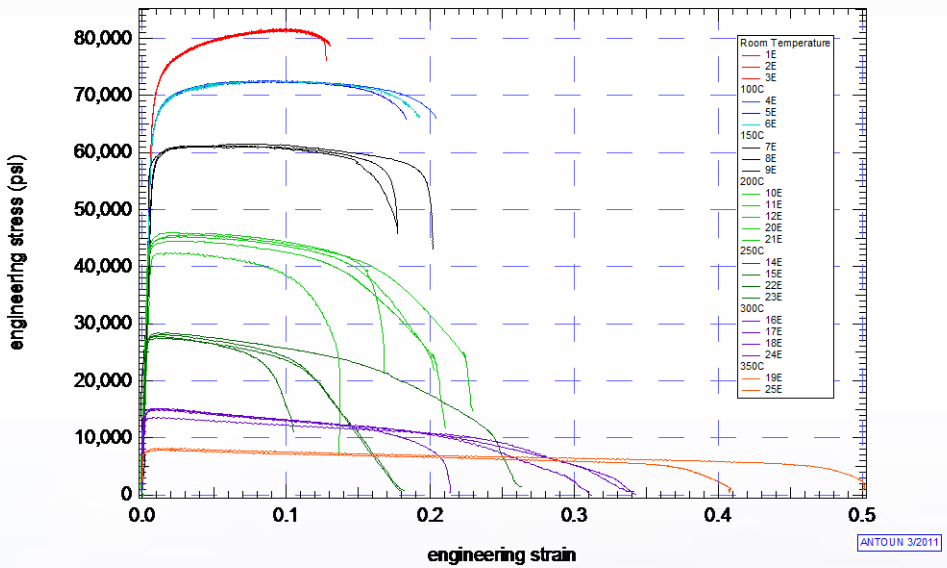


Tensile Characterization of Aluminum Alloys: RT to 350C

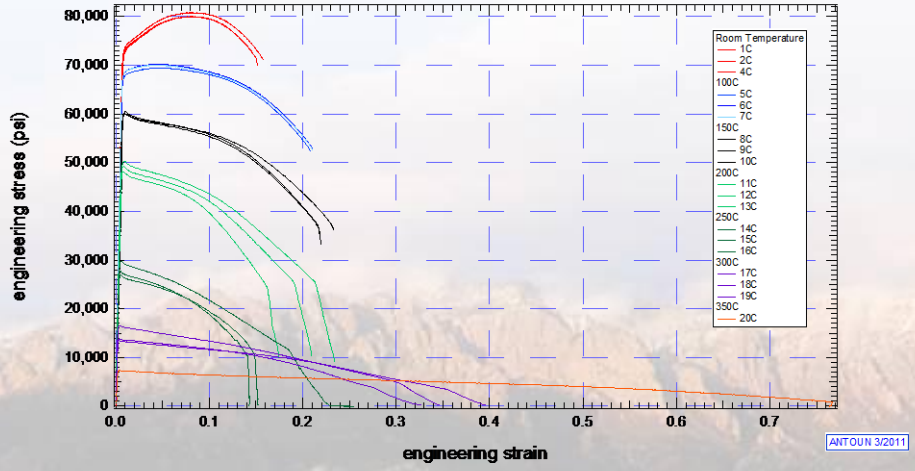
7075-T651 Aluminum



7079 Aluminum, Center Case



7050-T74 Aluminum



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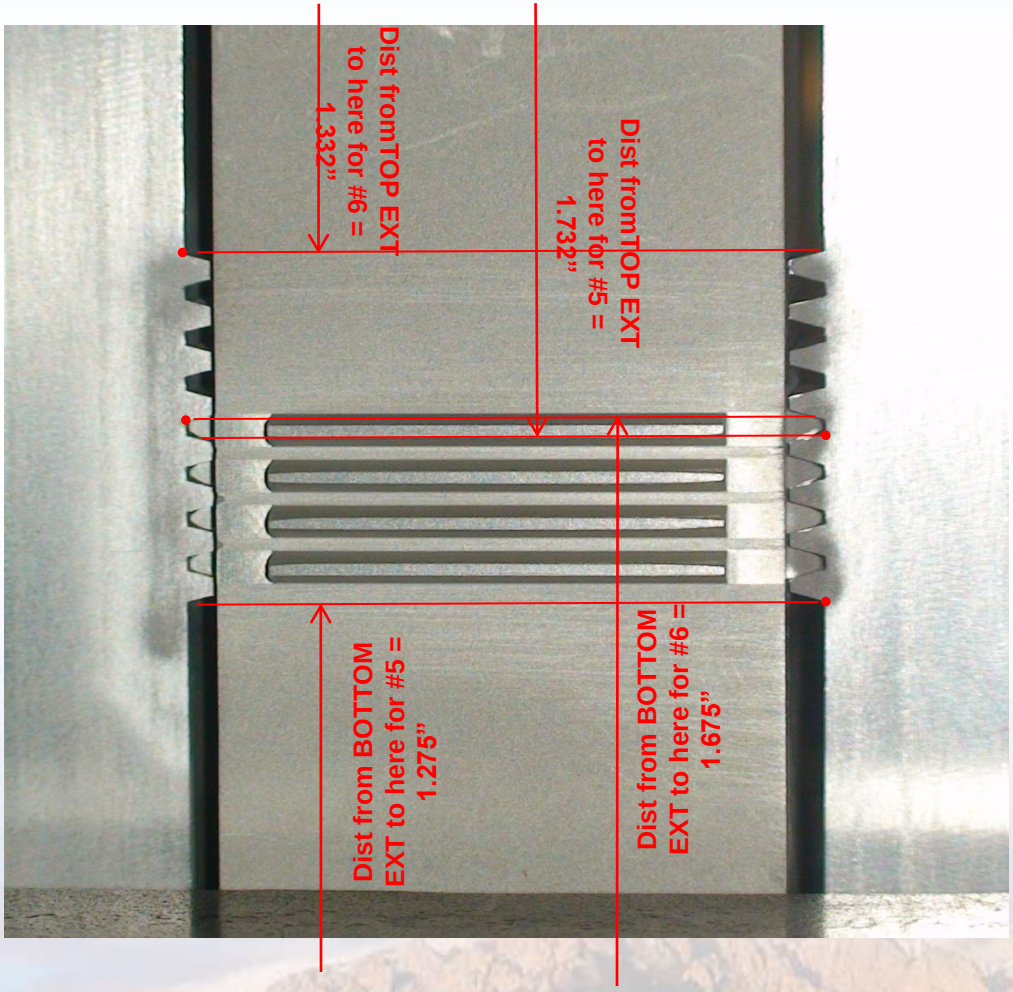
Linear Thread Specimen Details



After test completion the lower side threads are machined off and the center thread is rotated and moved up 0.4” to engage the next set of threads.

This allows opportunity to replicate experiments with the same specimen set.

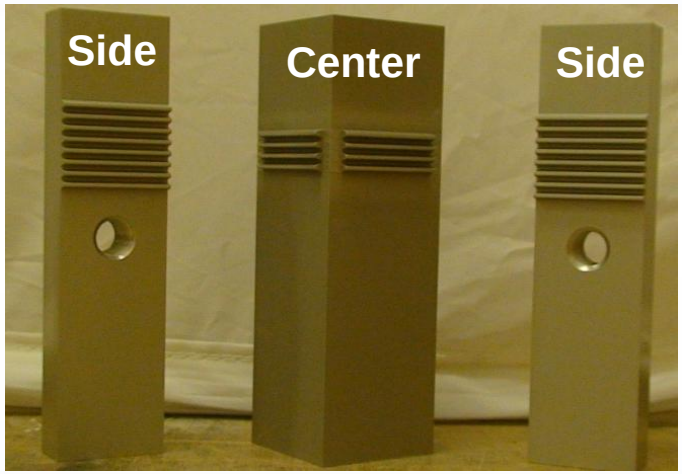
Experimental Measurements

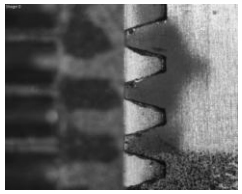
A linear thread experimental capability with supporting diagnostic methods was developed to allow direct observations and measurements of deformation/failure of individual and multiple threads.

