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automotive CAE GRAND CHALLENGE

Experimental Calibration and Validation of Radioss Adhesive Laws for Automotive Structural Adhesives

Daniel Campos & Brian Croop

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OVERVIEW OF DATAPOINTLABS

- Experience
  - 31 years of experience in materials testing and characterization
    - ISO 17025:2017 accredited, operating on an end-end digital platform
    - Nadcap accredited [Aerospace / Defense] (Metallic/Non-Metallic Materials Testing)
- Operations
  - Testing 2000+ materials per year
  - Standard 5-day turnaround
  - Comprehensive one-stop testing capability
    - +200 unique tests: all aspects of mechanical, thermal and rheological characterization
- Capabilities
  - Materials: plastics, composites, foam, rubber, metals, additive materials, films, adhesives
  - May be characterized over a wide range of temperature and environmental conditions

ITHACA, NY USA

Nadcap
Administered by PRI
ACCREDITED
Certificate# 17231205927
Non Metallic Materials Testing

ISO
ISO 17025

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MOTIVATION AND OBJECTIVES

Motivation

- Opportunity to bring our testing and simulation expertise into the growing structural adhesives market

- Increasing use of bonded joints in structural applications
- Traditional development relies heavily on:
  - Component-level tests
  - Subsystem and system assembly testing
- High cost and long lead times associated with experimental validation

- Introduction of FEA enables:
  - Early-stage design optimization
  - Reduction in the number of physical tests
  - Decreased dependency on subsystem and system-level tests
- Faster design iterations and shorter development cycles
- Improved understanding of failure mechanisms at joint level

Objectives

- Evaluate the predictive capability of adhesive material laws LAW36 and LAW59
- Development of a robust and transferable methodology for adhesive model calibration across different solvers
- Strengthening internal know-how in fracture-based adhesive testing and modeling

ADHESIVES MODELS IN RADIOSS

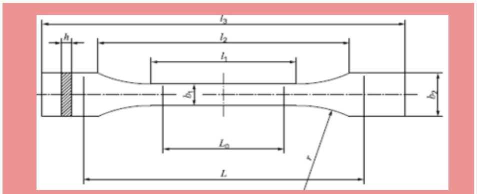
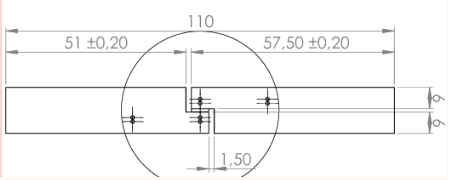
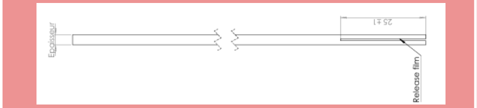
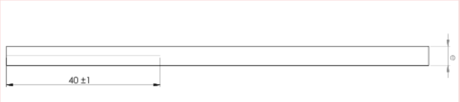
LAW 36: PLAST_TAB

- Isotropic elasto-plastic material
- User-defined functions for the work-hardening portion of the stress-strain curve
- Strain-rate dependent
- Easy to implement
- Available for shell and solid elements
- Compatible with multiple failure models

LAW59 + FAIL: CONNECT

- Anisotropic elasto-plastic material
- User-defined functions for the work-hardening portion of the SS for normal and shear directions
- Strain-rate dependent
- Available only to solid hexahedron elements
- Compatible only with /FAIL/CONNECT
    - Displacement criteria
    - Energy criteria

