SAND2019-4999C

Exceptional service in the national interest

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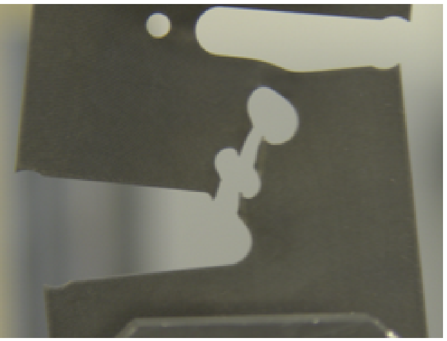

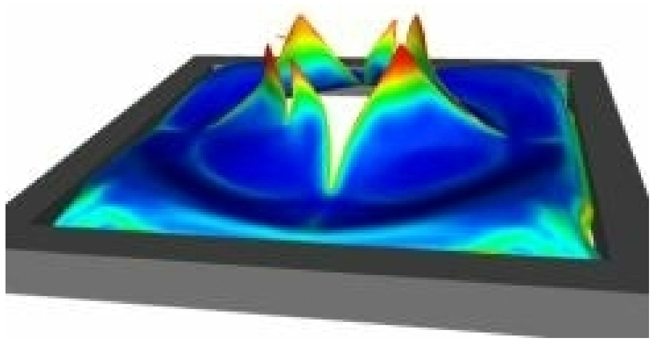

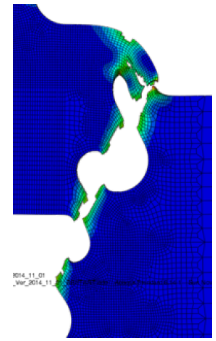

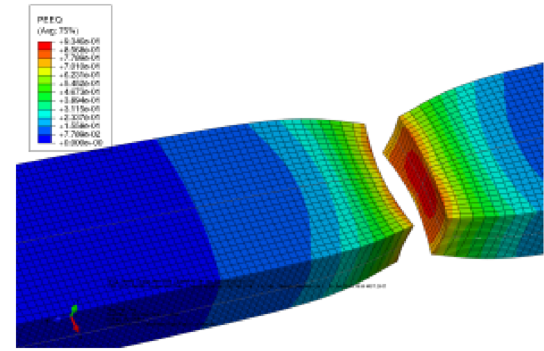

Lessons Learned from the Sandia Fracture Challenges

Brad Boyce
Materials Science and Engineering Center
Sandia National Laboratories

February, 2019

Damage Mechanics Challenge Workshop – Purdue University

U.S. DEPARTMENT OF ENERGY   NNSA National Nuclear Security Administration

Fracture is a pervasive problem…

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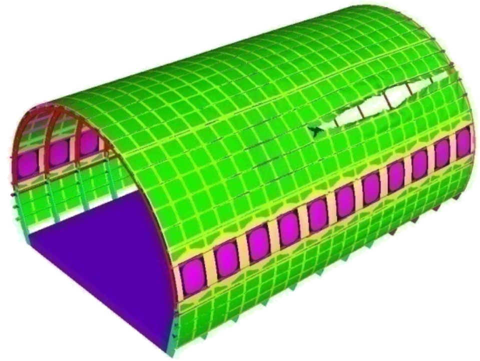


Airframe Shoe-Bomb Scenario

Cargoship Rena (2011)

Nuclear safety: operational and threat environments.

Structural survivability of electric grid.

Hydrogen storage in GM fuel cell vehicles

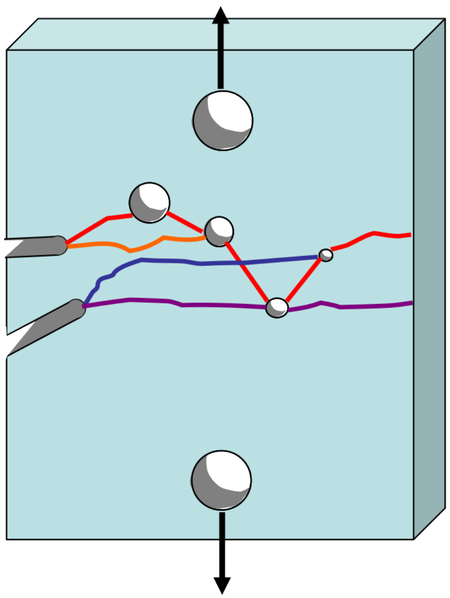
.

Minnesota I-35W Bridge Collapse..

Metal Forming

OBJECTIVE: *Assess how well we can blindly predict metallic fracture of an unfamiliar geometry*

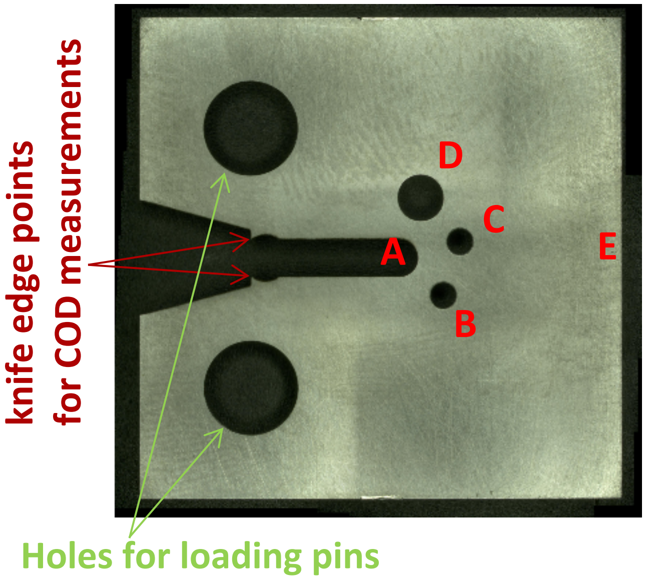
PHILOSOPHY:

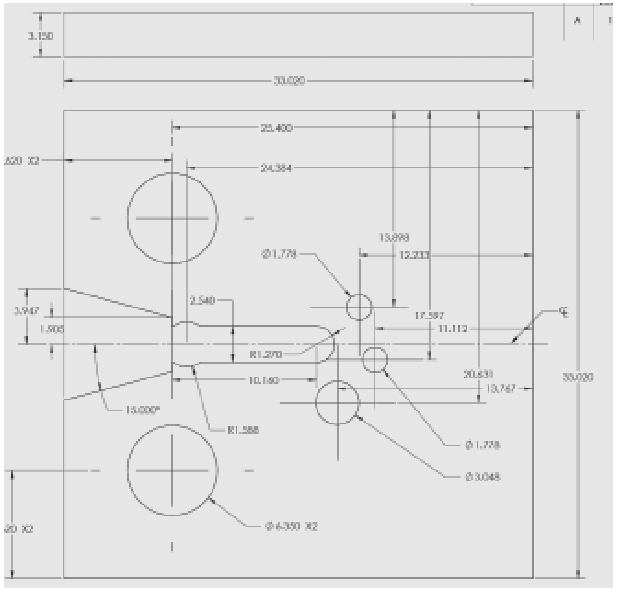


"Crack-in-a-maze" Concept

- Replicate real-world engineering constraints (time, budget, information)
- **Blind** predictions are reported before confirmation experiments are available
- 'Toy Problem' is geometrically simple but captures salient difficulties of real-world problems
- Assess the whole prediction stream: (physics, numerical methods, code, calibration & people)
- Do not specify the models/tools/methods to be used: let the engineers use their judgement & strengths
- Verify the experimental outcome in multiple labs, and disseminate results *after* blind predictions are reported
- Use the assessment to inspire improvements
- **COMPETITION DRIVES INNOVATION**

The SFC1 Challenge





Alloy: 15-5PH H1100

The challenge. When loaded at room temperature at a loading rate of 0.0005 inches/sec,

(Q1) What is the force and COD displacement[1] at which a crack first initiates[2]?

(Q2) What is the path of crack propagation? (Use feature labels A-E to describe path)

(Q3) If the crack does propagate to either holes B,C, or D, at what force and COD displacement does the crack re-initiate out of the first hole?

Boyce, et al., *Int. J. Fracture*, 2014

Details of the Material & Geometry Were Provided

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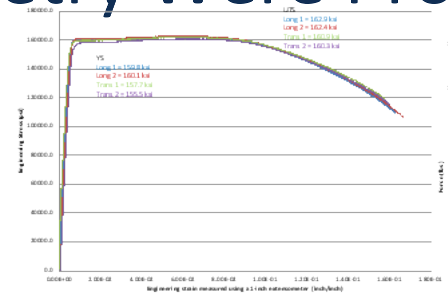
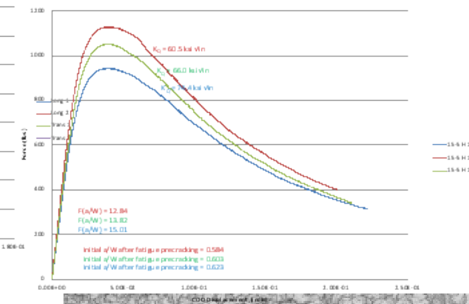
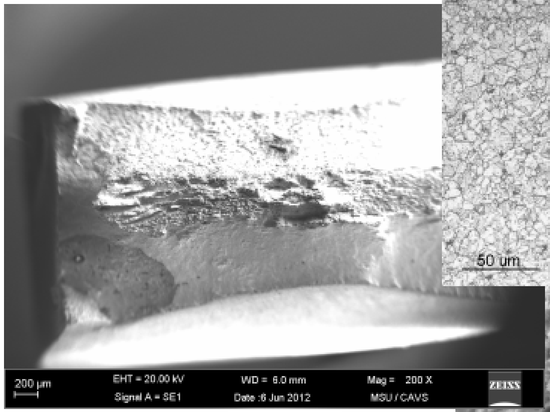
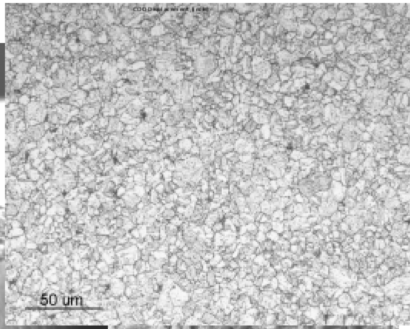
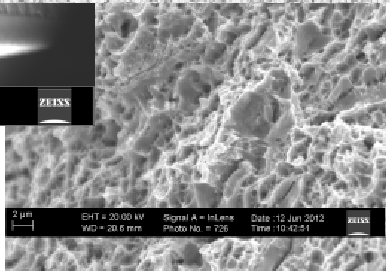
- Multiple tensile stress-strain curves for both longitudinal and transverse deformation
- Multiple Sharp-crack 'fracture toughness' force-displacement curves on sheet of same thickness as challenge
- Images of the fracture surface, side view of the necking region
- Material certification, including material chemistry and mechanical properties
- Detailed heat treatment records
- Measured hardness values
- Engineering drawings that were also sent to machinists for specimen manufacture



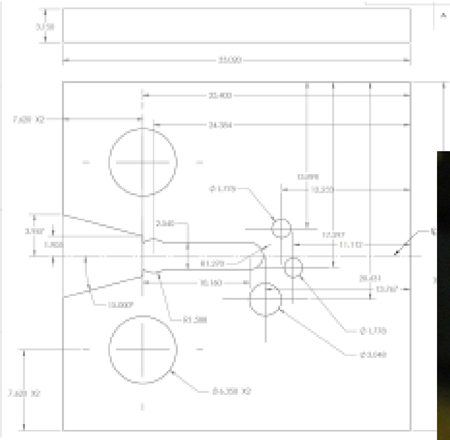








Mississippi State (Horstemeyer et al)



Boyce, et al., *Int. J. Fracture*, 2014

Leverage the external mechanics community

Sandia National Laboratories

The University of Texas at Austin

NASA

MINES ParisTech

MIT Massachusetts Institute of Technology

Cornell University Founded A.D. 1865

Northwestern University 1851

GE

Univerza v Mariboru

The American University in Cairo

UIC University of Illinois at Chicago

Natural Resources Canada / Ressources naturelles Canada

CanmetÉNERGIE
Leadership en écoInnovation

RWTH Aachen University

ONERA
THE FRENCH AEROSPACE LAB

UCLA Bruins

GLOBAL ENGINEERING & MATERIALS, INC.
Engineering and Innovative Solutions

University of Miami

UT Dallas

Chongqing University 1929

Tsinghua University 1911

Zhejiang University 1897

University of Cincinnati

Missouri

Dalian University of Technology 1949

NSWC Naval Surface Warfare Center — A Tradition of Excellence

The University of Arizona

Ruhr Universität Bochum

RUB

Each team attempted to blindly predict the failure scenario

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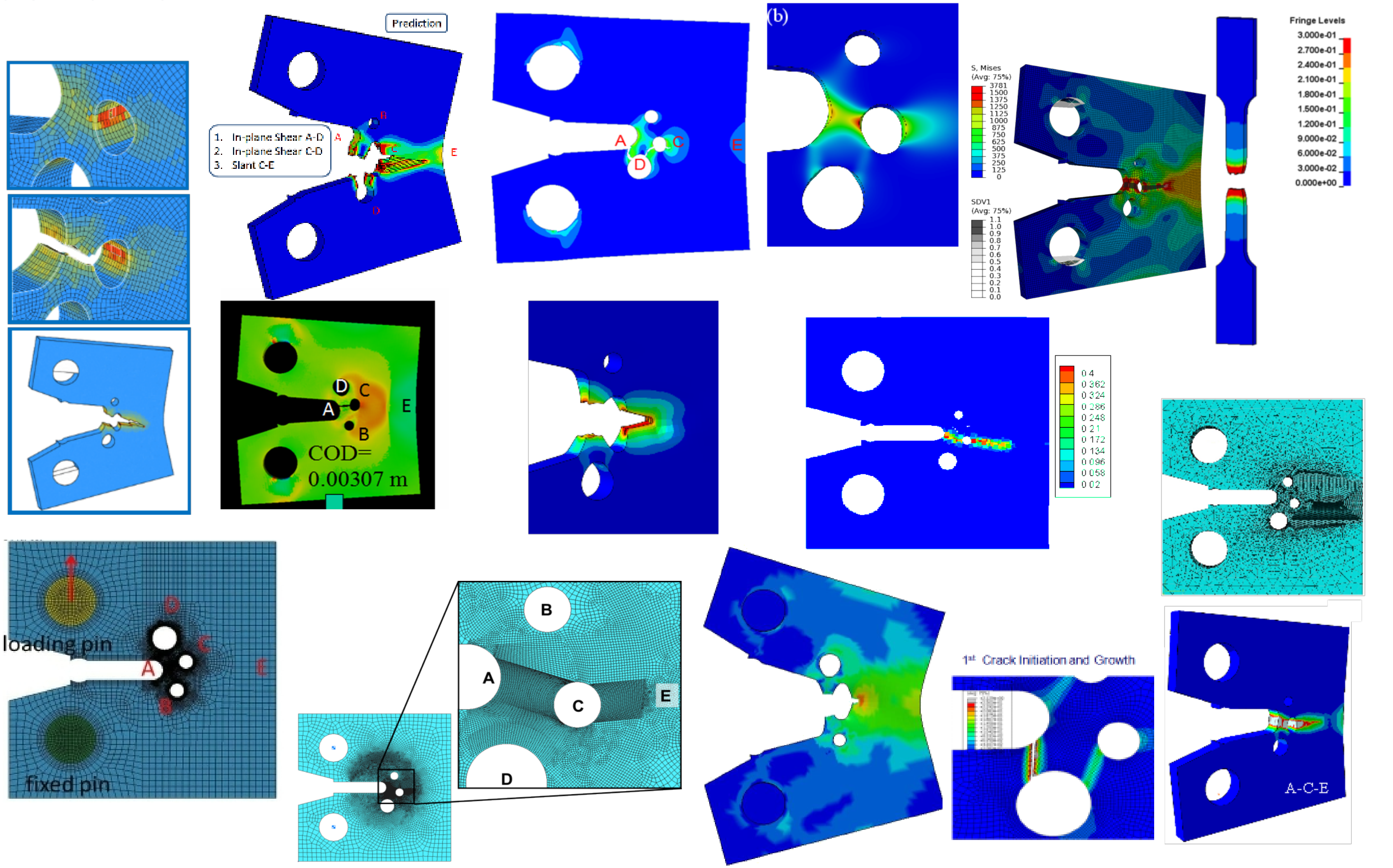
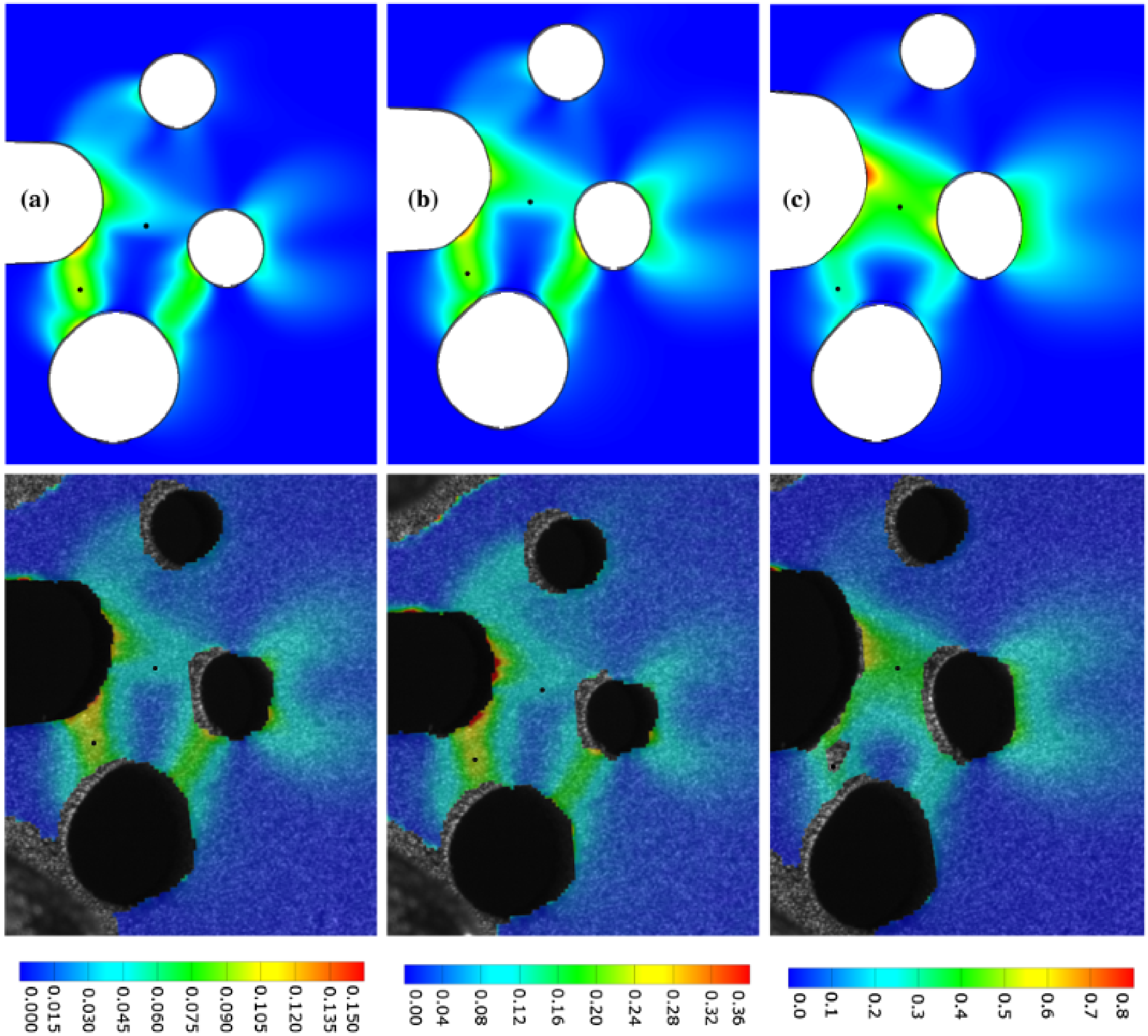