- **Axial load, axial displacement, transverse load and transverse displacement across the thread joint are continuously monitored during deformation.**
- **High resolution images of the threaded section are captured for post failure analysis using digital image correlation techniques.**
- **Boundary conditions and applied mechanical loading were specifically controlled for finite element modeling/analyses of experiments.**

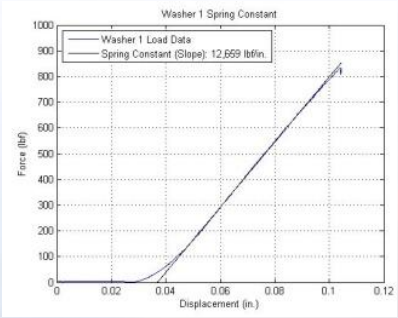
Linear Thread Experimental Setup

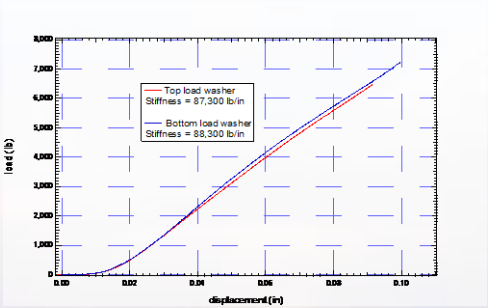
Linear thread specimen pairing



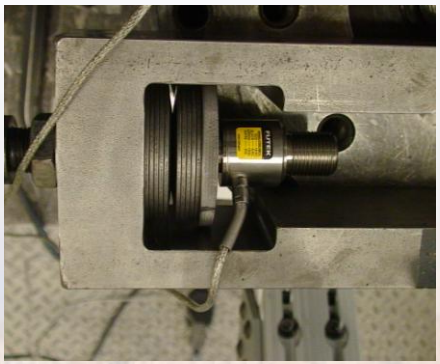


Starting thread engagement is controllable.





Compliance of threaded joint can be set to any level, ranges used so far – 12,700 to 88,300 lb/in.



- **Lateral loads monitored above and below thread**
- **Structural compliance is mechanically imposed using Belleville washer arrangement**

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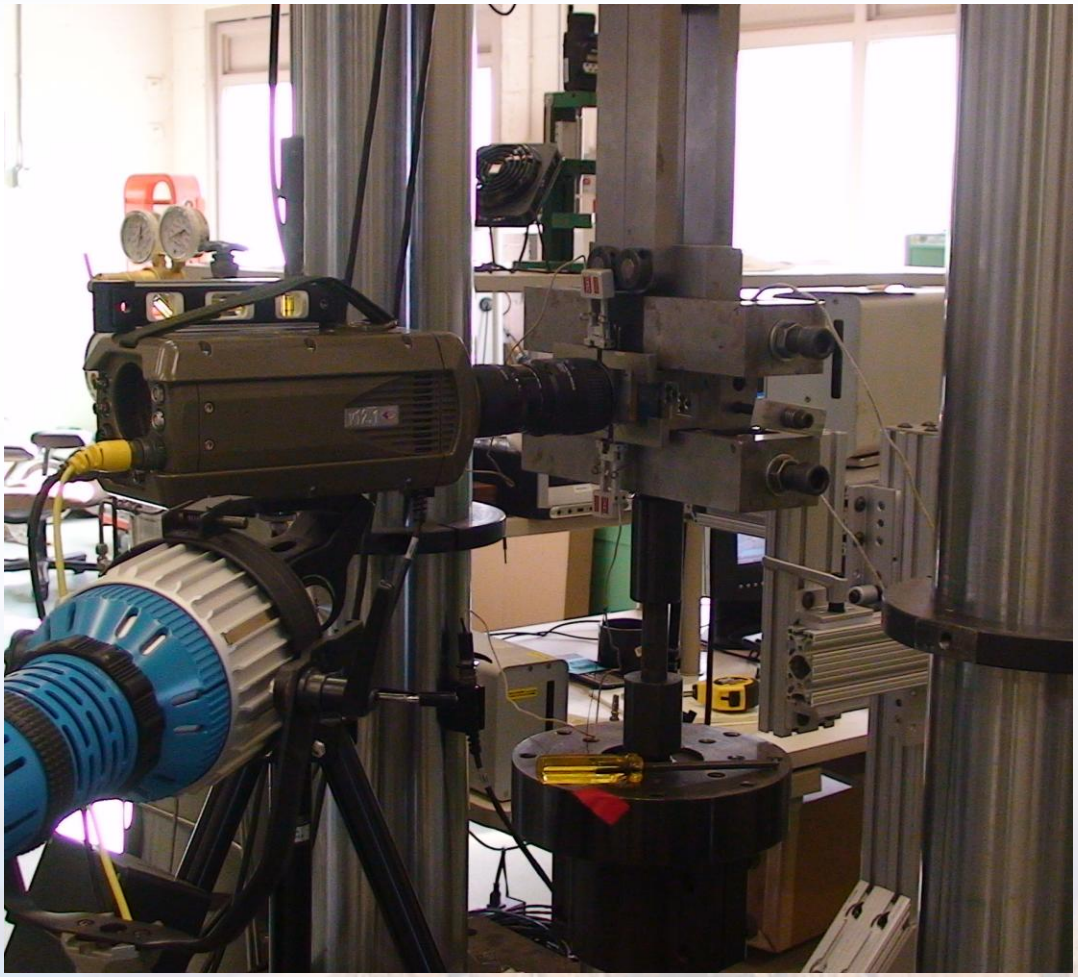
Linear Thread Experimental Setup



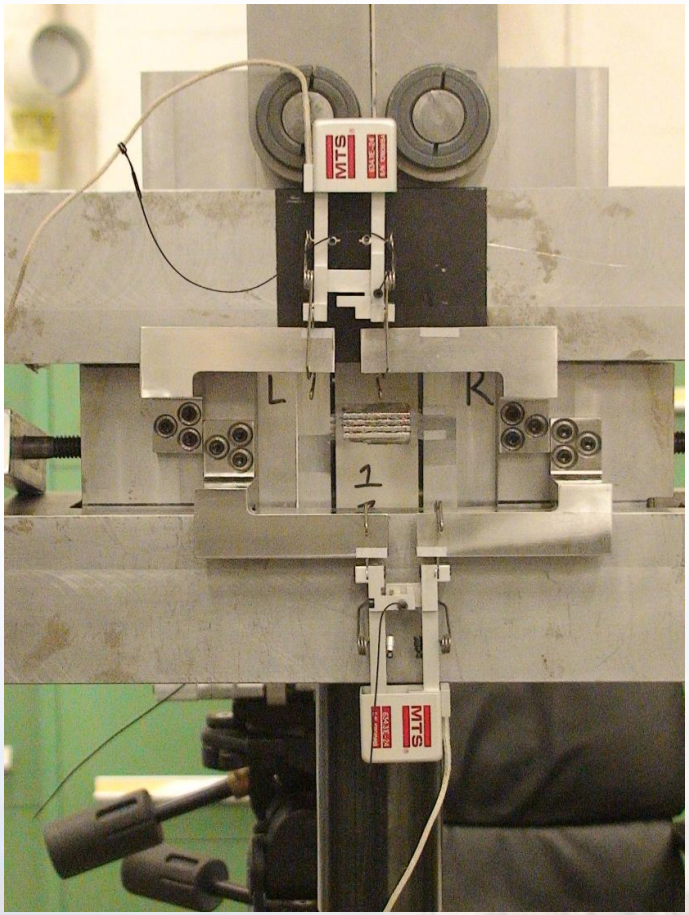
Measurements:

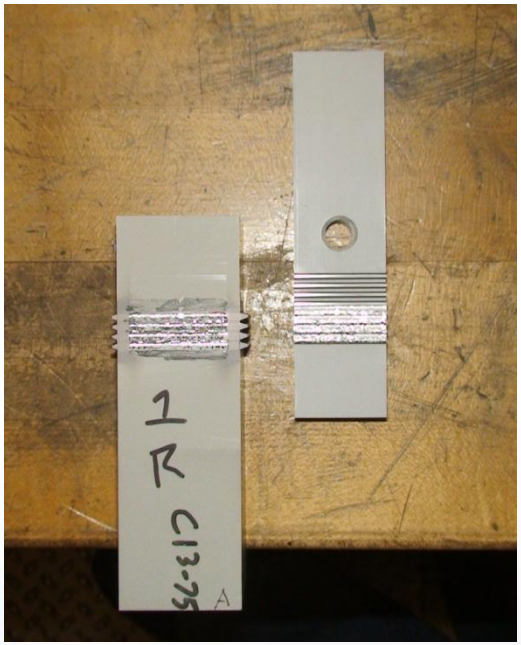
- Axial load (frame)
- Axial displacement (frame=0.001 in/s)
- Thread axial displacement (laser extensometer)
- Thread transverse displacement (top extensometer)
- Thread transverse displacement (bottom extensometer)
- Transverse load (top load washer)
- Transverse load (bottom load washer)

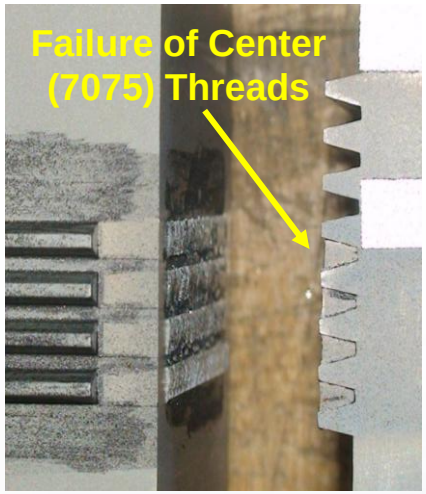
Observations:

- Optical images (video camera)
- High speed imaging (Phantom camera)
- Post-processing with DIC

Experimental Results
TEST #5 7050-T74 side threads, 7075-T7351 center threads

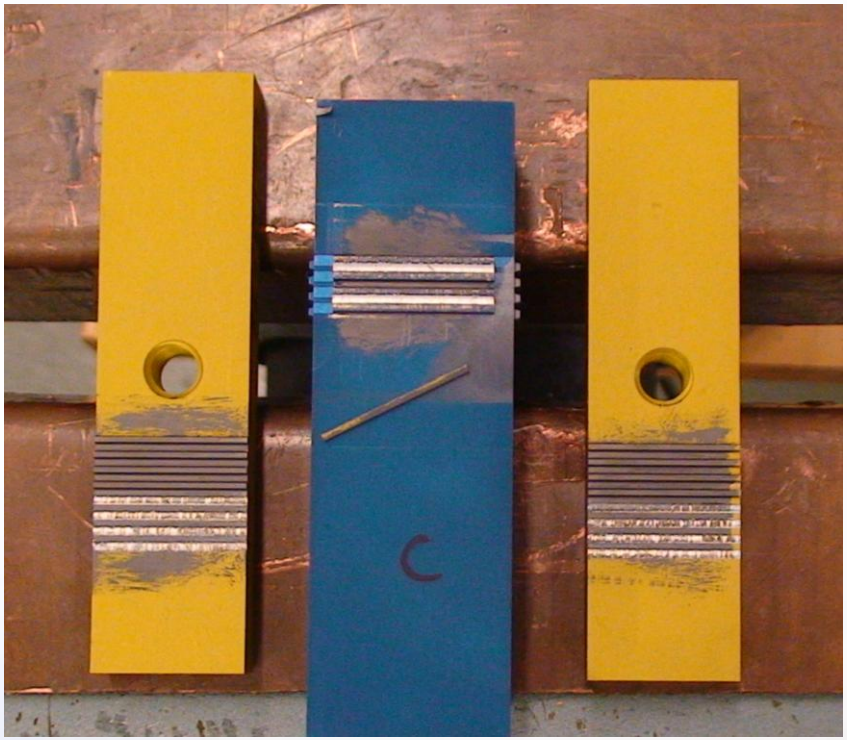


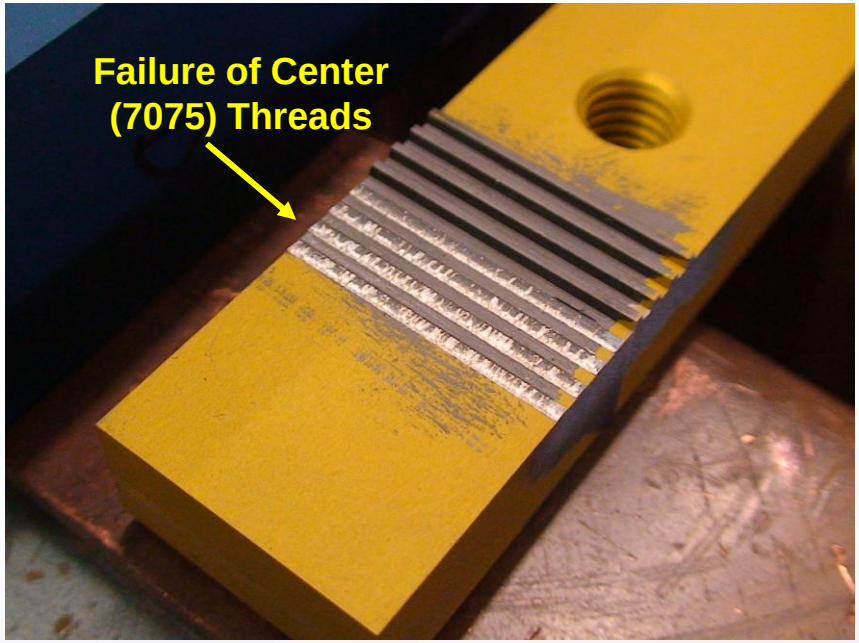




- **Thread failure by shear mechanism.**
- **7075 (center threads) failed due to lower strength relative to 7050 alloy**

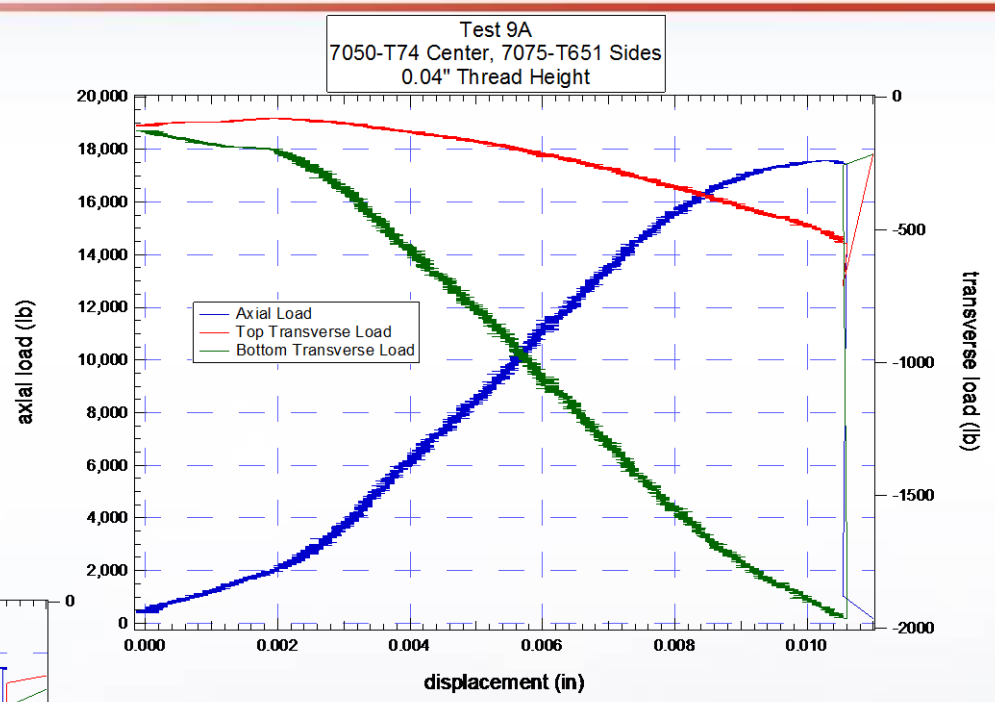
Experimental Results
TEST #9A 7075-T7351 side threads, 7050-T74 center threads

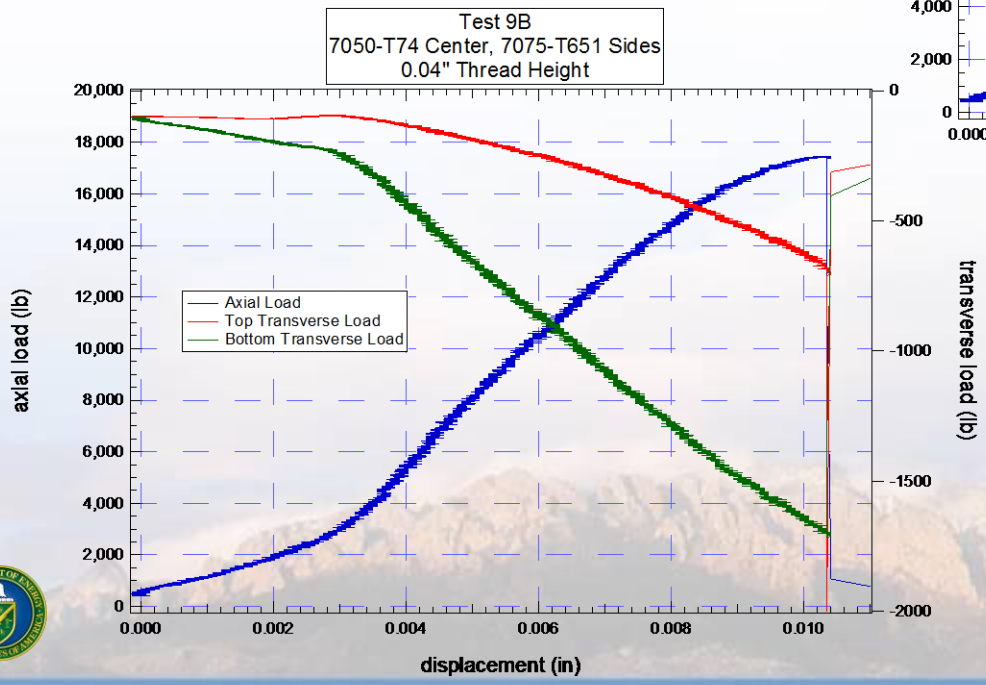




- Thread failure by shear mechanism.
- 7075 (side threads) failed due to lower strength relative to 7050 alloy (center threads)

Experimental Measurements: TESTS #9A, 9B
7075-T7351 side threads, 7050-T74 center threads





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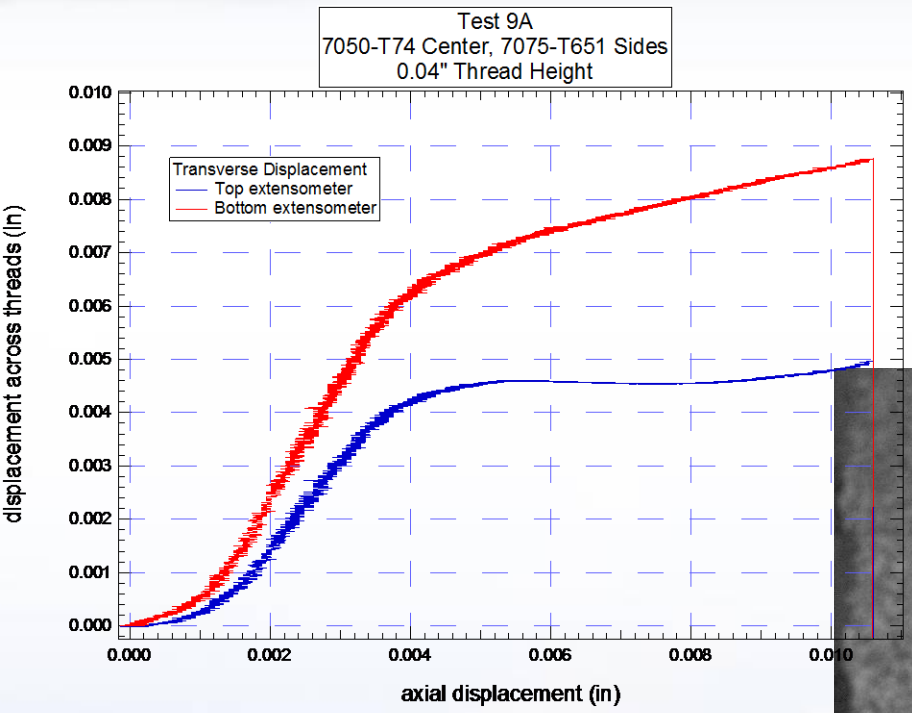
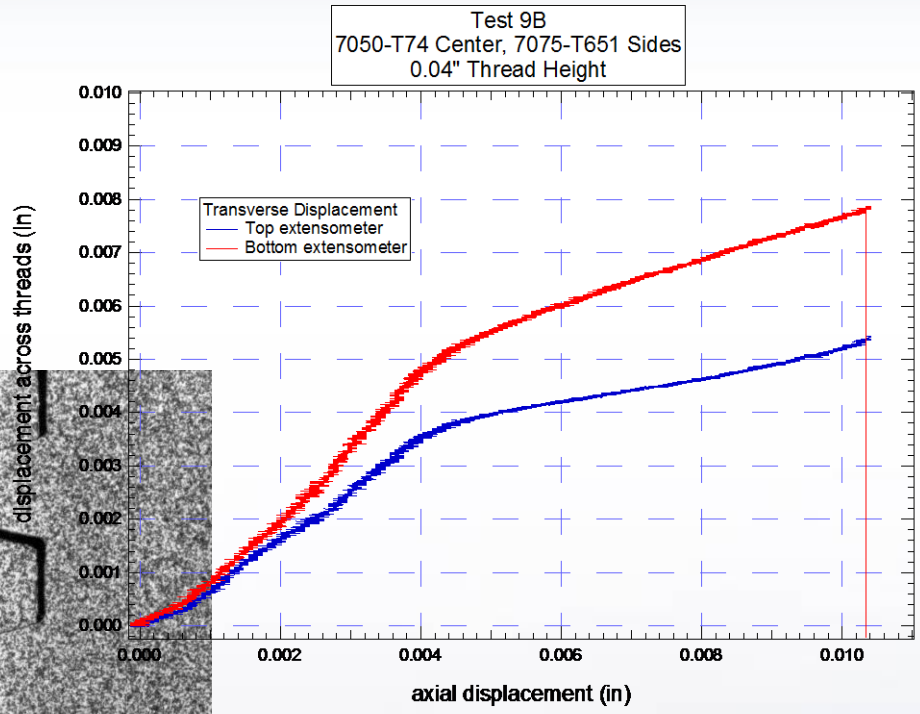
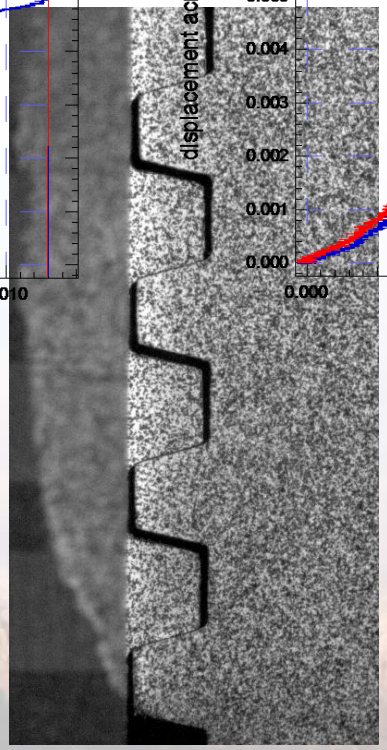
Experimental Measurements: TESTS #9A, 9B
7075-T7351 side threads, 7050-T74 center threads