Boyce, et al., *Int. J. Fracture*, 2014

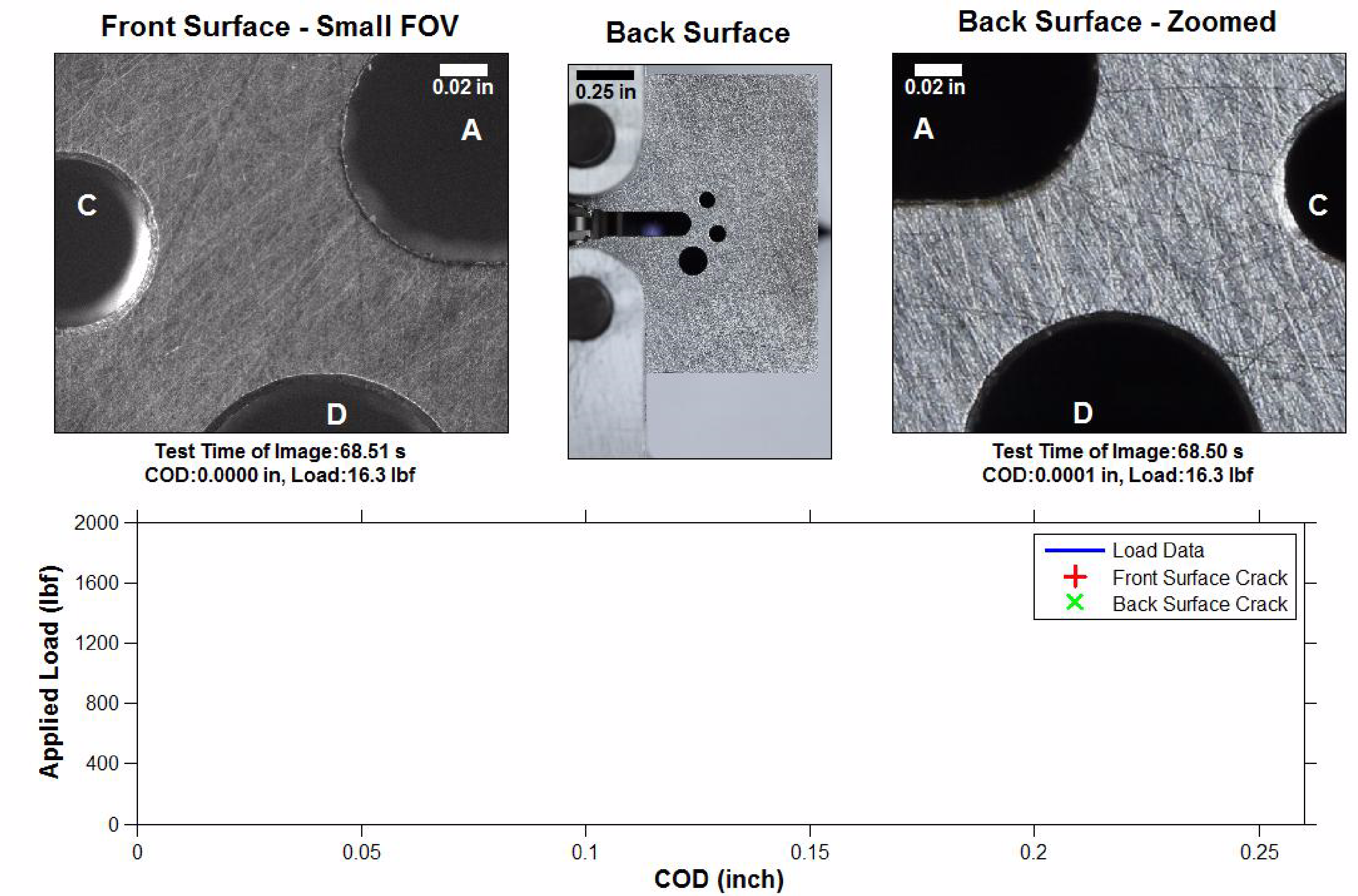
The challenge geometry creates a competition between a tensile failure and shear mode

Prediction
(Gross & Ravi Chandar)

Experimental
Digital Image Correlation

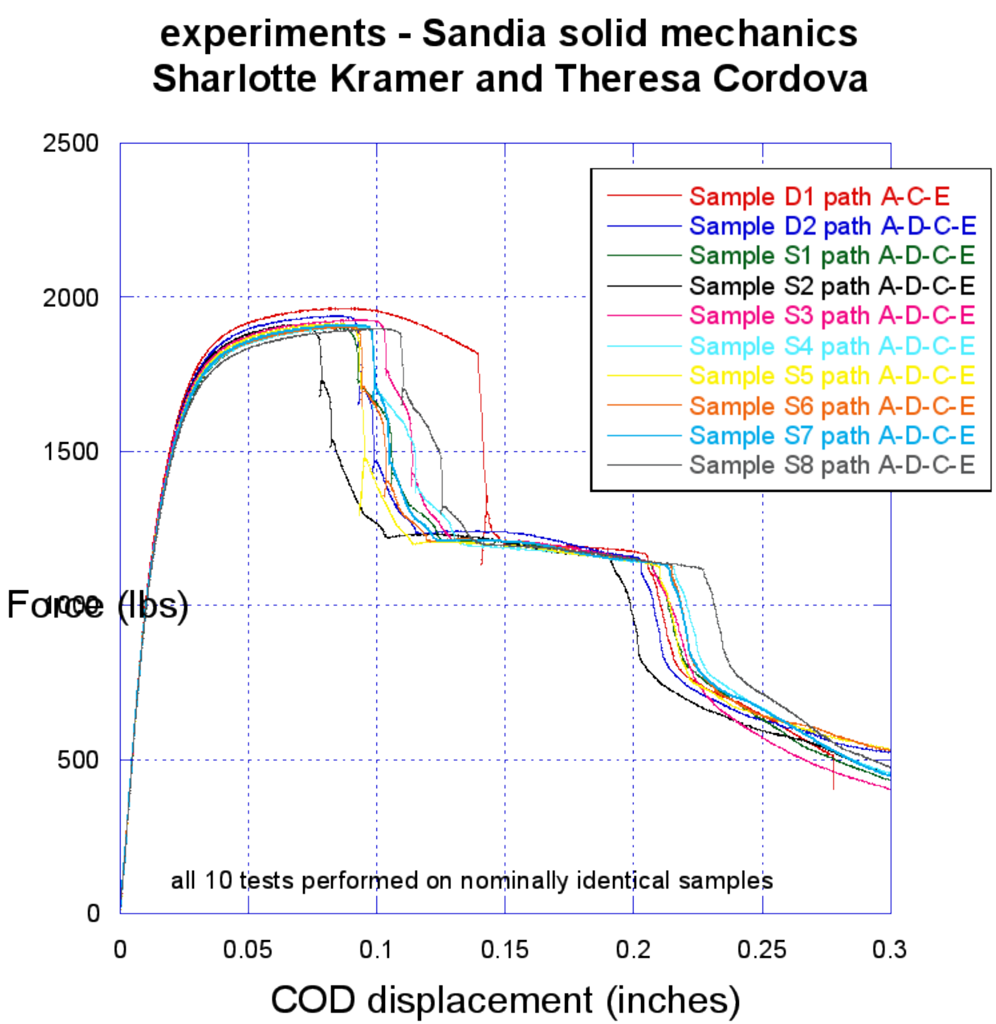


The deformation and fracture behavior is determined experimentally

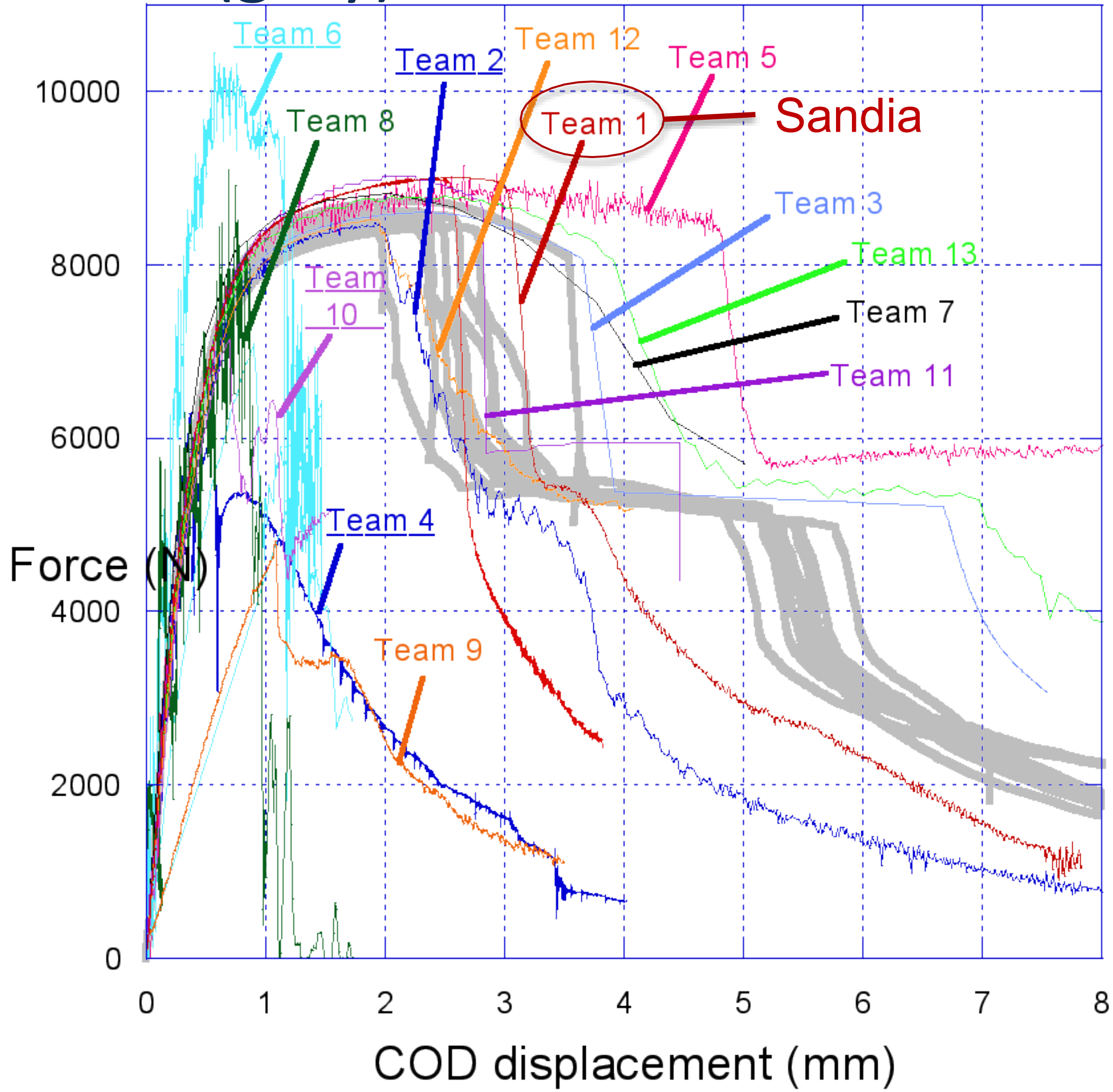


Boyce, et al., *Int. J. Fracture*, 2014

This time, more scatter in the experimental response

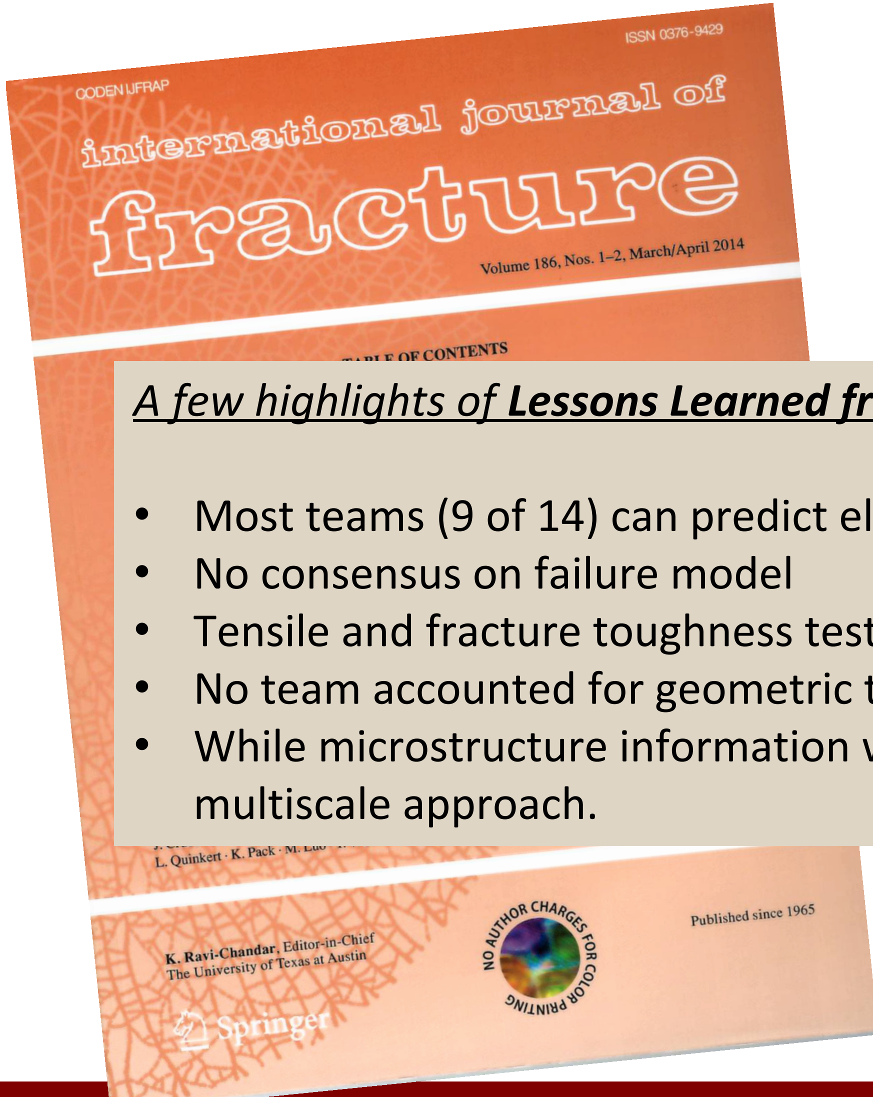


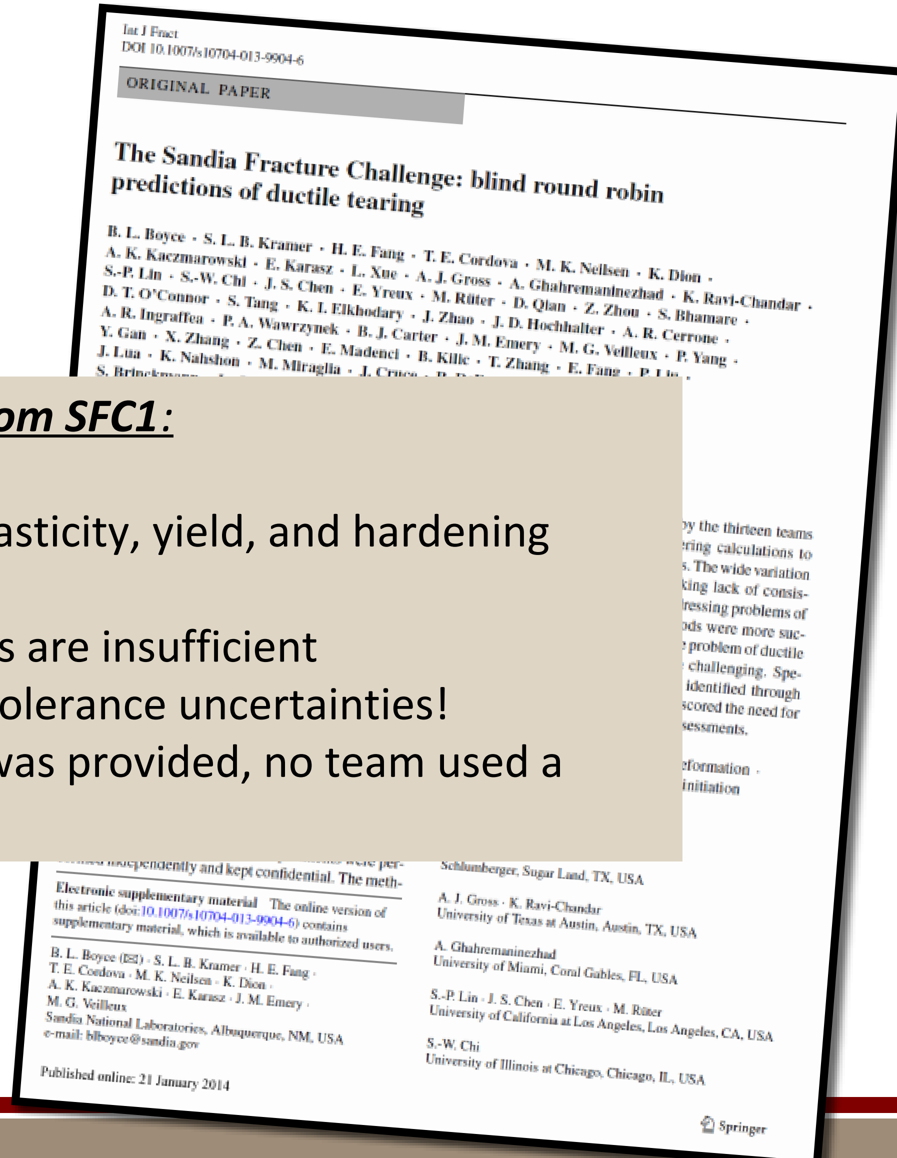
Overlay: Predictions (colors) compared to experiments (gray)



Note: Crack path 'A-C-E' represents both scenarios where the crack initiated in hole A growing towards hole C and scenarios where the crack initiated in hole C and grew back to hole A; similarly for crack path A-D-C-E.