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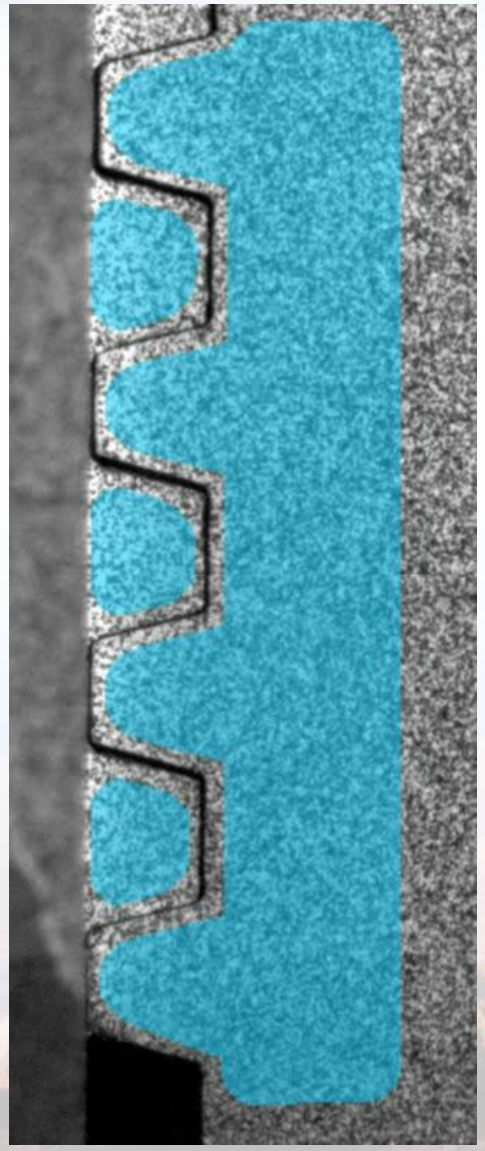
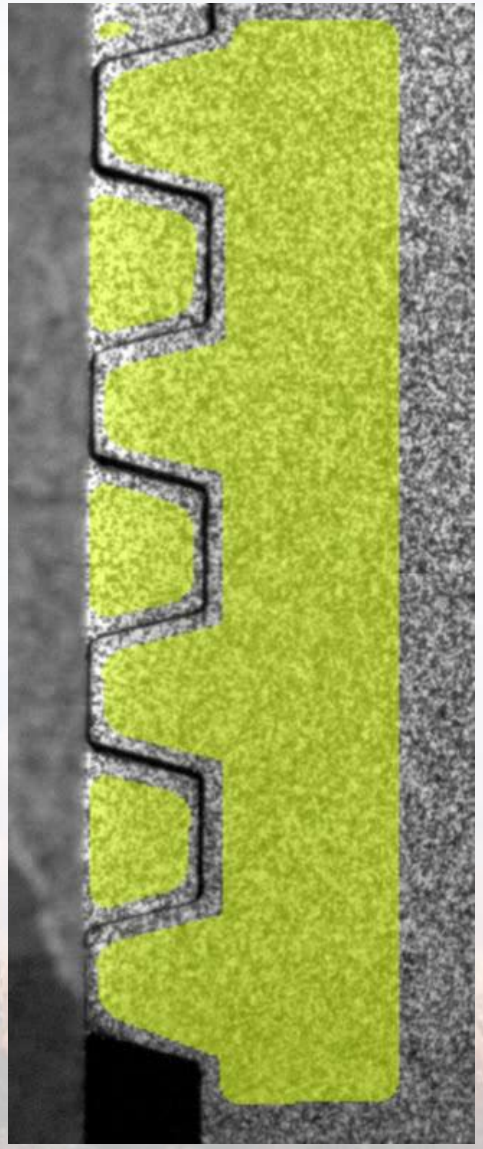
Digital Image Correlation (DIC) Results

ε_{xx}

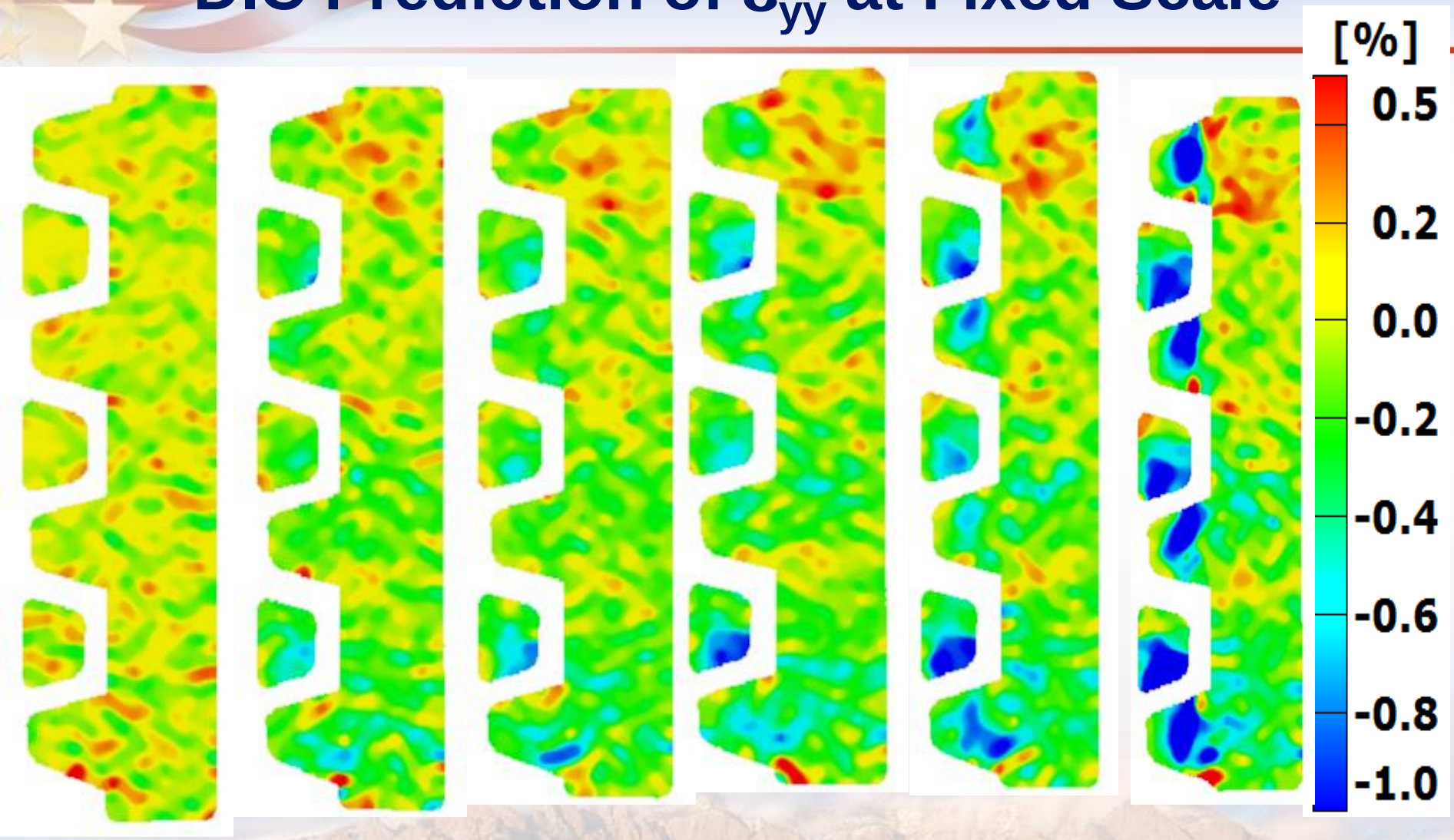




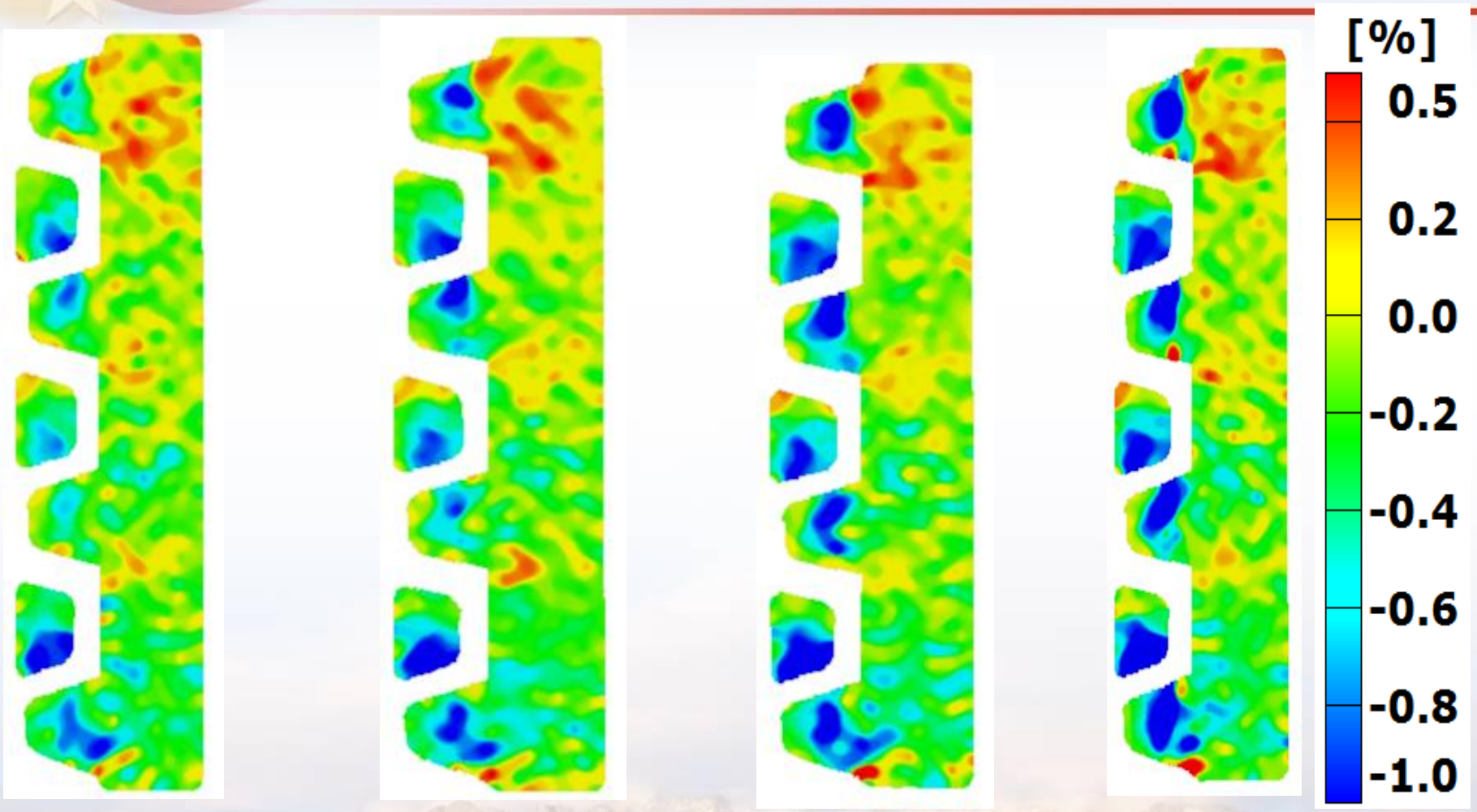
ε_{yy}

Every 10th frame collected from Phantom high speed camera used for DIC

DIC Prediction of ε_{yy} at Fixed Scale