More details available in Special Issue of International Journal of Fracture (2014)




Int J Fract
DOI 10.1007/s10704-013-9904-6

ORIGINAL PAPER

The Sandia Fracture Challenge: blind round robin predictions of ductile tearing

B. L. Boyce · S. L. B. Kramer · H. E. Fang · T. E. Cordova · M. K. Neilsen · K. Dion · A. K. Kaczmarowski · E. Karasz · L. Xue · A. J. Gross · A. Ghahremaninezhad · K. Ravi-Chandar · S.-P. Lin · S.-W. Chi · J. S. Chen · E. Yreux · M. Rüter · D. Qian · Z. Zhou · S. Bhamare · D. T. O'Connor · S. Tang · K. I. Elkhodary · J. Zhao · J. D. Hochhalter · A. R. Cerrone · A. R. Ingraffea · P. A. Wawrzynek · B. J. Carter · J. M. Emery · M. G. Veilleux · P. Yang · Y. Gan · X. Zhang · Z. Chen · E. Madenci · B. Kilic · T. Zhang · E. Fang · P. Liu · J. Lua · K. Nahshon · M. Miraglia · J. Cruce ...

... independently and kept confidential. The meth-

Electronic supplementary material The online version of this article (doi:10.1007/s10704-013-9904-6) contains supplementary material, which is available to authorized users.

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Published online: 21 January 2014

Springer

<u>*A few highlights of **Lessons Learned from SFC1**:*</u>

- Most teams (9 of 14) can predict elasticity, yield, and hardening
- No consensus on failure model
- Tensile and fracture toughness tests are insufficient
- No team accounted for geometric tolerance uncertainties!
- While microstructure information was provided, no team used a multiscale approach.

Boyce, et al. (50 authors), *Int. J. Fracture*, 2014

The 2014 Sandia Fracture Challenge (SFC2)

Predict the forces and displacement associated with crack initiation and propagation in the geometry shown on the right.

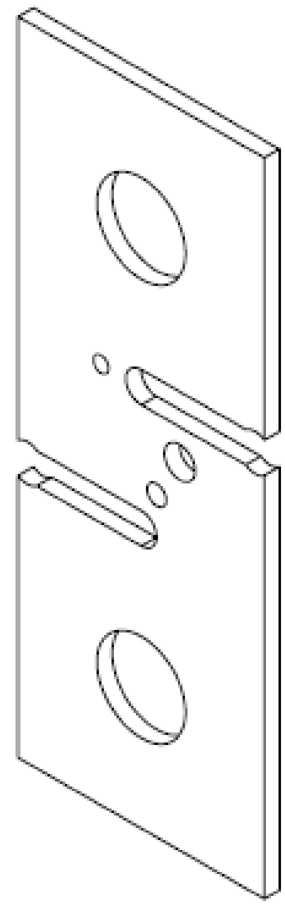
Material: Ti-6Al-4V, 3.15 mm-thick sheet.

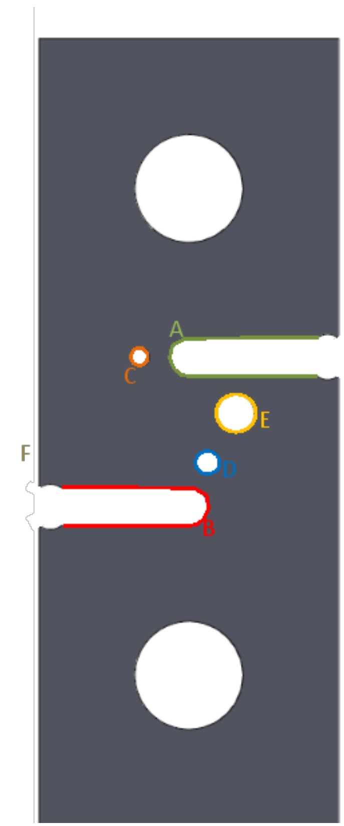
Loading Rate: : 25.4 mm/sec and 0.0254 mm/sec.

Extensive material property information available

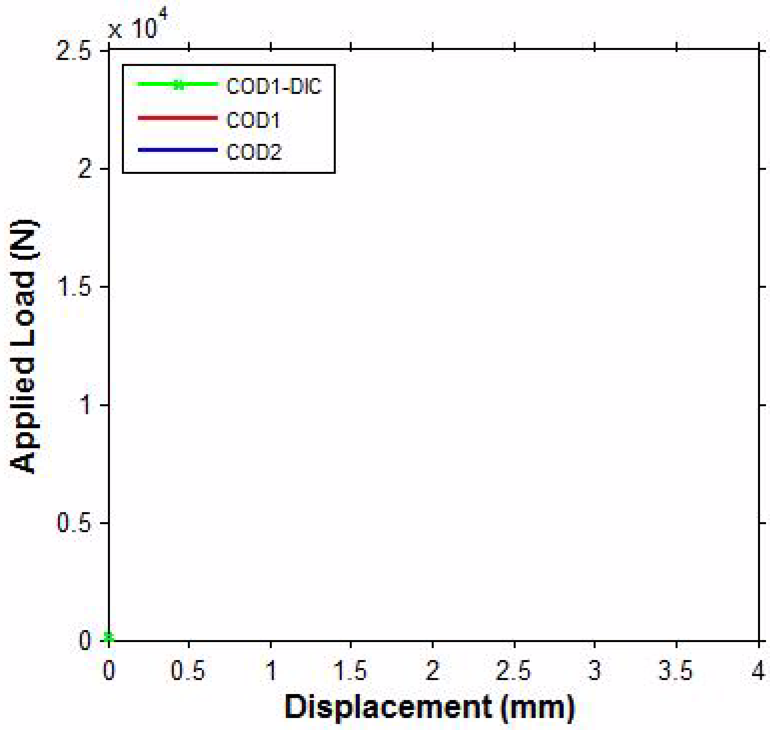
- tensile tests in both sheet axes at 2 rates
- shear failure tests in both axes at 2 rates
- images of all broken samples
- exact measured geometry of each test coupon

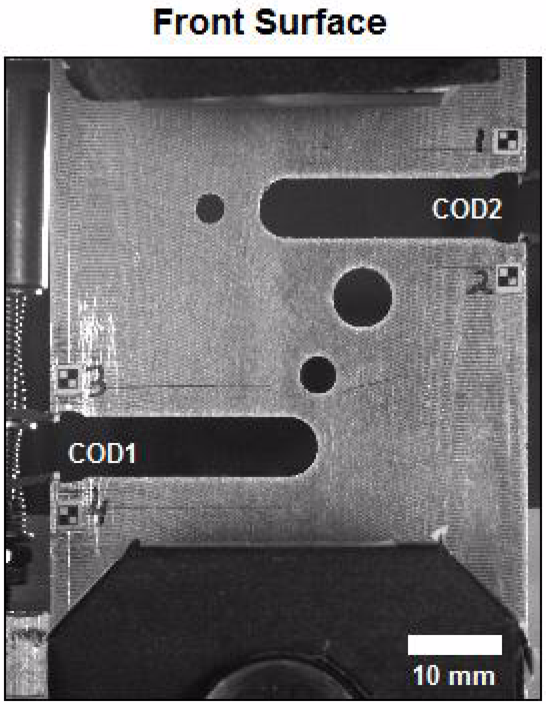
Prediction Deadline: November 1st, 2014



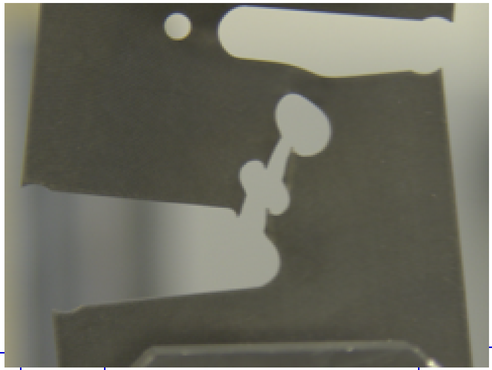


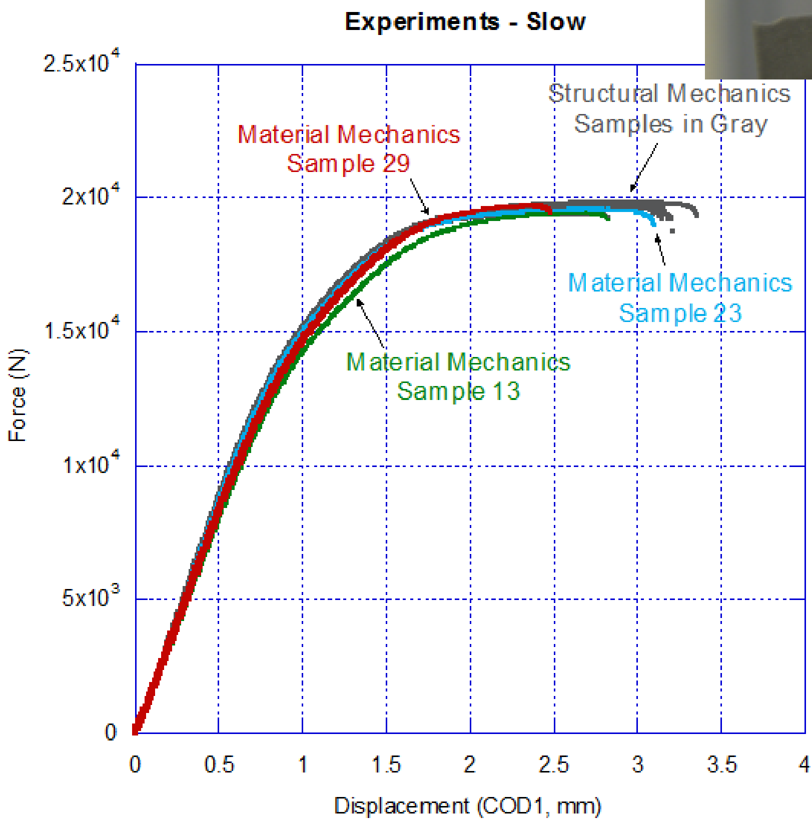
Experimental outcome of SFC2

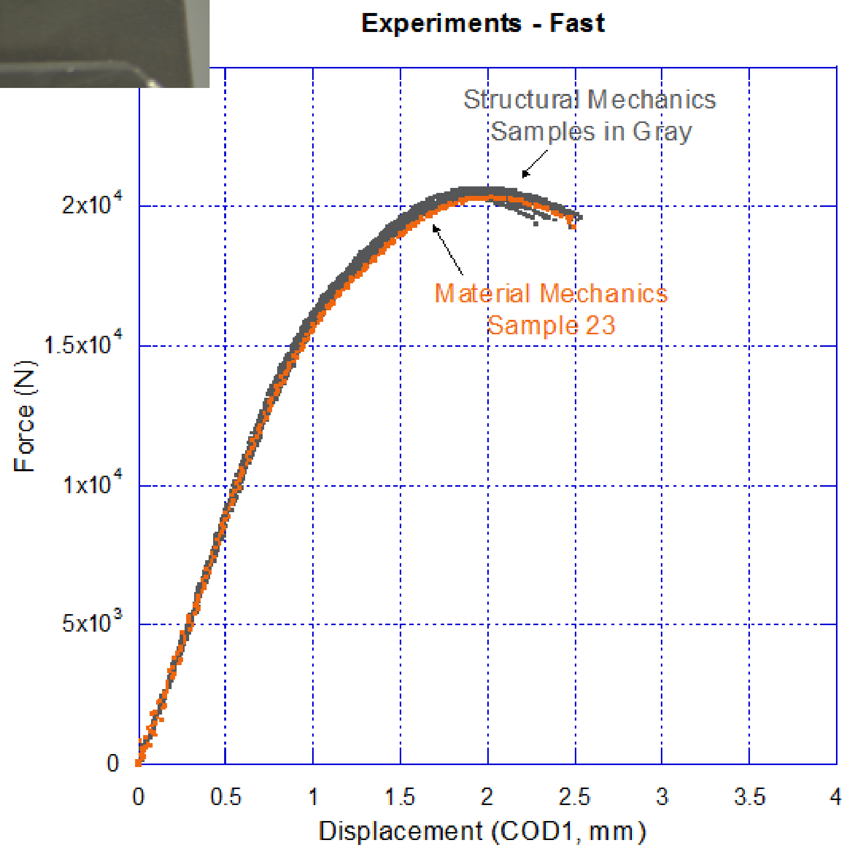




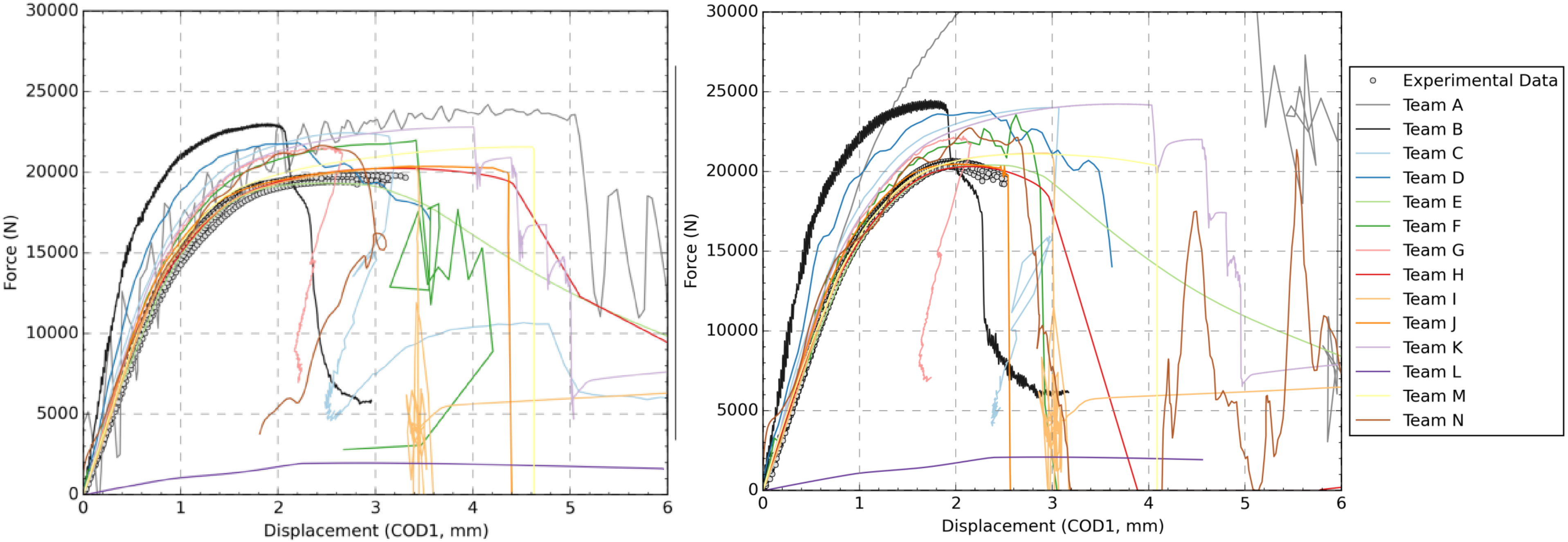
Experimental Force-Displacement Curves up to the point of First Fracture





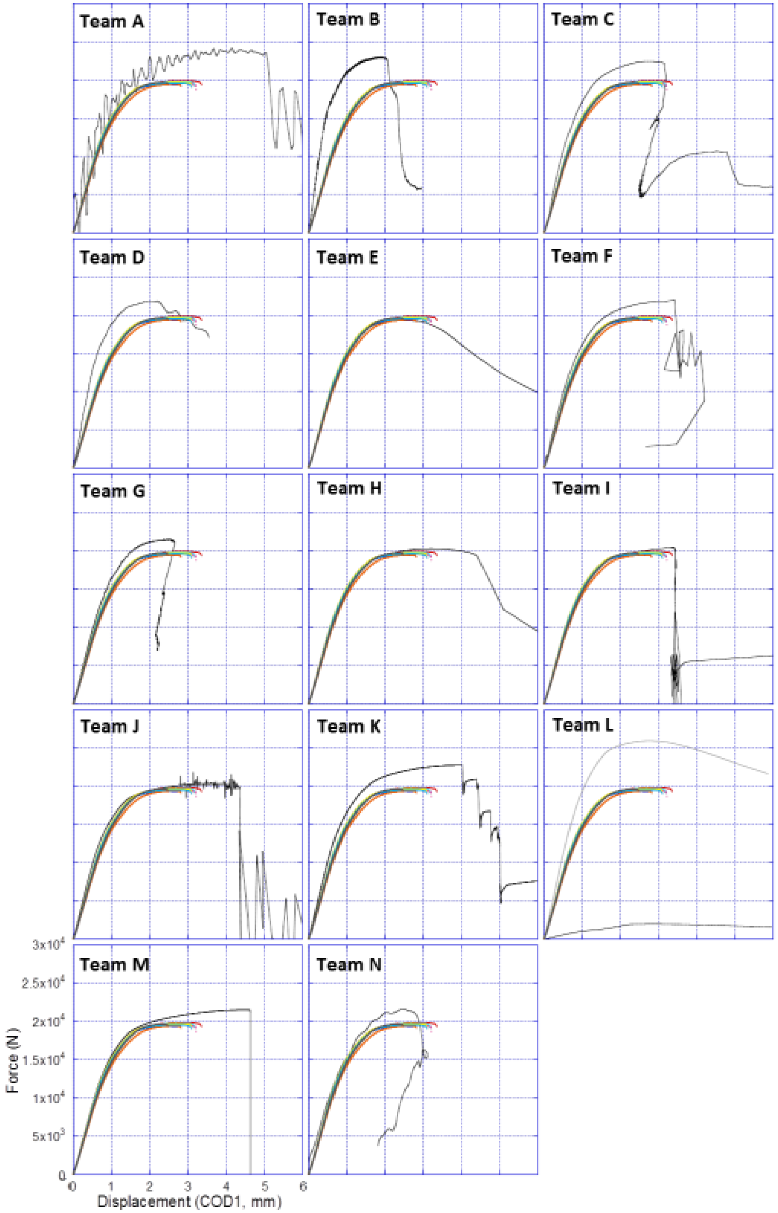


A complex comparison, but general improvement…



- One team (low purple line) made a human error to sum all reaction nodes
- 57% of teams could predict behavior up to peak force within 10% of the expt'l scatter
- Post-necking behavior and crack initiation continue to be a source of significant discrepancy
- Teams tended to systematically <u>overpredict</u> stiffness & yield