DIC Prediction of ε_{yy} at Fixed Scale



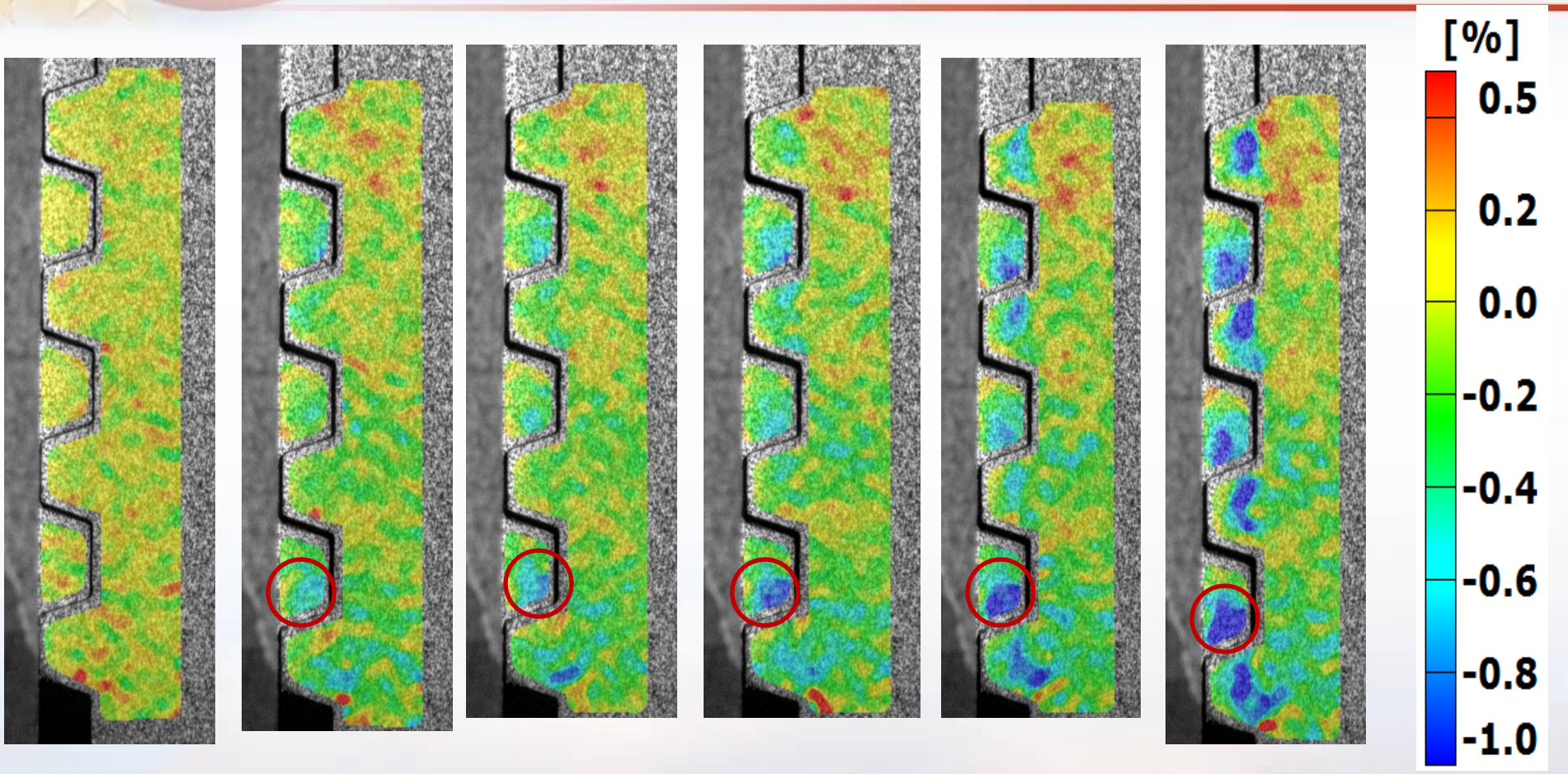
Stg 130

Stg 135

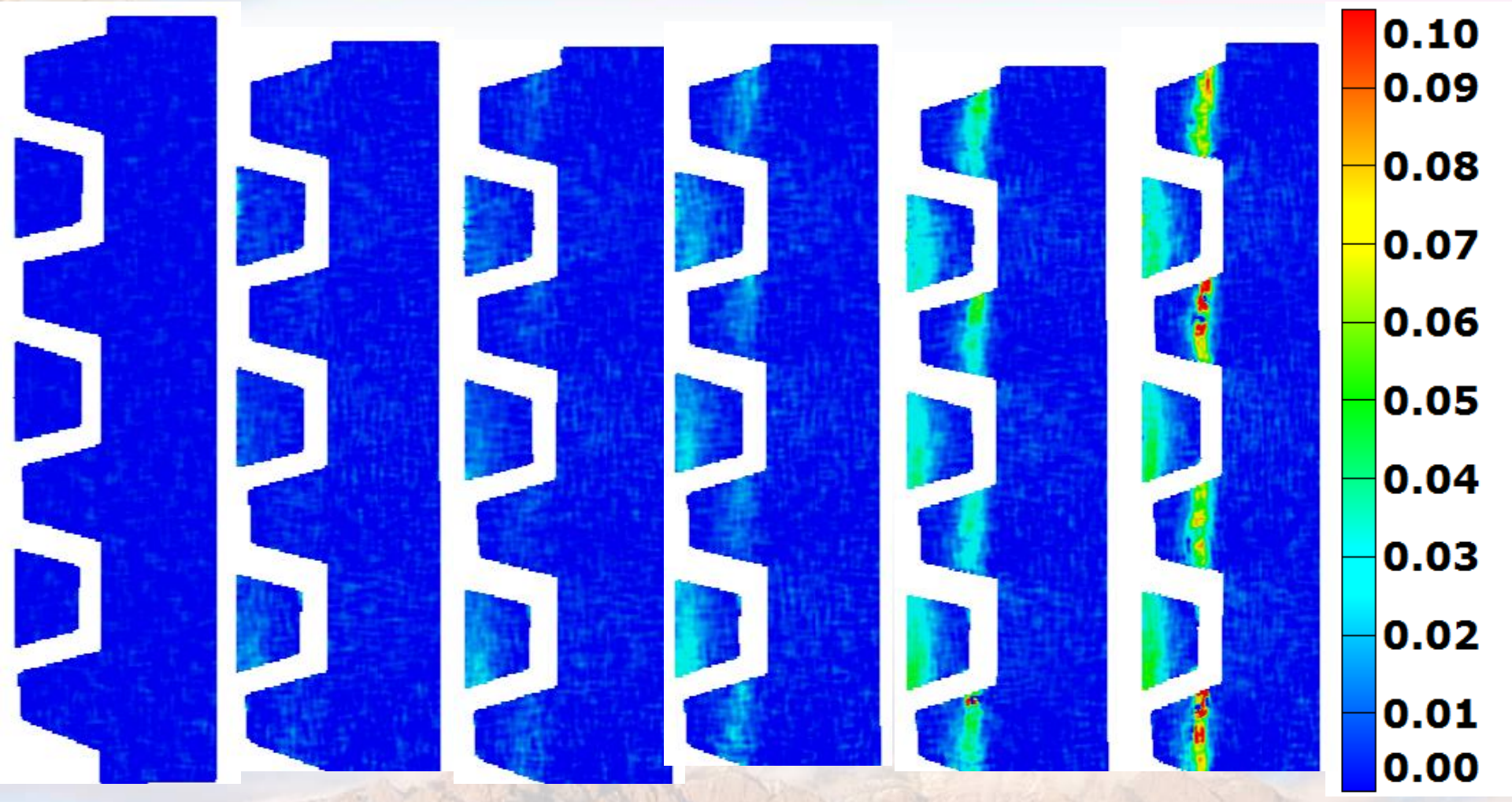
Stg 140

Stg 144
(before failure)