Parsing the Individual Team Issues



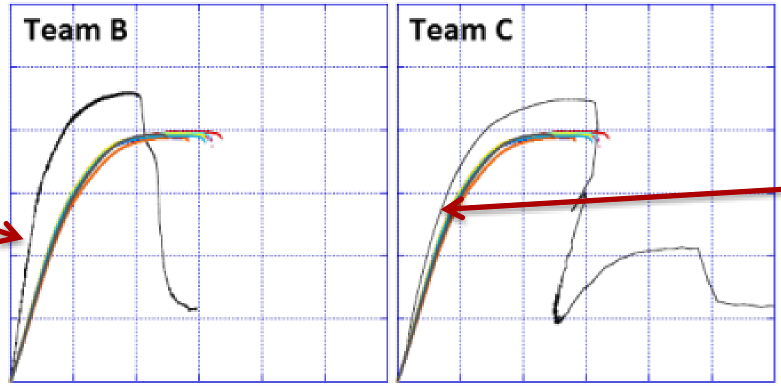
- Explicit vs Implicit Solver
- Thermomechanical Coupling
- Boundary Conditions
- Element Type
- Discretization Level
- Fracture Method (deletion, cohesive surface, etc)
- Uncertainty Method
- Anisotropic Plasticity Model (J2, Hill)
- Hardening Law (Power-law, Swift, Piecewise Linear)
- Failure Criterion (strain parameter, damage law, triaxiality dependence)
- Calibration Data Used

Lessons Learned:

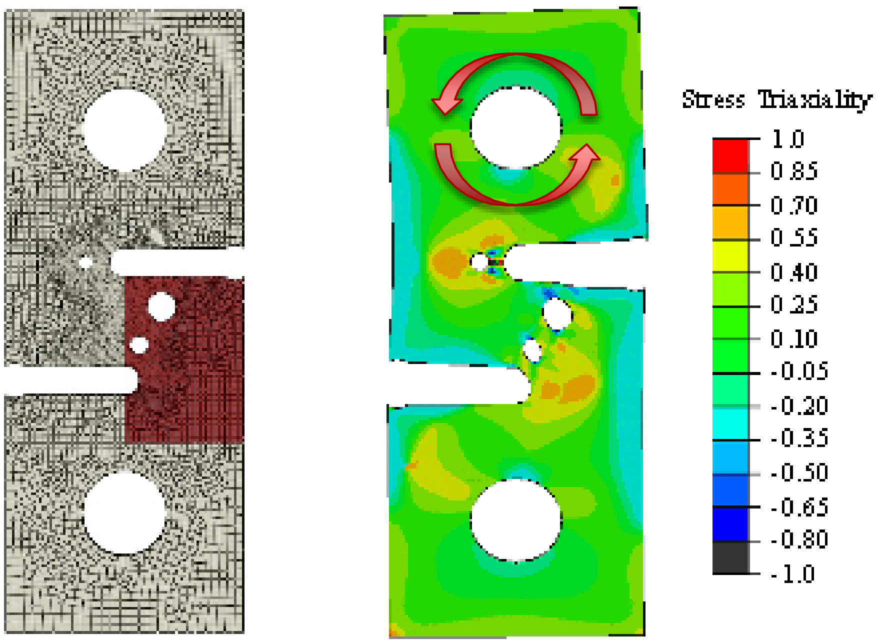
Gaps & Opportunities in Materials Mechanics for Predictive Tearing Fracture

Gap 1: ***Representing surface contact and friction***

Rigid, fixed pin contact



Rigid pin, friction coefficient



(a) (b)

- Apparent stiffness was overpredicted by ~1/2 the teams. In some cases the predicted stiffness was 2X the experimental result!
- Teams that chose fully constrained non-sliding pin contact tended to overpredict stiffness and peak forces.
- Frictionless or free-rotating pin contact appeared to mimic experiments most closely.

Gap 2: ***Accounting for sheet anisotropy***

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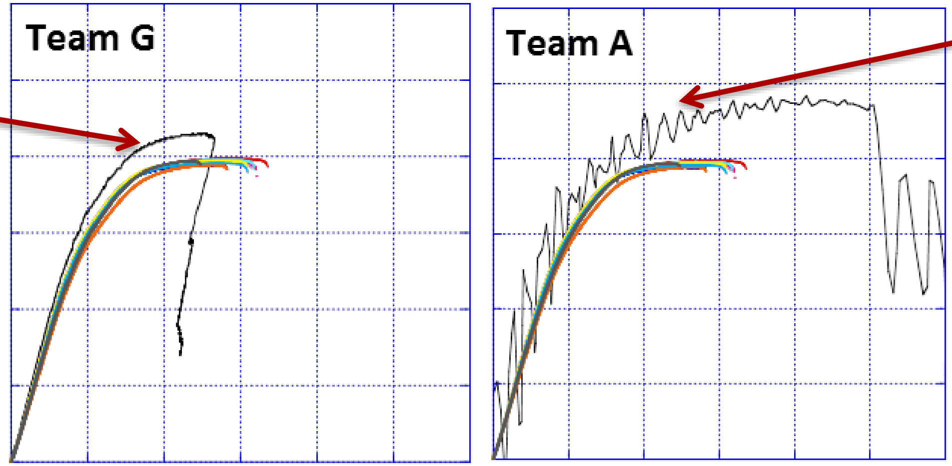
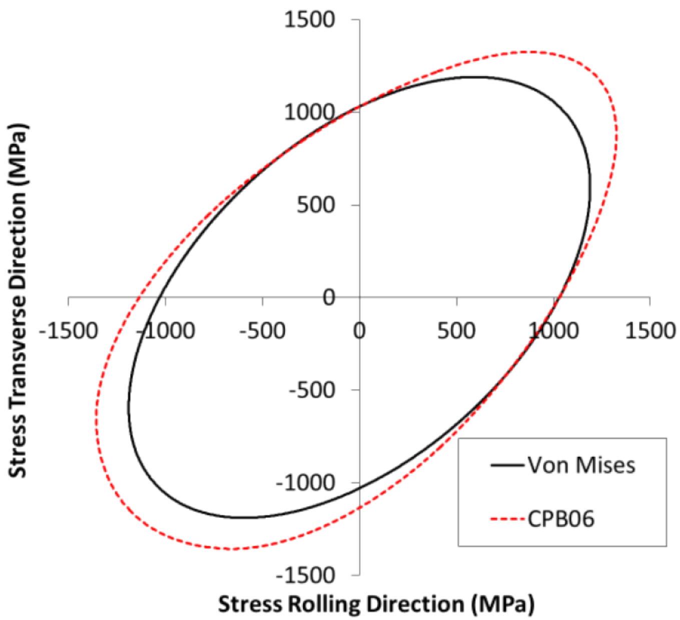
No anisotropy



J_2 plasticity law, No calibration to shear data



- Yield in shear was 0.88X the value of predicted by a Von Mises yield surface, indicating a response that is closer to Tresca.
- This effect was only observable by comparing the tensile yield points to the yield point of the non-standard shear test
- Teams that used a simple J_2 (von Mises) plasticity model tended to overpredict yield/hardening behavior since the yield in shear was softer than in tension.

Gap 3: ***Estimating thermal work coupling factor***

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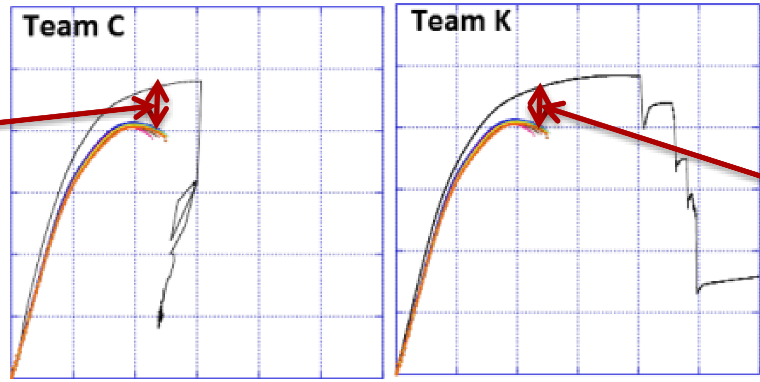
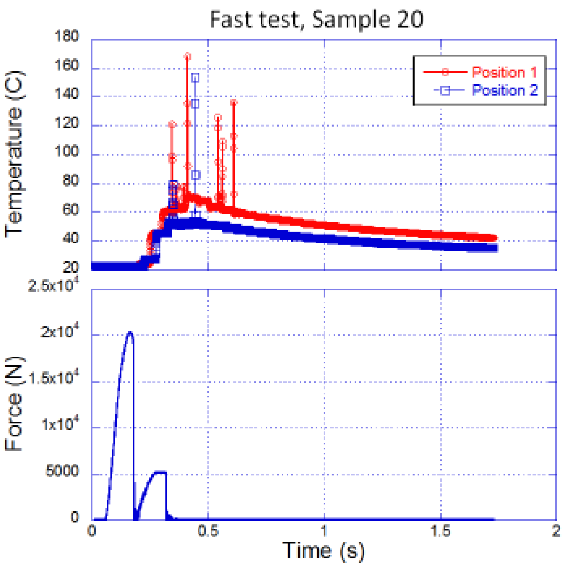
No thermal coupling



No thermal coupling



- There was a >60ºC temperature rise in the necking ligament under the faster loading condition.
- Many teams ignored the plastic-work induced thermal softening that occurs under modest dynamic loading
- Teams that chose either an adiabatic condition or some coupling parameter tended to capture some degree of extended necking behavior.
- There is little data (and even contradictory data from the same group!) on the plastic work thermal coupling parameter (Taylor-Quinney coefficient)

Volumetric heating rate

$$\dot{Q} = \eta \dot{W}^{p} = \eta \boldsymbol{\sigma} : \dot{\boldsymbol{\varepsilon}}^{in}$$

Taylor-Quinney coefficient

*Gap 4: **Choosing a realistic failure parameter***

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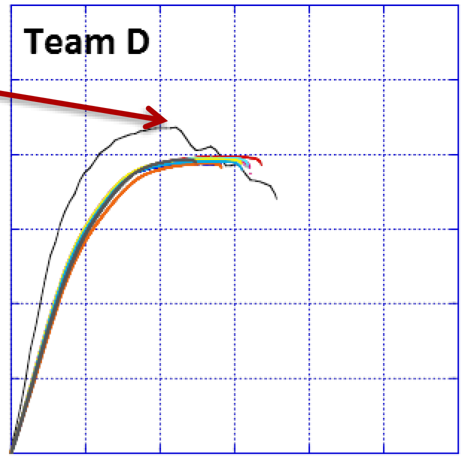
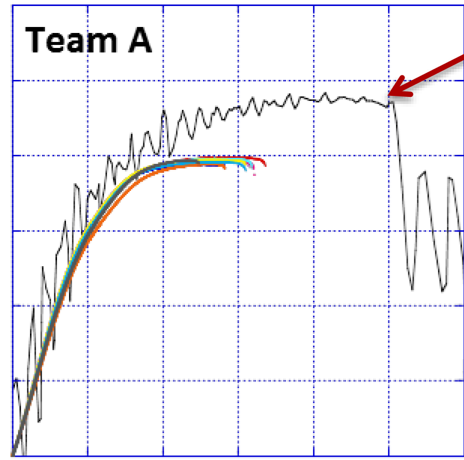
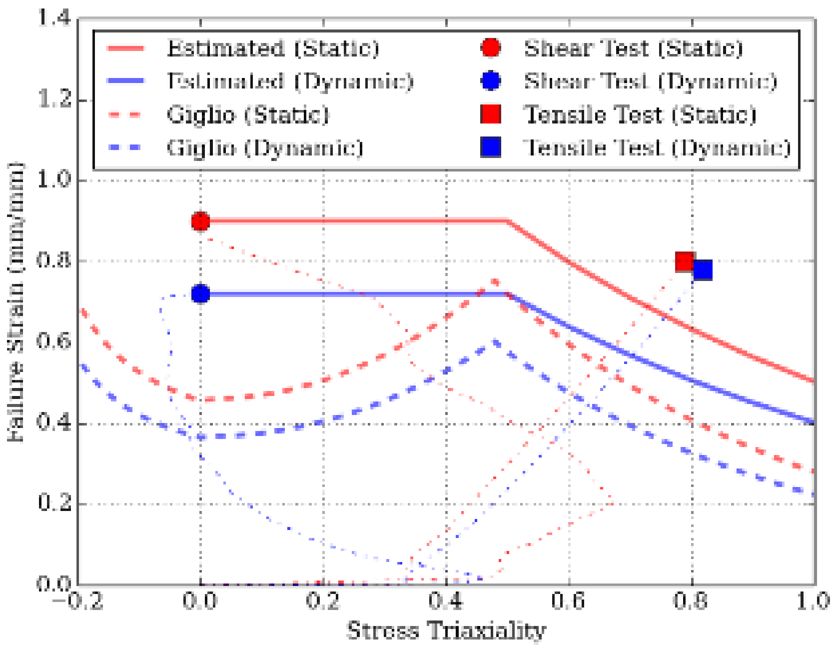
Plastic strain criterion does not account for triaxiality / shear





Failure parameter calibration only used tension data, not shear data.



- There is no concensus on a realistic model for crack initiation! **(Gurson is not sufficient)**
- Predictions tended to be more accurate if they used shear data and calibrated a triaxiality-dependent failure model.
- While a suite of various loading paths and triaxiality conditions is needed, there is no standards for such material testing. **(A tension test is not sufficient)**

More details available in Special Issue of International Journal of Fracture (2016)

Int J Fract
DOI 10.1007/s10704-016-0089-7

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SANDIA FRACTURE CHALLENGE 2014

The second Sandia Fracture Challenge: predictions of ductile failure under quasi-static and moderate-rate dynamic loading

B. L. Boyce · S. L. B. Kramer · T. R. Bosiljevac · E. Corona · J. A. Moore · K. Elkhodary · C. H. M. Simha · B. W. Williams · A. R. Cerrone · A. Nonn · J. D. Hochhalter · G. F. Bomarito · J. E. Warner · B. J. Carter · D. H. Warner · A. R. Ingraffea · T. Zhang · X. Fang · J. Lua · V. Chiaruttini · M. Mazière · S. Feld-Payet · V. A. Yastrebov · J. Besson · J.-L. Chaboche · J. Lian · Y. Di · B. Wu · D. Novokshanov · N. Vajragupta · P. Kucharczyk · V. Brinnel · B. Döbereiner · S. Münstermann · M. K. Neilsen · K. Dion · K. N. Karlson · J. W. Foulk III · A. A. Brown · M. G. Veilleux · J. L. Bignell · S. E. Sanborn · C. A. Jones · P. D. Mattie · K. Pack · T. Wierzbicki · S.-W. Chi · S.-P. Lin · A. Mahdavi · J. Predan · J. Zadravec · A. J. Gross · K. Ravi-Chandar · L. Xue

Received: 2 November 2015 / Accepted: 5 February 2016

Abstract Ductile failure of structural metals is relevant to a wide range of engineering scenarios. Computational methods are employed to anticipate the critical conditions of failure, yet they sometimes provide inaccurate and misleading predictions. Challenge scenarios, such as the one presented in the current work, provide an opportunity to assess the blind, quantitative predictive ability of simulation methods against a previously unseen failure problem. Rather than evaluate the predictions of a single simulation approach, the Sandia Fracture Challenge relies on numerous volunteer teams with expertise in computational mechanics to apply a broad range of computational methods, numerical algorithms, and constitutive models to the challenge. This exercise is intended to evaluate the state of health of technologies available for failure prediction. In the first Sandia Fracture Challenge, a wide range of issues were raised in ductile failure modeling, including a lack of consistency in failure models, the importance of shear calibration data, and difficulties in quantifying the uncertainty of prediction [see Boyce et al. (Int J Fract 186:5–68, 2014) for details of these observations]. This second Sandia Fracture Challenge investigated the ductile rupture of a Ti–6Al–4V sheet under both quasi-static and modest-rate dynamic loading (failure in ~0.1 s). Like the previous challenge, the sheet had an unusual arrangement of notches and hole that added geometric complexity and fostered a com petition between tensile- and shear-dominated failu

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Published online: 14 March 2016

The SFC is one of the most downloaded articles in Int. J. Fracture:

As of August, 2017:

SFC1 paper downloads: 6,800
SFC2 paper downloads: 4,300

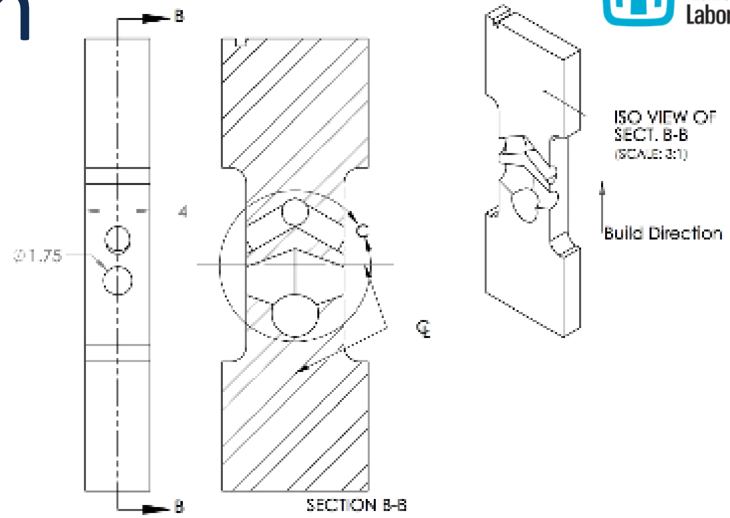
Typical paper in IJF: 200-800 downloads over a similar timeframe.

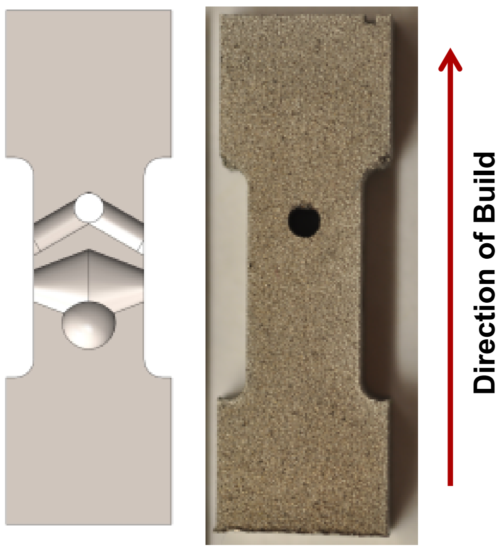
SFC3 Problem Definition

Sandia National Laboratories

Predict the deformation and failure of the geometry shown on the right

- **Material:** Additively manufactured 316L stainless steel from a commercial vendor; Laser Powder Bed Fusion also known as Direct Metal Laser Sintering (DMLS) method with 20-micron layers
- **Loading Rate:** 0.0127 mm/s
- **Extensive material property information available**
  - Base material tensile tests Notched tensile tests for fracture properties
  - Micro-computed tomography (CT) of all Challenge geometry specimens to quantify the void content
  - Cross-sections of undeformed specimens
    - Characterization of void content using optical microscopy with higher resolution than micro-CT
    - Electron backscattter diffraction (EBSD) for grain structure characterization of the Challenge geometry
  - SEM imaging of tensile test and notched tensile test fracture surfaces
- **Challenge Issuance: December 15th, 2016**
- **Prediction Deadline: July 15th, 2017**





Drawing (Top Image), Central Cross-Section Schematic (Bottom Left Image), and Front (Bottom Right Image) Views of the Challenge Geometry

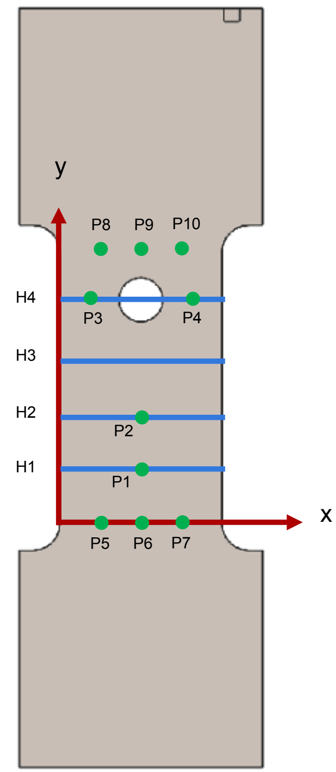
Quantities of Interest

Far-field Response:

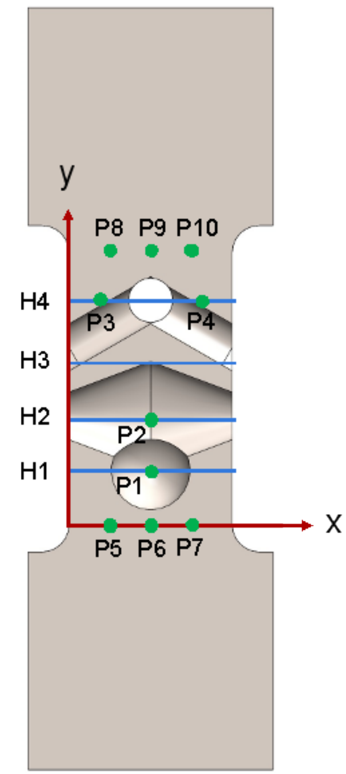
Predict the macroscopic Force-Displacement Response

Local Response: Predict local Hencky (logarithmic) strain during the deformation at four locations, P1-P4, and the strain profiles across lines H1-H4.

report nominal (average) value and optionally report the 80-percentile upper bound and 20-percentile lower bound values



Front Surface View of Challenge Geometry

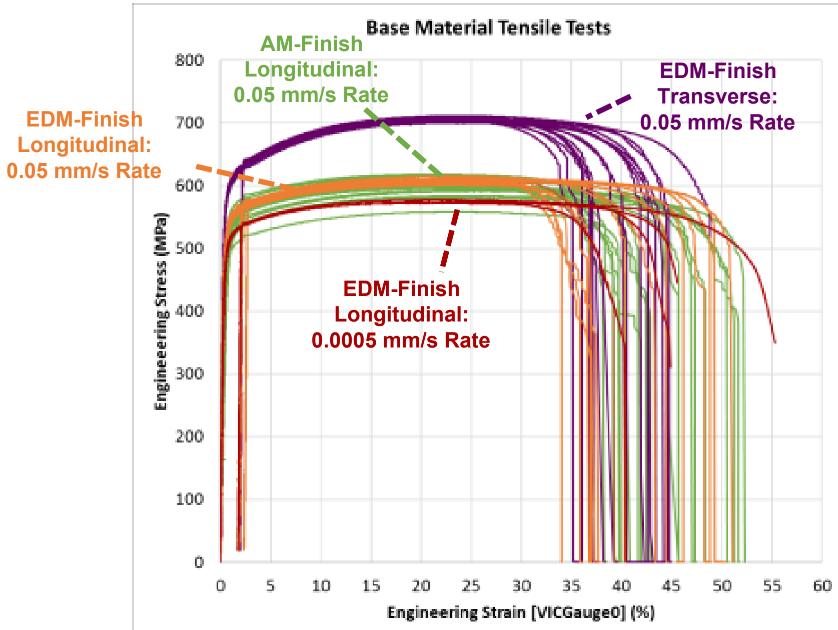


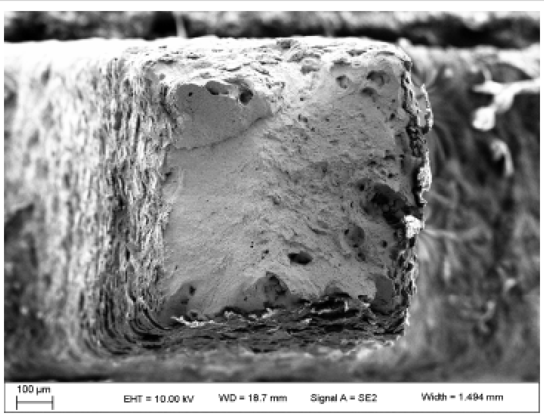
Midplane View of Challenge Geometry

Examples of Provided Data

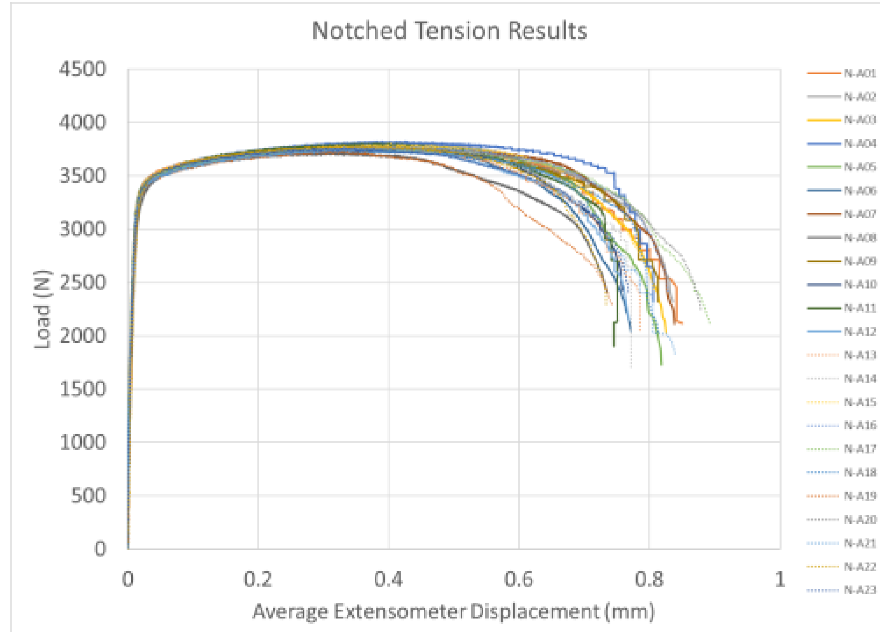
Sandia National Laboratories

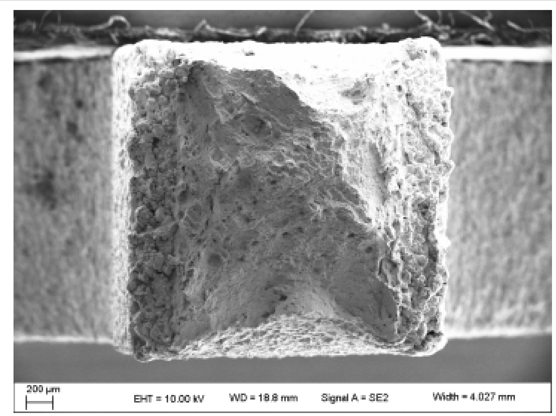
Base Material Test Data (Top); SEM Image of Fracture Surface of Tensile Specimen LTA04 (Bottom)





Notched Tensile Test Data (Top); SEM Image of Fracture Surface of Notched Tensile Specimen NA05 (Bottom)

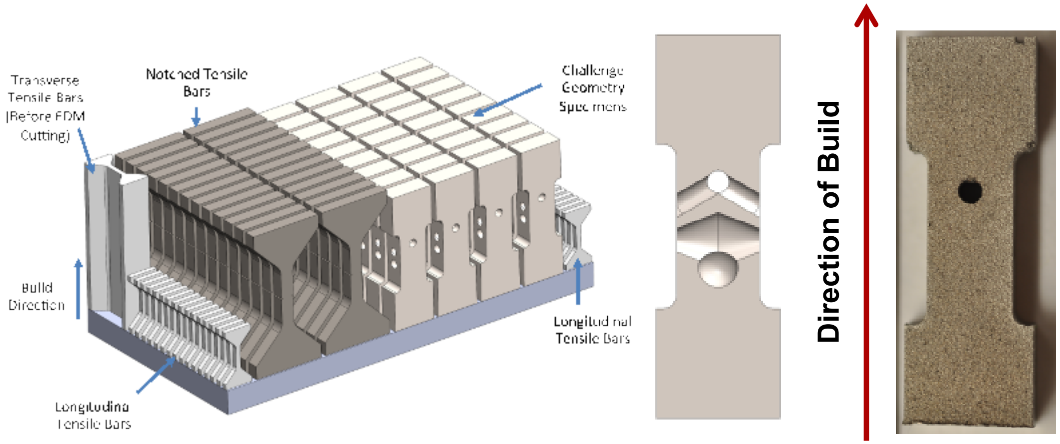


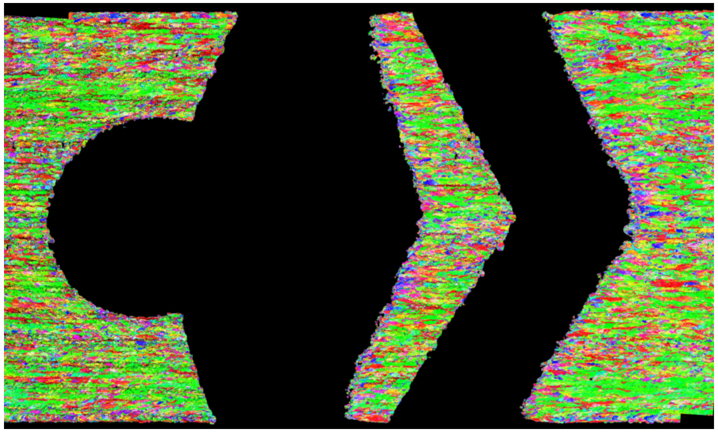


Examples of Provided Data

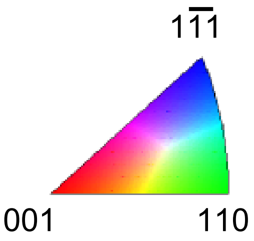
Sandia National Laboratories

AM Build of All Test Specimens (Left); Central Cross-Section Schematic (Center) and Front Views of the Challenge Geometry (Right)

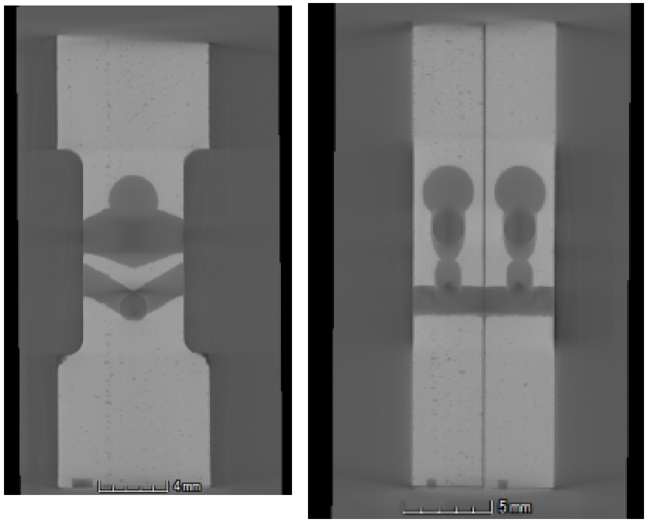




EBSD Inverse Pole Figure (IPF) in Build Direction

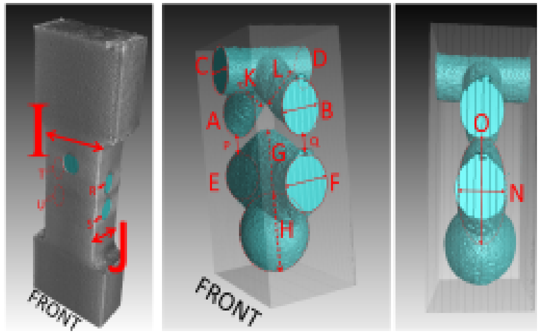


Example of micro-CT Scans of Challenge Geometry



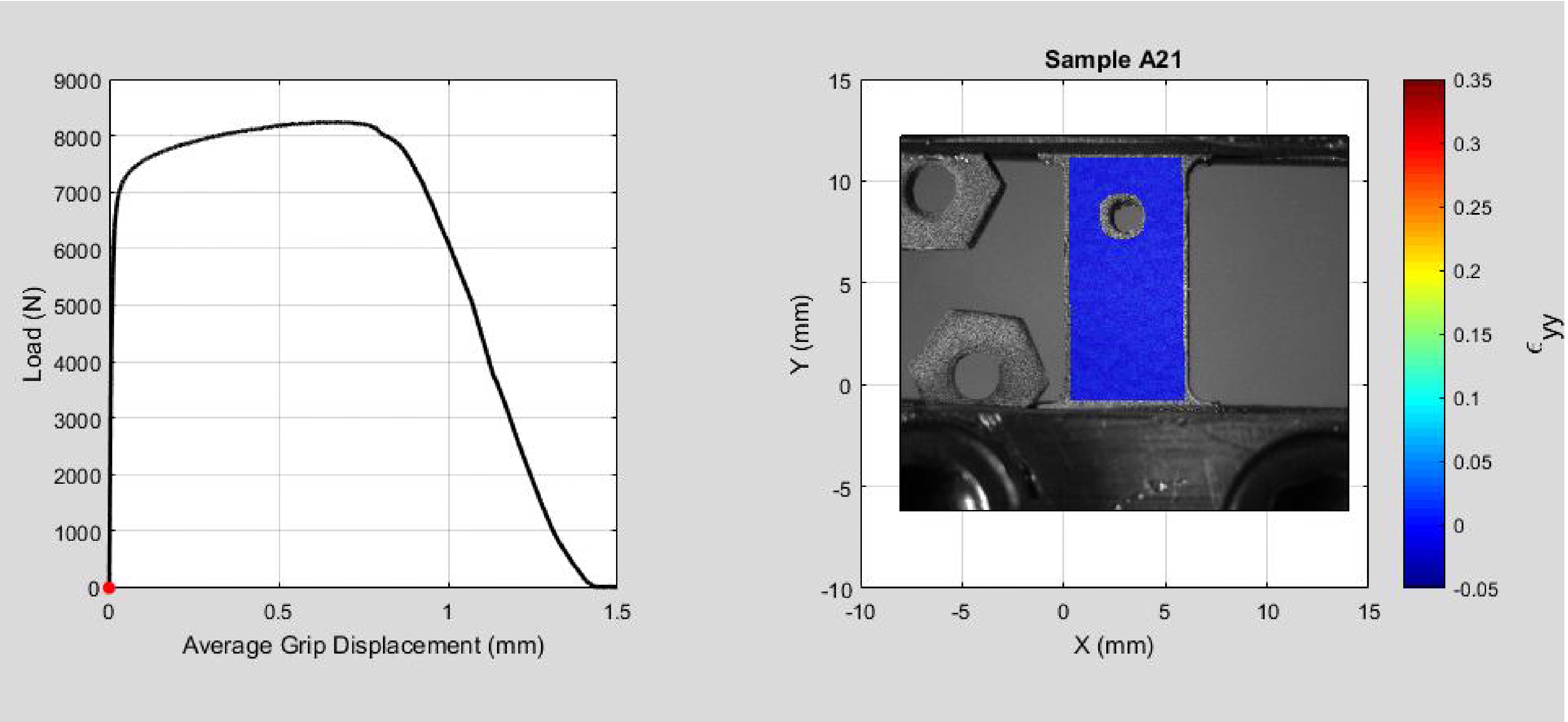
A32 Front View "Thick Slab" Image

Side View Image of A32 (left) and A15 (Right)



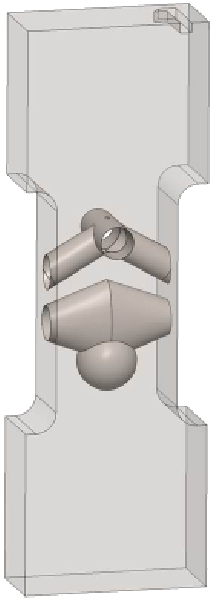
Reconstructed micro-CT Scans with Provided Feature Measurements

Challenge Geometry Experimental Result



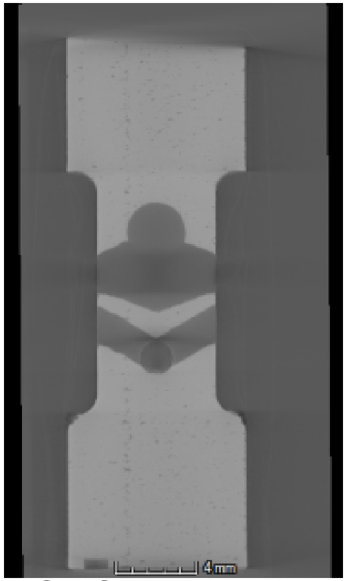
Underway… The 3rd Sandia Fracture Challenge

An additively manufactured structure with internal chambers that cannot be manufactured by conventional methods