DIC Prediction of ε_{yy} at Fixed Scale

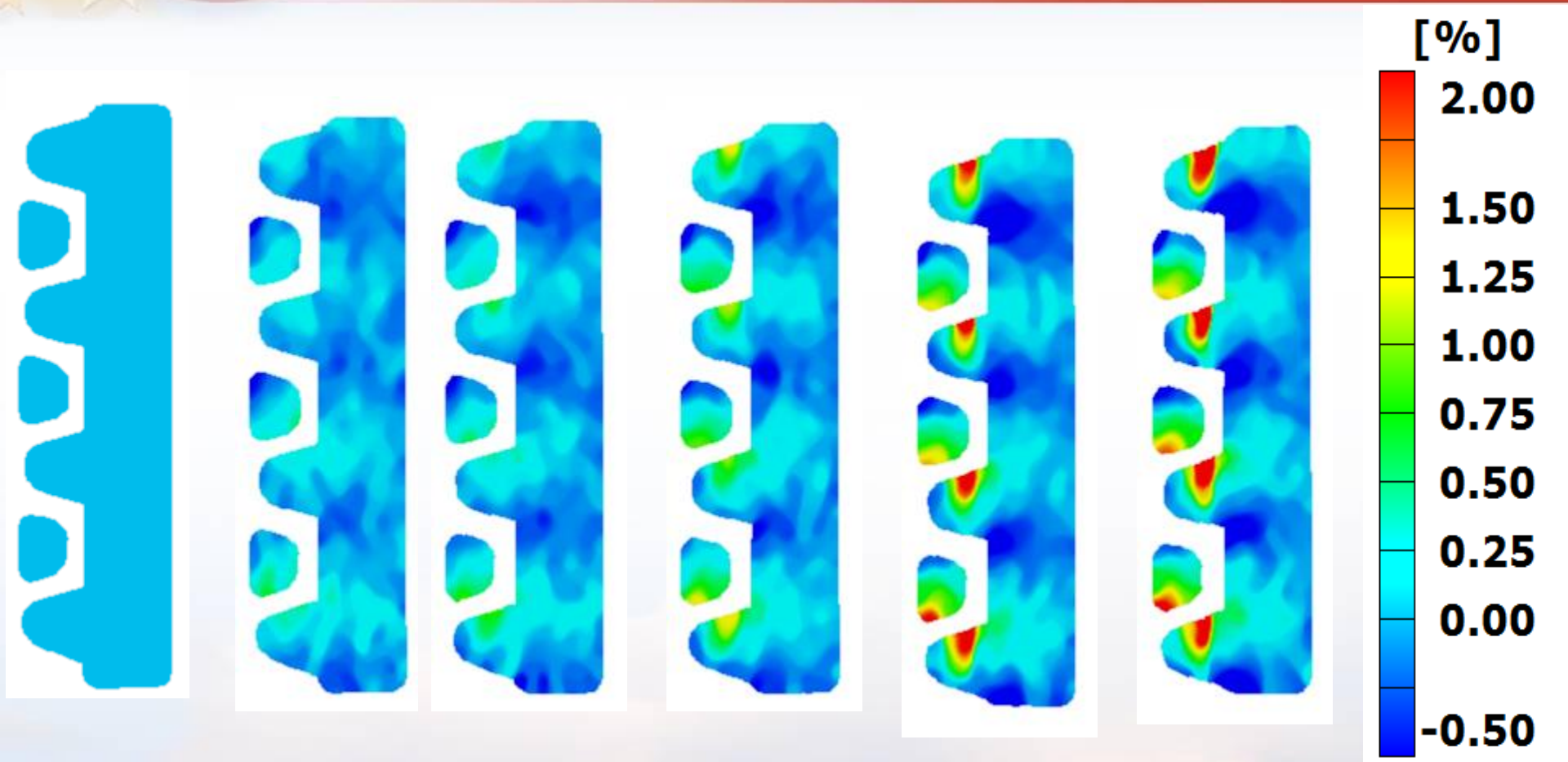


DIC Prediction of Shear strain, ε_{xy} at Fixed Scale



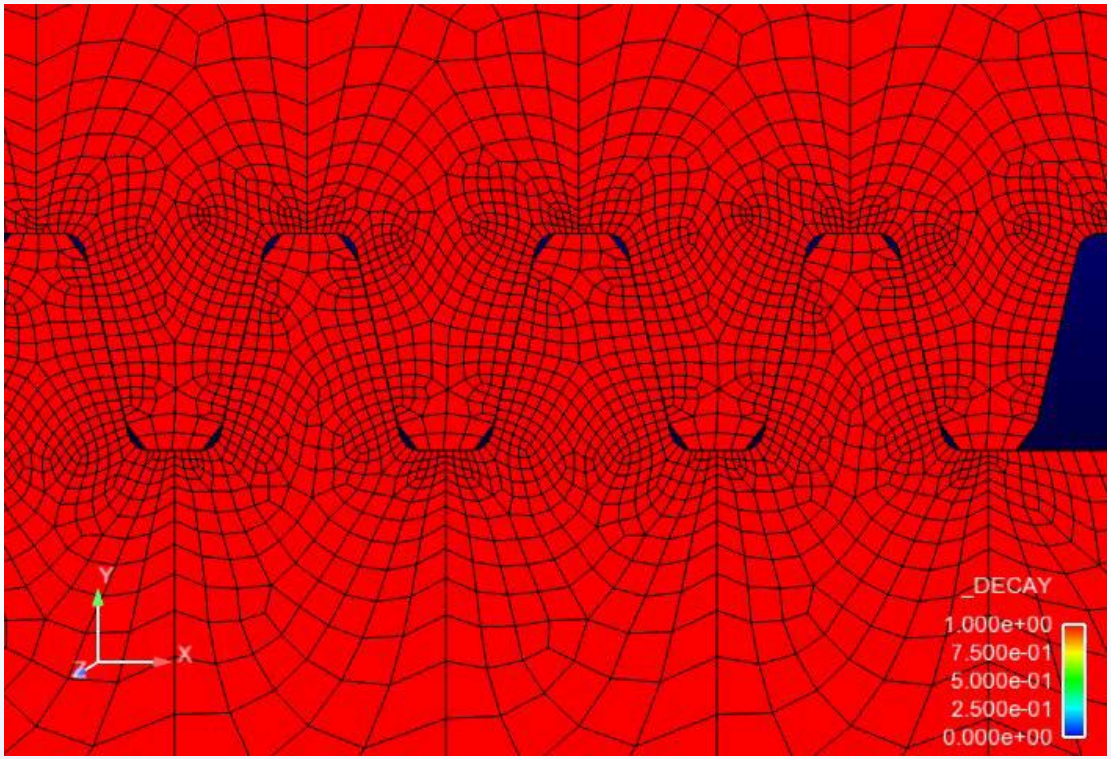
Stg 1 Stg 110 Stg 120 Stg 130 Stg 140 Stg 144(before failure)

DIC Prediction of ε_{xx} at Fixed Scale



Stg 1 | Stg 110 | Stg 120 | Stg 130 | Stg 140 | Stg 144(before failure)

FE Modeling and Analyses



Limitations:

- **Best guess (no experimental evidence) on crack-opening strain parameter (energy dissipation during failure) .**
- **Failure is tension only – not very good for coarse mesh – improves with mesh refinement.**

Mesh: 3D with B.C.'s front and back to make it 2D plane strain. 7680 nodes – 3503 elements

Code: SIERRA-ADAGIO quasistatics, iterative nonlinear conjugate gradient solver uniform gradient (single integration point with hourglass control) hex element

Material Model: Elastic-Plastic strain hardening, Failure criterion is tearing parameter.

Stress decay from failure criterion based on crack-opening strain in element.

Element deletion on decay of stress to zero.

Conclusions and Next Steps

- Study of the failure of large diameter shallow engagement threads has been enabled by the development of a linear thread apparatus and experimental methods
- Thread loading is conducted in displacement control. Results have been repeatable.
- DIC is being implemented to provide additional quantitative results to compare to FE analyses.
- FE modeling is progressing, mesh convergence studies completed, element failure method chosen. Experimental data will enable validation of analysis methods.
- Next steps:
  - Vary thread engagement to determine how it affects thread failure mode
  - Conduct similar experiments at 200C
  - Higher speed imaging of thread deformation may be needed near failure
  - Conduct similar experiments with thermal gradient along thread length