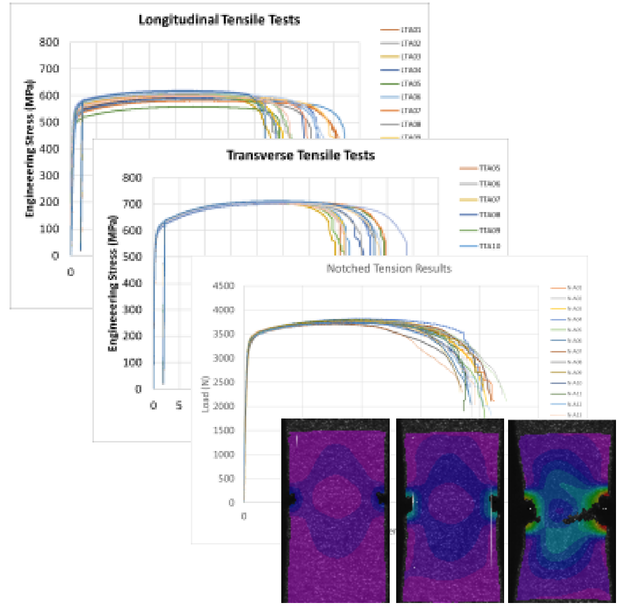


CAD

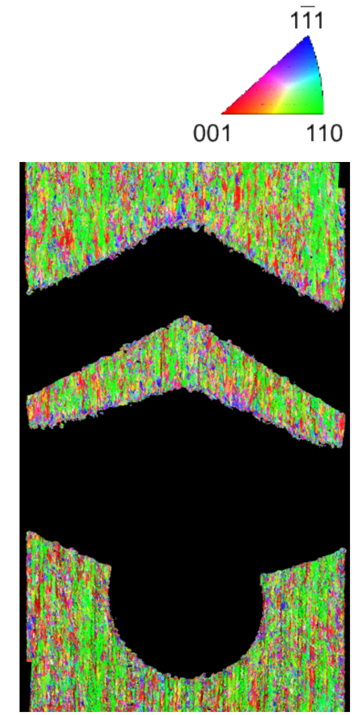
Optical Image



CT Scan showing internal porosity



Notch & smooth bar calibration data (with DIC) from the same build



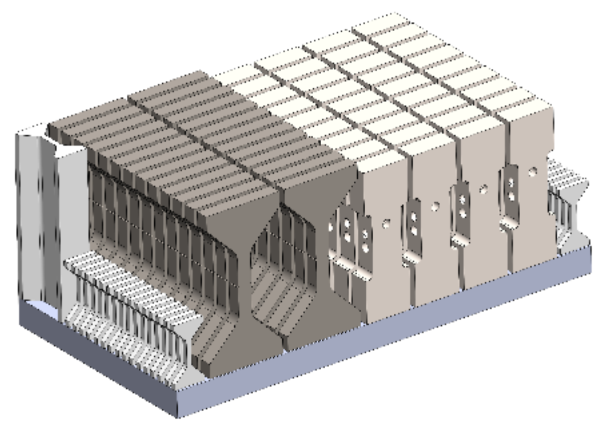
Microstructure & Texture data

Provided the following engineering data…

- x-ray CT scans
- tensile & notch tensile tests
- EBSD Microstructure, surface roughness, etc.

Predict the variability in failure response…

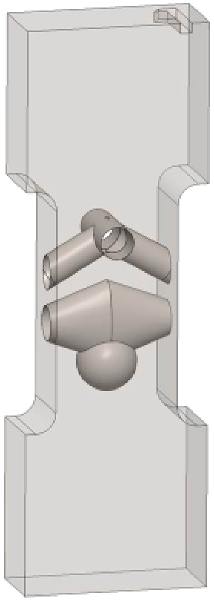
- location of crack initiation
- forces associated with crack initiation
- local surface strains during deformation



Underway… The 3rd Sandia Fracture Challenge

Sandia National Laboratories

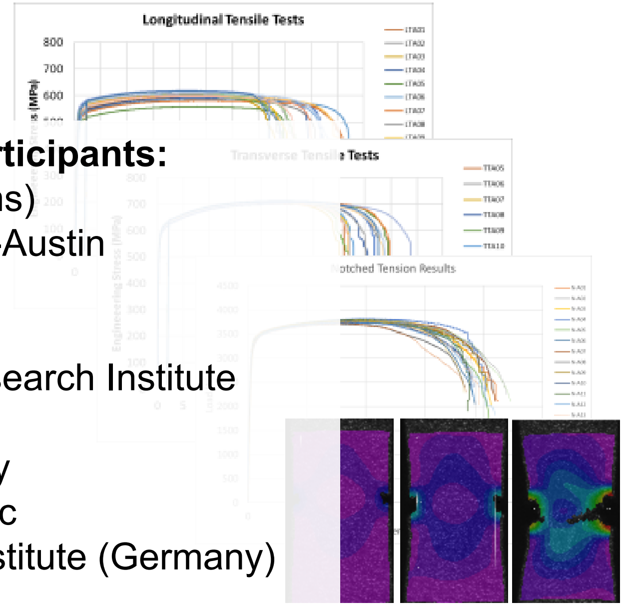
An additively manufactured structure with internal chambers that cannot be manufactured by conventional methods



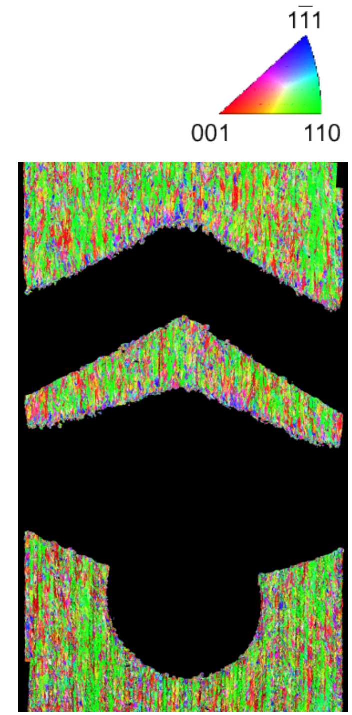
CAD

Optical Image

CT Scan showing internal porosity



Notch & smooth bar calibration data (with DIC) from the same build



Microstructure & Texture data

Pre-registered Participants:

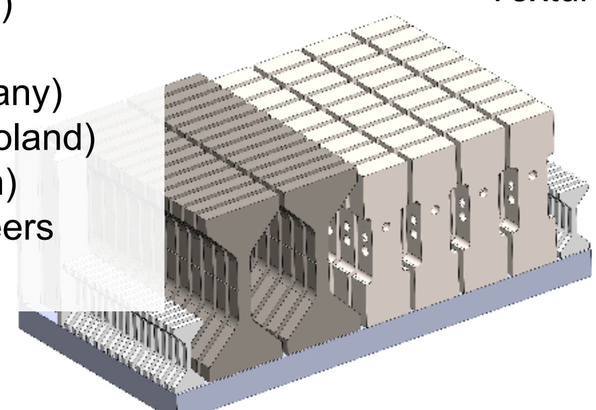
1. Sandia (3 teams)
2. Univ. of Texas-Austin
3. MIT
4. Purdue
5. Southwest Research Institute
6. Exponent
7. Pratt & Whitney
8. General Electric
9. Max-Planck Institute (Germany)
10. Univ. of Utah
11. OCAS NE (France)
12. RWTH Aachen (Germany)
13. Thinkviewer
14. Regensburg Univ. (Germany)
15. Kazimierz Wielki Univ. (Poland)
16. Tecnalia Research (Spain)
17. US Army Corps of Engineers
18. US Army ARDEC

Provided the following engineering data…

x-ray CT scans
tensile & notch tensile tests
EBSD Microstructure, surface roughness, etc.

Predict the variability in failure response…

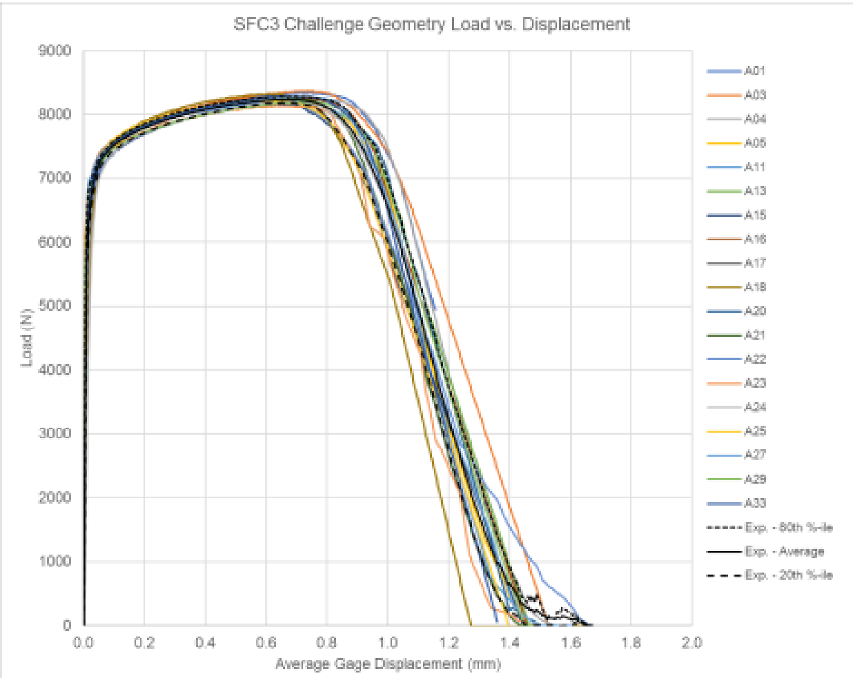
location of crack initiation
forces associated with crack initiation
local surface strains during deformation



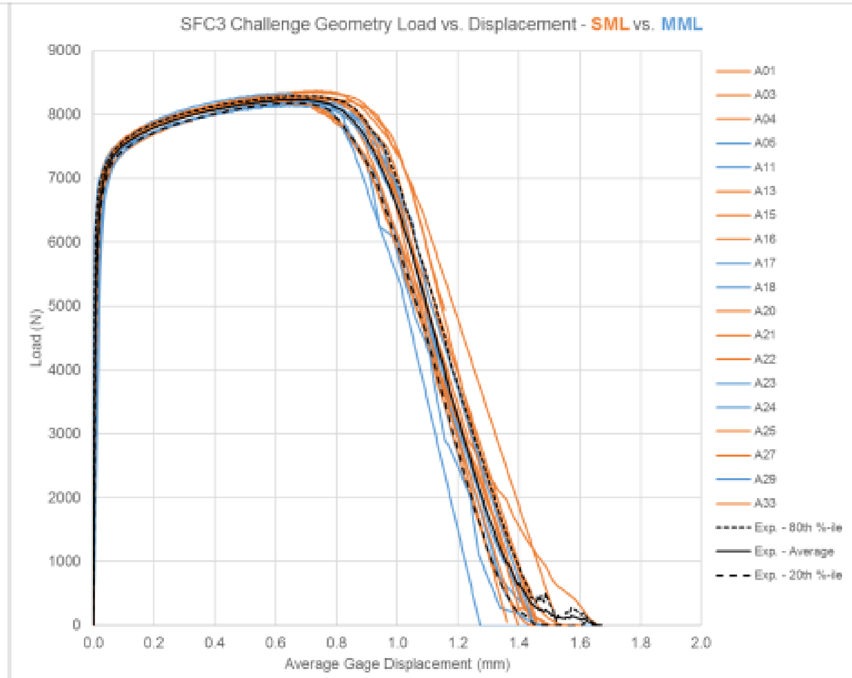
Experiments: Overall Force-Displacement Response

Report the force vs. gage displacement D for the test.

19 Specimens with Average and Bounds



Comparison of Tests From Two Laboratories



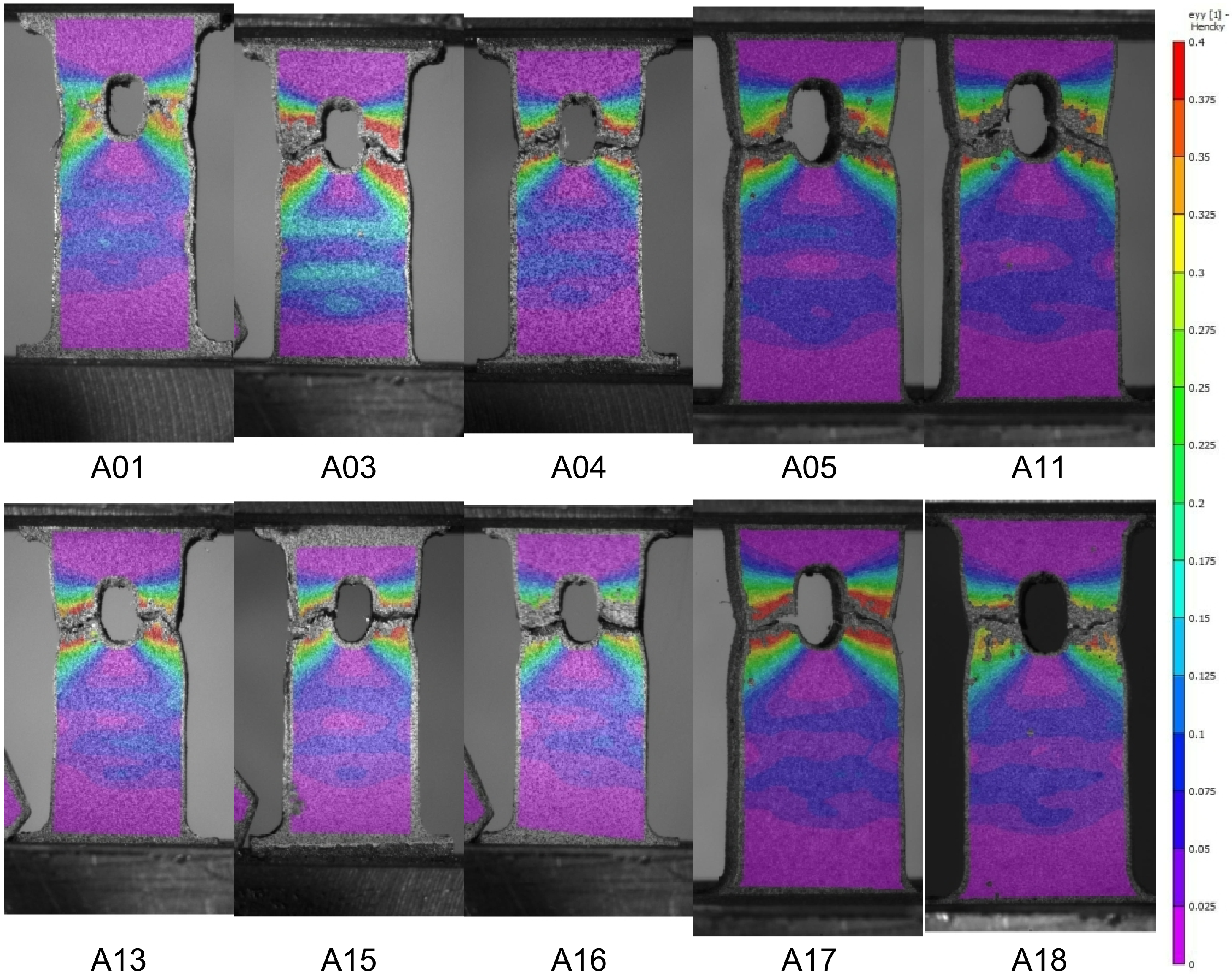
- Relatively repeatable experimental data set with all specimen failing in nominally the same location
- Experimental data from two testing laboratories (12 specimens for the Structural Mechanics Laboratory and 7 specimens from the Material Mechanics Laboratory) overlap
- 20th percentile, average, 80th percentile forces were determined from the population of 19 specimens where data was available at each value of displacement

Experiments: Local DIC Strain

The image shown for A01 is immediately before complete failure, where DIC correlation was lost.

Crack path is similar for each specimen, but are not necessarily following the angled channels in every specimen.

Note: SML DIC setup had the left camera perpendicular to the specimen face, while the MML DIC setup had the left camera at an angle relative to the specimen face.



21 Teams of Challenge Participants

Sandia National Laboratories

Universities

UTSA The University of Texas at San Antonio™

Massachusetts Institute of Technology

Cornell University Founded A.D. 1865

OTH Ostbayerische Technische Hochschule Regensburg

The University of Texas at Austin

The University of Utah®

Uniwersytet Kazimierza Wielkiego w Bydgoszczy

Industry

SwRI Southwest Research Institute

Exponent®

OCAS

100 Jahre 1917–2017 Max-Planck-Institut für Eisenforschung

Government Laboratories

Sandia National Laboratories

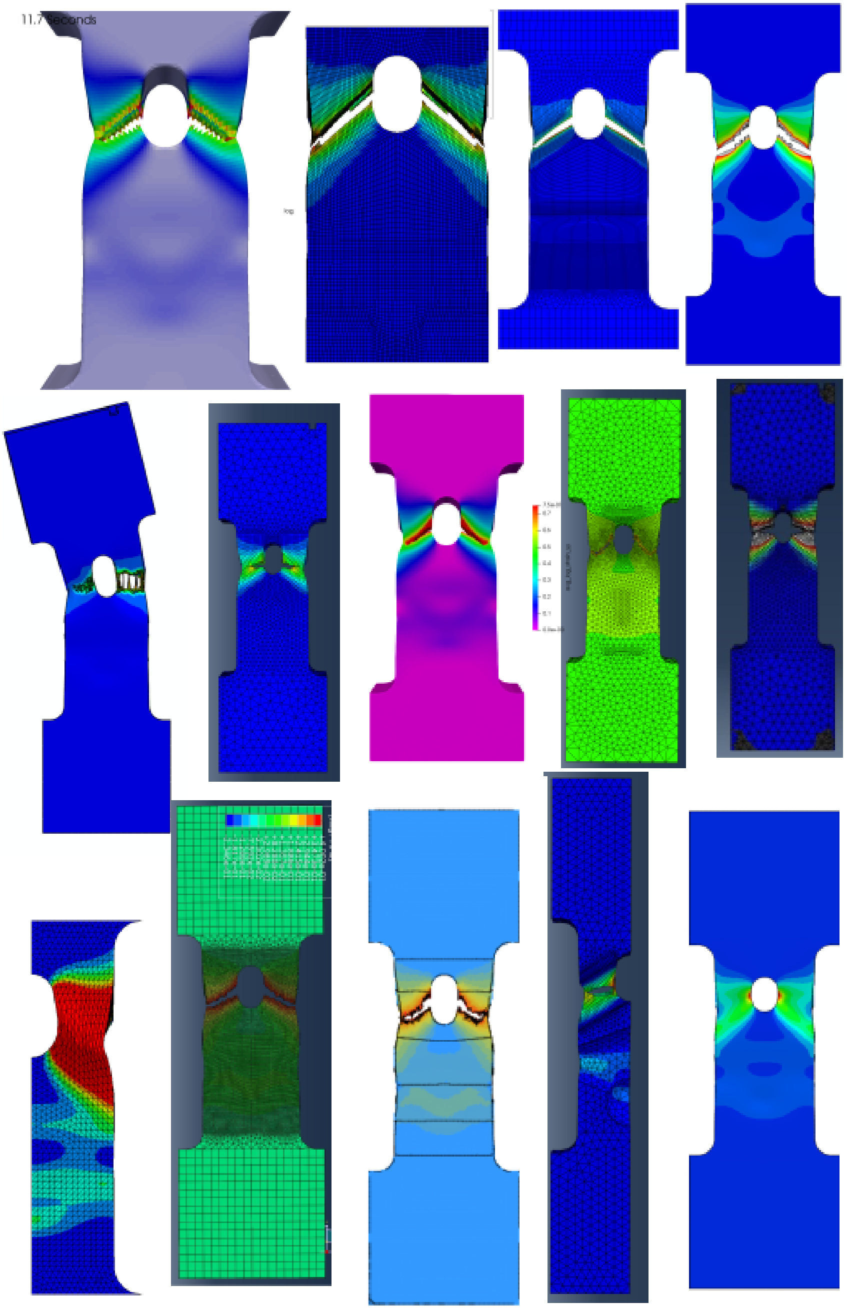
US Army Corps of Engineers

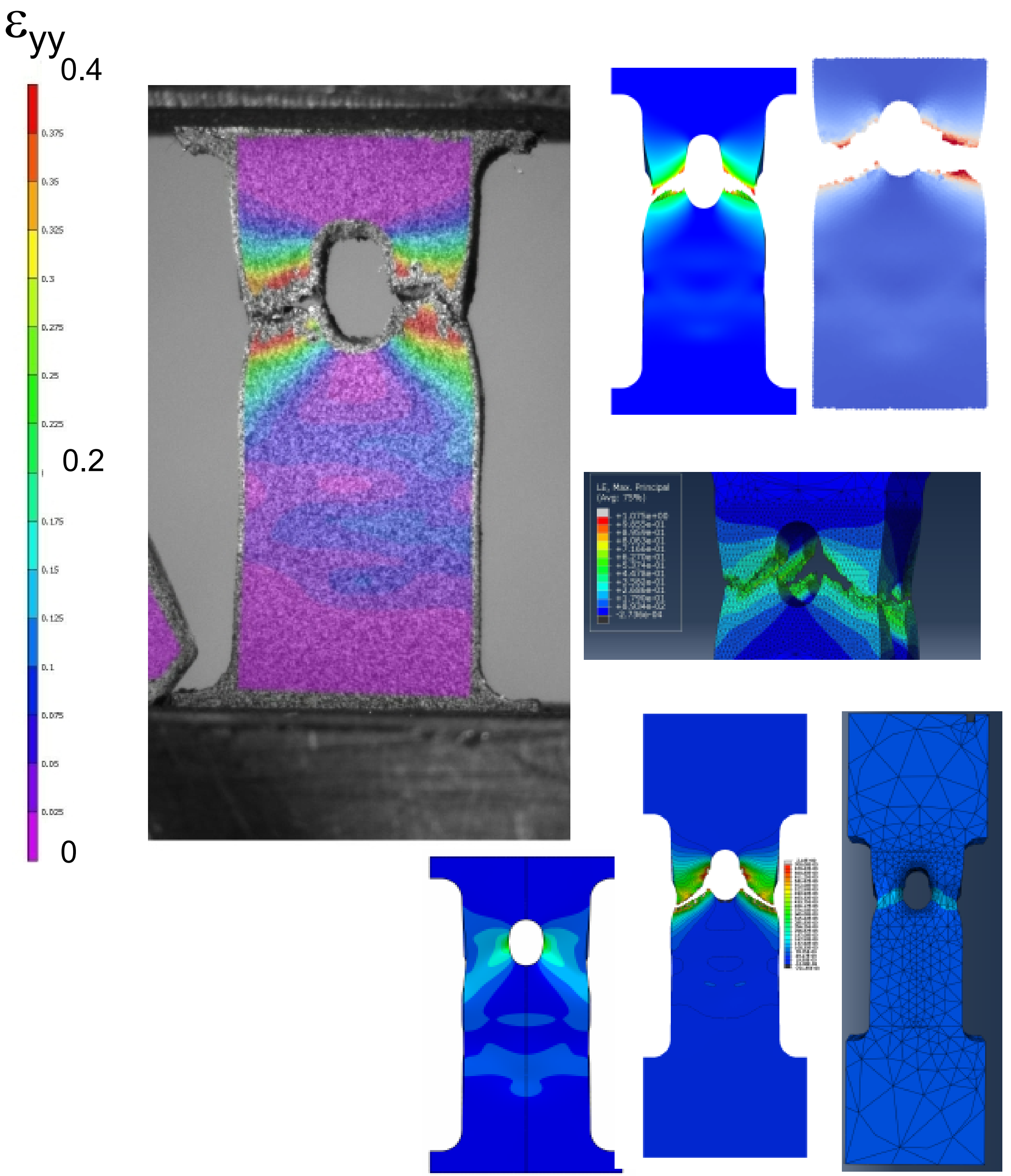
Natural Resources Canada / Ressources naturelles Canada

CanmetÉNERGIE

Leadership en écoInnovation

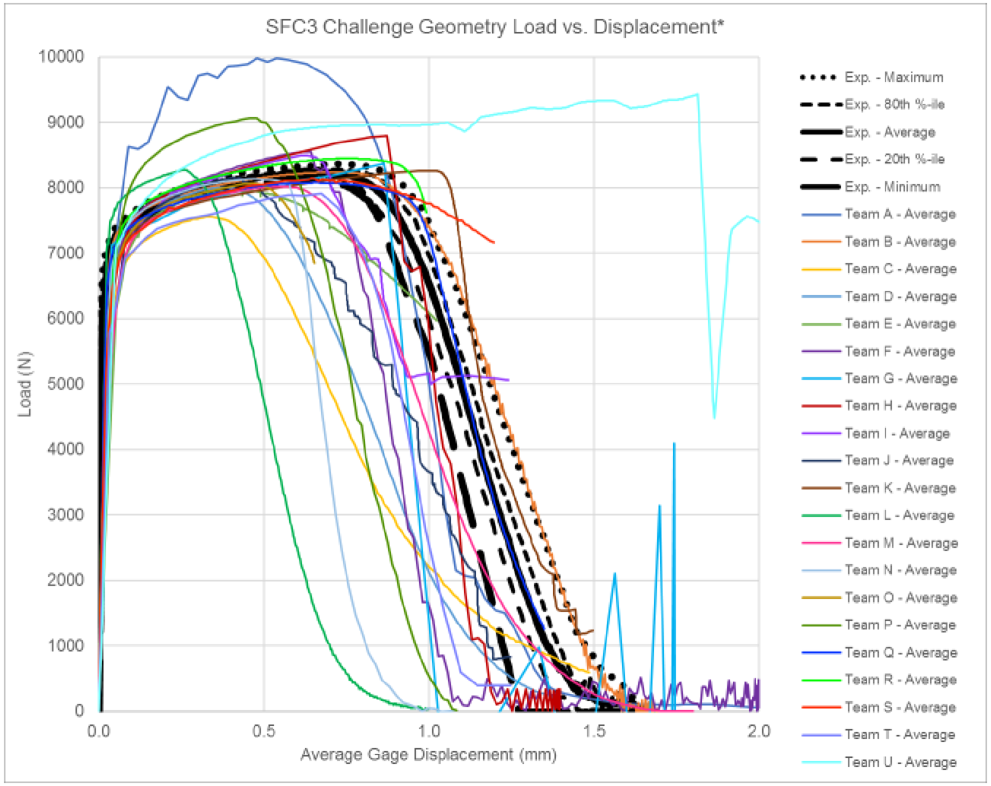
Predictions: Strain-Field Maps





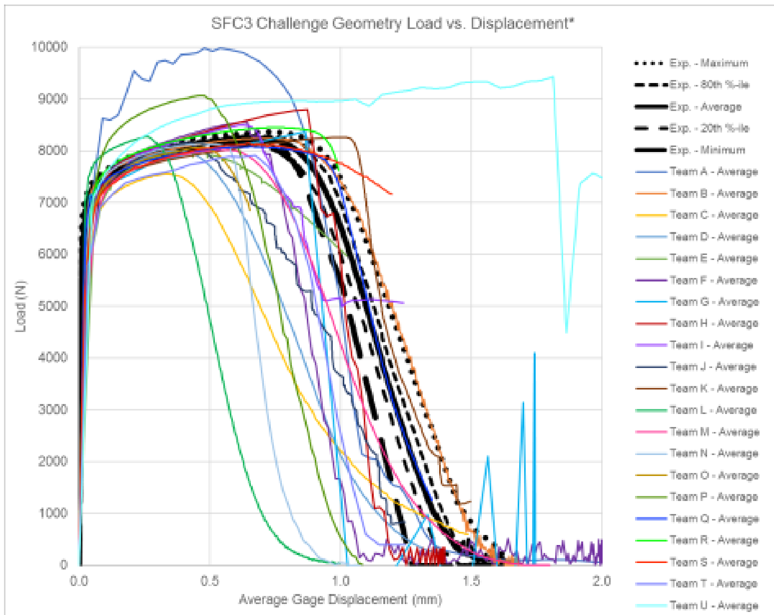
Predictions: Far-Field Force-Displacement

21 Nominal Predictions with Exp. Average and Bounds



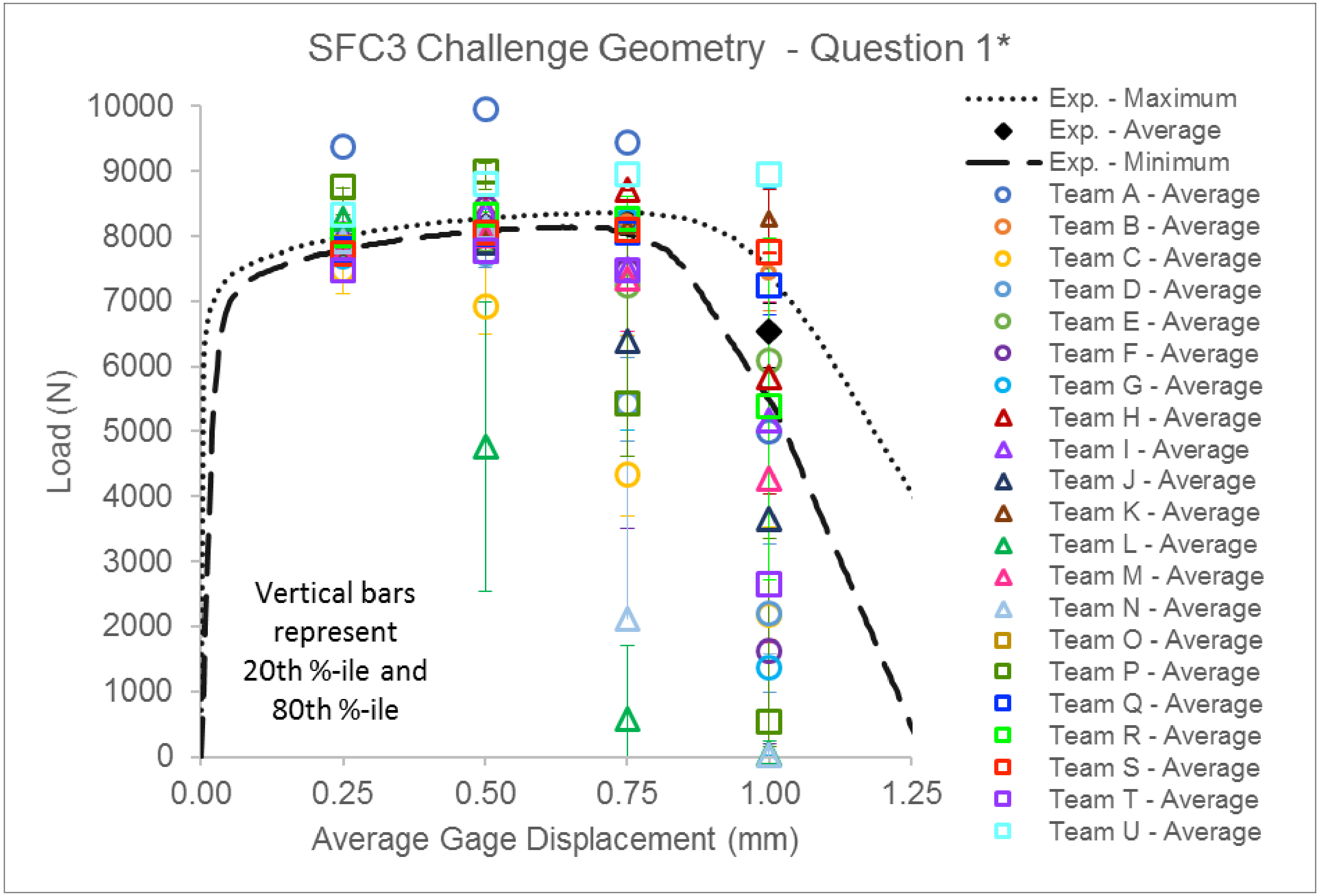
- More teams under-predicted the failure displacement than over-predicted.
- There were only two teams whose nominal prediction fell within the bounds of the experimental data (Teams B and Q).
- The uncertainty bounds on predictions ranged from too small to too large with most unlike the experiments where there was little initial variability with moderate variability after peak load.

Prediction Methods

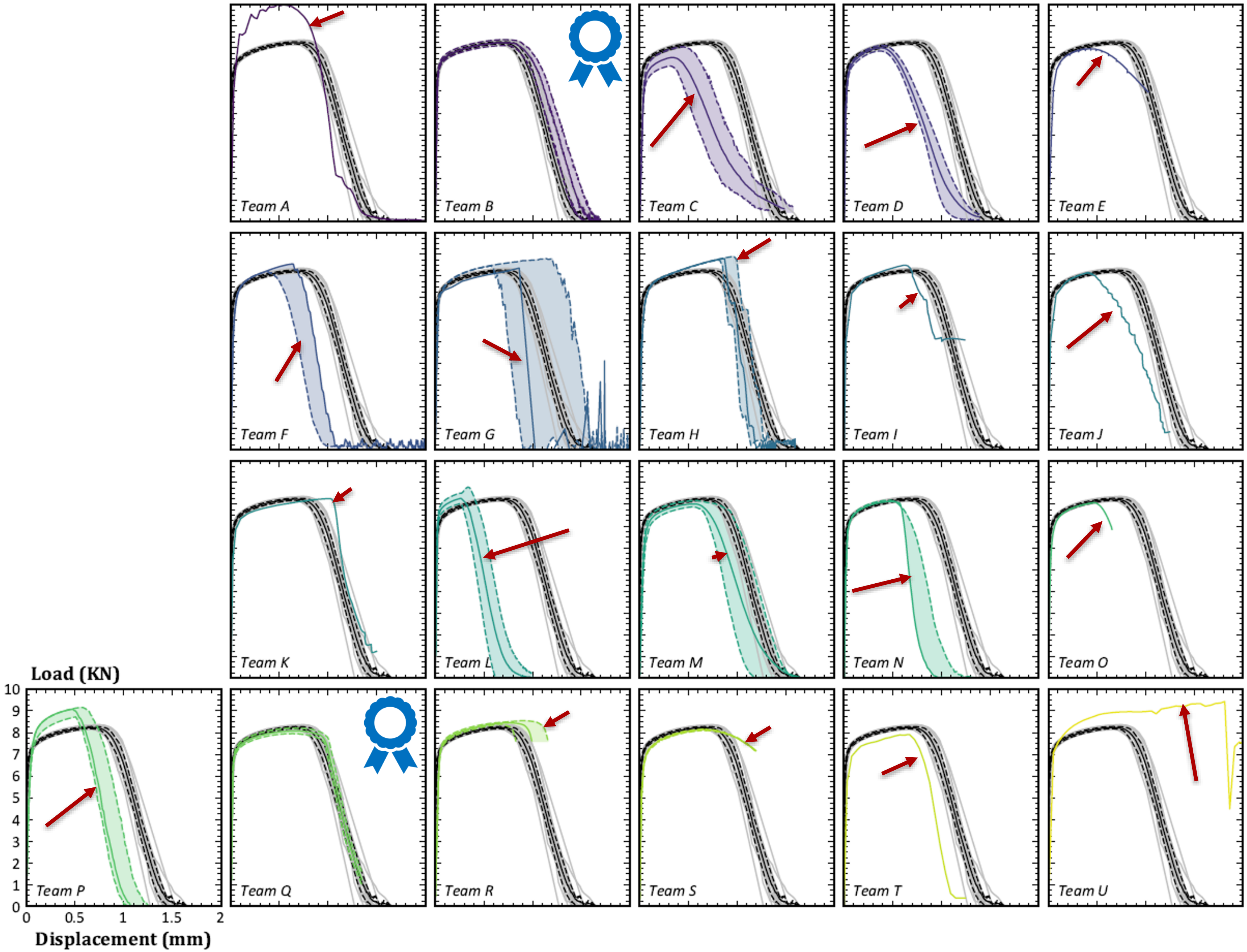


- **The 21 predictions were obtained from a variety of methods**, for example:
  - **Solvers**: Explicit vs. Implicit; Quasi-statics vs. Dynamics
  - **Fracture Method**: Element deletion, Peridynamics with bond damage, XFEM, Damage (stiffness degradation), and Adaptive remeshing
  - **Uncertainty**: Material and geometric
  - **Plasticity**: J2 plasticity or Hill yield with Isotropic hardening, mixed Swift-Voce hardening, kinematic hardening, or custom hardening curves
  - **Fracture Criteria**: GTN model, Hosford-Coulomb, triaxiality-dependent strain, critical fracture energy, damage-based model, critical void volume fraction, and Johnson-Cook model
  - **Damage Evolution**: Damage accumulation / evolution, crack band model, fracture energy, displacement value threshold, incremental stress triaxiality, Cocks-Ashby void growth, and void nucleation / growth / coalescence
  - **Calibration Data**: Various combinations of the tensile specimens, the notched tensile specimens, and literature data
- **All 21 predictions correctly identified the nominal crack path with initiation at the through-thickness hole**
- **12 teams offered uncertainty bounds on their predictions**

Predictions: Overall Force-Displacement

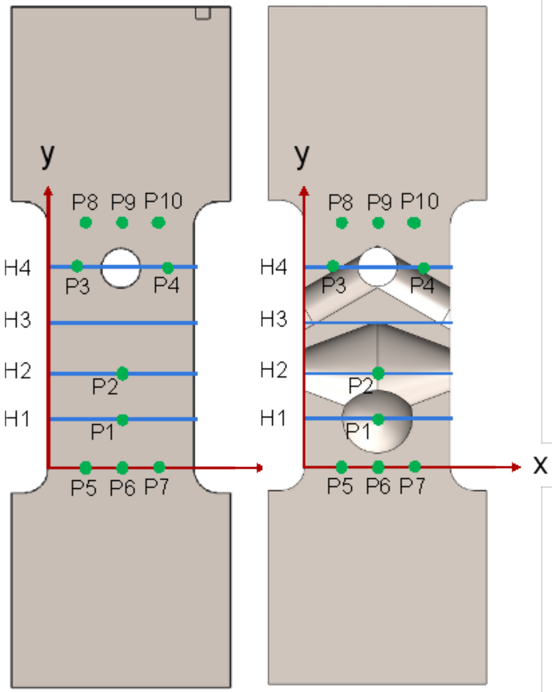


Several teams predicted the initial structural yield, but the variation broadened with increasing displacement.

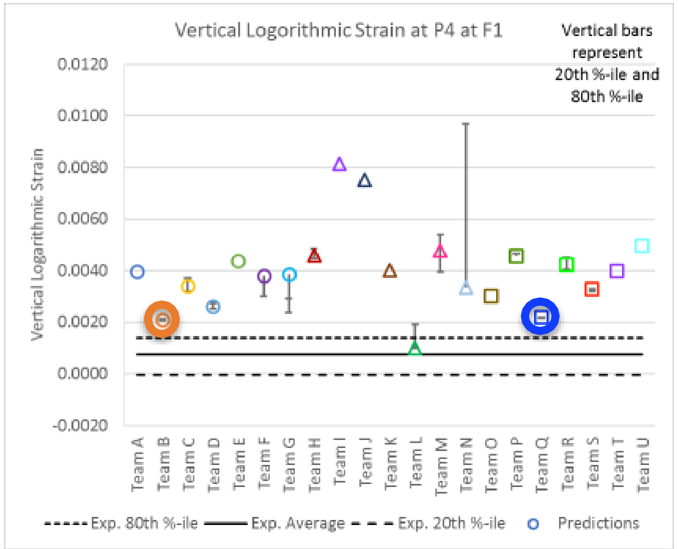


Team A
Team B
Team C
Team D
Team E
Team F
Team G
Team H
Team I
Team J
Team K
Team L
Team M
Team N
Team O
Load (KN)
10
9
8
7
6
5
4
3
2
1
0
Team P
0
0.5
1
1.5
2
Displacement (mm)
Team Q
Team R
Team S
Team T
Team U

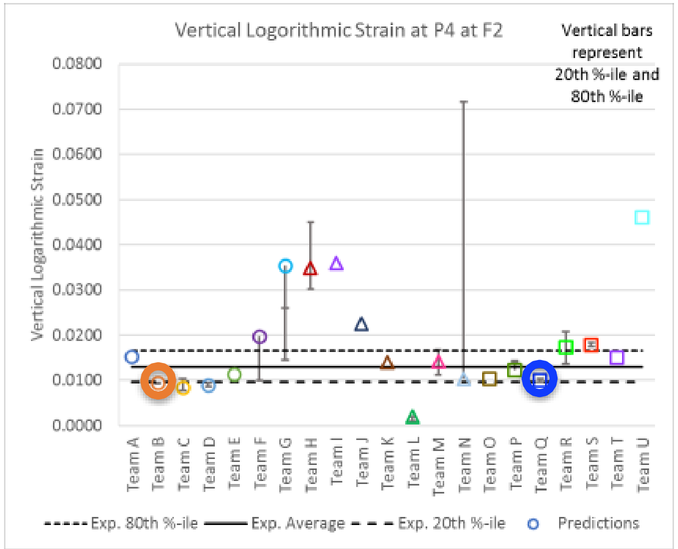
Predictions: Local Strain at Point P4



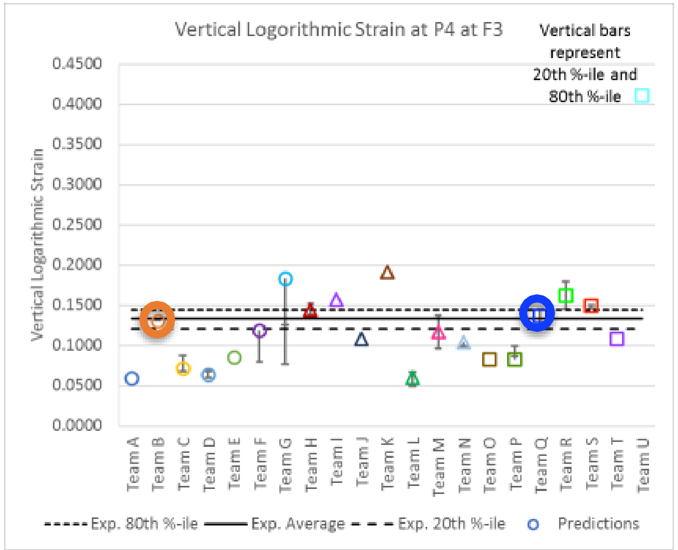
@75% peak force



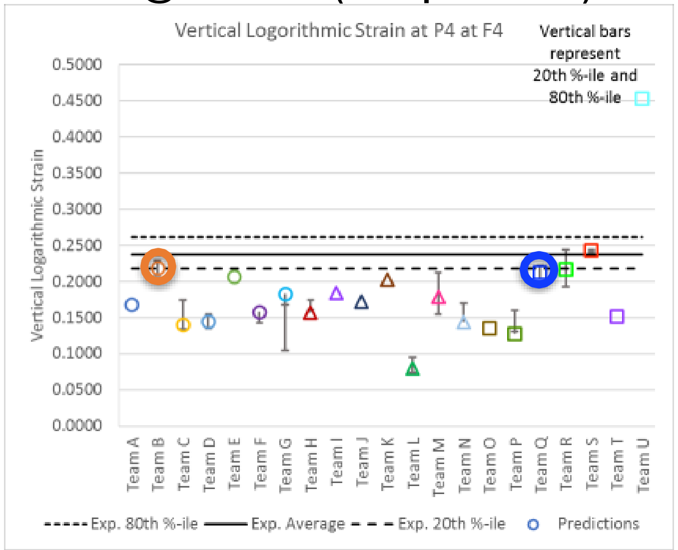
@ 90% peak force



@peak force

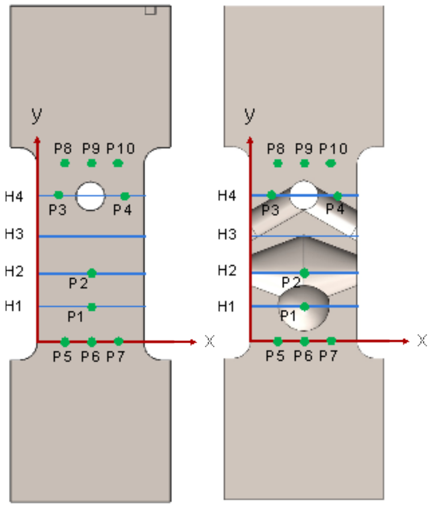


@90% force (after peak force)

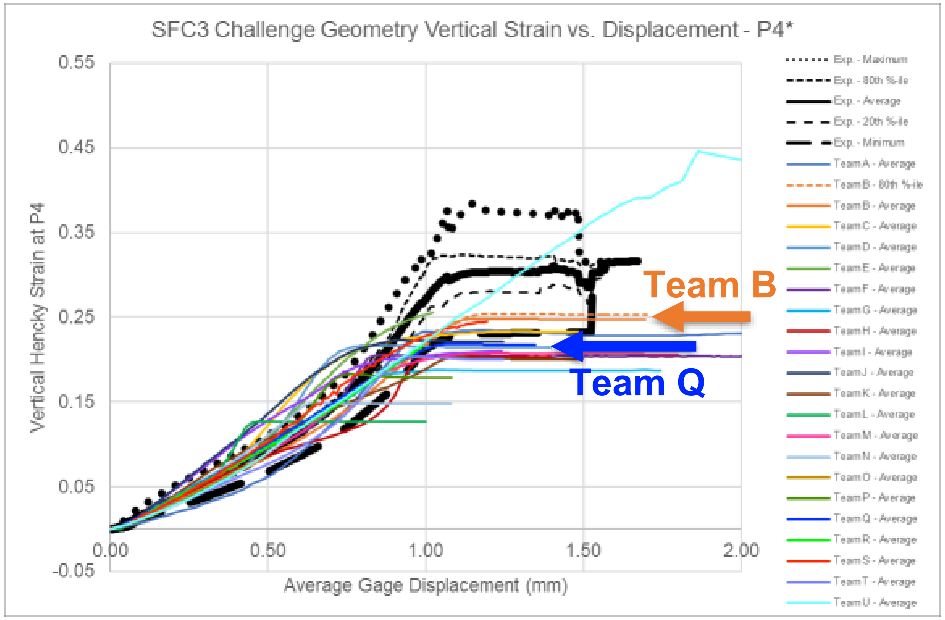


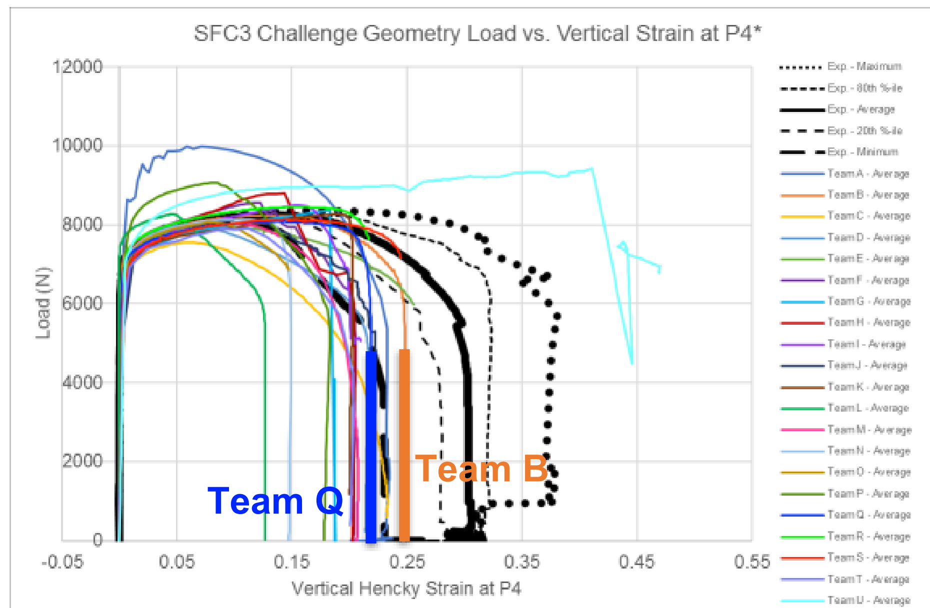
Generally, the predictions were initially too high, particularly for F1, and then were under-predicting by F4.

Predictions: Local Strain Evolution @ P4



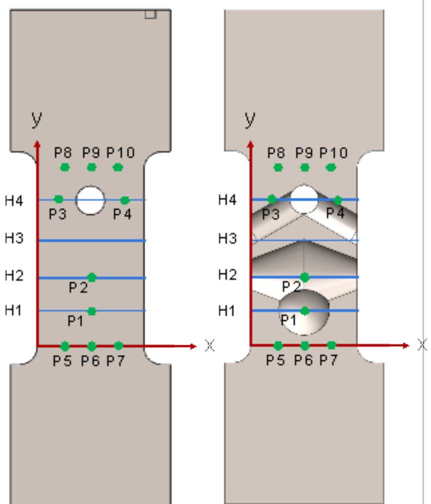
Challenge Geometry (Surface – Left, Cutaway – Right)





Strain predictions close to failure were generally too low.

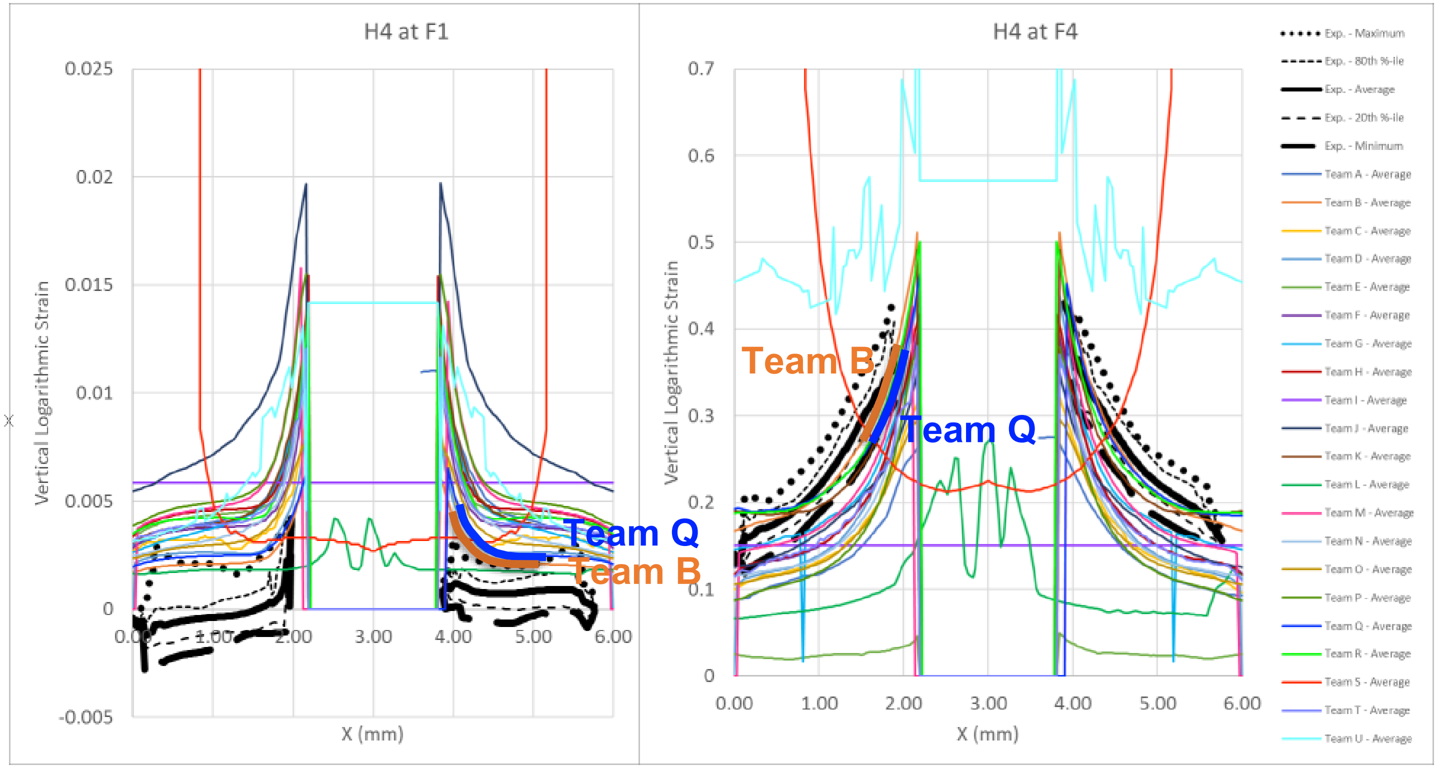
Predictions: Local strain profiles along line H4



Challenge Geometry
(Surface – Left,
Cutaway – Right)

Before peak force
@75% of peak force

After peak force
@90% of peak force



Most teams over-predicted the nominal strain during initial loading, but many team's predictions improved for higher forces.

Assessment of Success: Teams B and Q

Team B:

1) Correct approach to model large-strain plasticity. Hardening model was fit past necking using inverse method

2) Non-associative flow rule (Hill'48) based on a Lankford ratio obtained by DIC analysis.

3) Without data to calibrate stress-state dependency, our past experience guided us to use a constant fracture strain failure criteria.

Team Q:

1) Robust, efficient iterative model refinement tools.

2) The diverse team led to deliberate decisions on assumptions.

3) Improvements to our tools based partly on experience in SFC2.

4) Dedicated significant time to the solution (~700 hours)

IMPACT…. Who cares; how is this helping?

1. Provides a documentation of **'state-of-the-art'**.
   - Evidence to support use of codes in engineering problems
   - Educates analysts who use but do not develop these methods

2. Illustrates **key deficiencies** in structural mechanics predictions
   - Fracture is not a readily 'solved' problem in some cases
   - Motivates mechanicians and code developers to fix deficiencies
   - **Opportunities for lower length scales** to address gaps?

3. Raises International **awareness on the need for improved simulation capabilities**
   - Revitalize & guide funding in this 'mature' area (e.g. NSF)
   - Revitalize the prestige in working on failure of structural metals
   - Establishes well-documented 'toy problems' for future assessment & benchmarking

Minnesota I-35W Bridge Collapse.

Guidance on executing a blind challenge…

1. Learn from examples: SFC, NIST AMBench, Numisheet
2. Identify a problem of broad interest
3. Solicit participation from a broad network of experts
4. Give sufficient time for participation
5. Be thoughtful about how much calibration info you provide
    - Too much data can be discouraging, but may reflect reality
    - Intentionally omitting data can reveal teams' approximation methods
    - Provide all relevant info in an easy-to-access format
6. Chose evaluation metrics with an uncontroversial "ground truth"
    - Experiments that are not controversial (repeated in multiple labs?)
    - Higher fidelity / trustworthy models?
7. Keep the playing field level
    - All open data is shared among all participants.
    - No participant should have an unfair advantage
    - Known key background literature should be distributed
8. Think about how to compile data: request consistent submission format
9. Reward participation (e.g. joint publications)

sandia.gov/srp

STRUCTURAL RELIABILITY PARTNERSHIP

Sandia National Laboratories

The purpose of the Structural Reliability Partnership is to coordinate research, share best practices, and leverage investments from multiple institutions on areas of mutual interest in the domain of structural reliability.

17 member institutions, >$4M in leveraged funding

Members		
Core	Strategic	Contributing
Sandia National Laboratories; Mississippi State University; Texas (The University of Texas at Austin)	Oak Ridge National Laboratory; NIST National Institute of Standards and Technology	PennState; UT Dallas; UC Davis Aggies; UC San Diego; University of Louisville; University of Colorado Boulder; Clemson University; The University of New Mexico; The University of Utah; UIC University of Illinois at Chicago; INL Idaho National Laboratory; Pratt & Whitney (A United Technologies Company)

Participants: ExxonMobil; Boeing; Colorado School of Mines (1874); Michigan State University; Johns Hopkins University; Purdue University; Pacific Northwest National Laboratory; Illinois (University of Illinois at Urbana-Champaign); NAVSEA Warfare Centers; Georgia Tech; NSF; NASA; Lawrence Livermore National Laboratory