EXPERIMENTAL TEST MATRIX

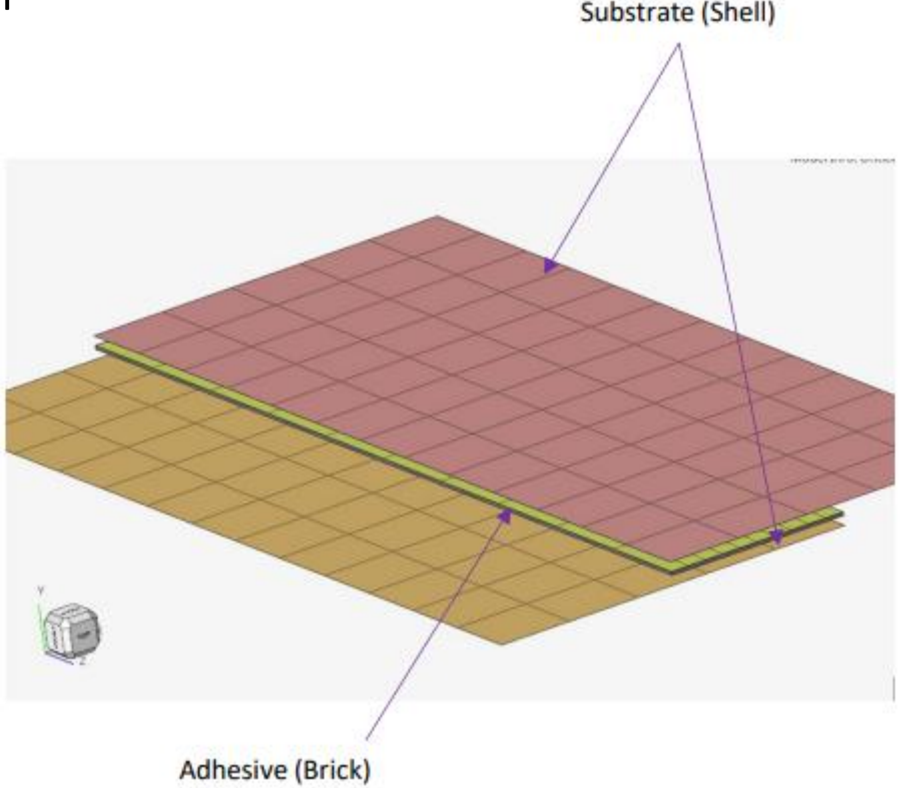
Test Name	Test Geometry	Standard	Material Parameters	Description
Bulk Tensile Test		ISO 527-2	Young Modulus Poisson’s Ratio Hardening Curves	Resistance to elastic deformation and transverse contraction in tension
Thick Adherent Shear Test (TAST)		ISO 11003-2	Shear strength Tangential Hardening Curves	Maximum stress in shear
Mode I Fracture Toughness		EN 6033	Mode I Fracture Energy	Resistance to crack propagation (opening mode)
Mode II Fracture Toughness		EN 6033	Mode II Fracture Energy	Resistance to crack propagation (shear mode)

* All test conditions per performed for 3 Speeds and 3 Thicknesses

NUMERICAL MODELING APPROACH

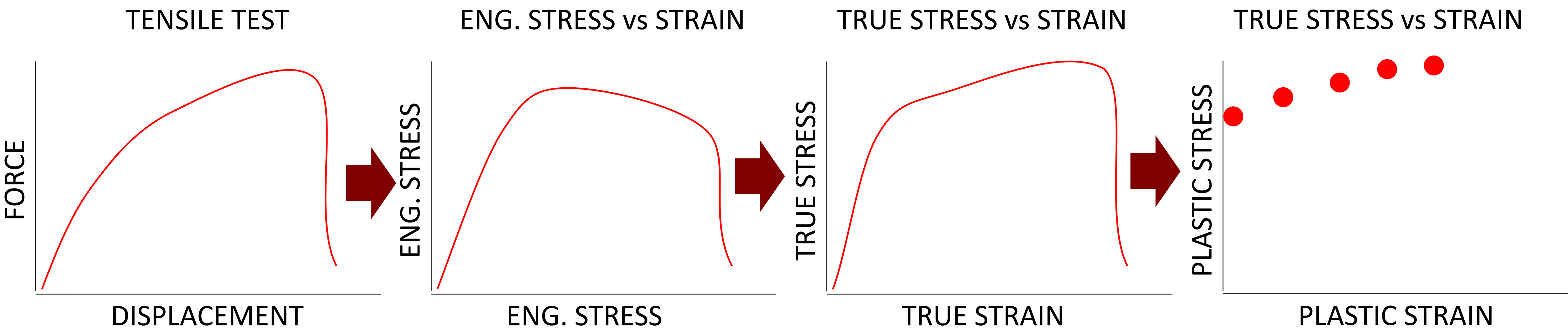
MODELING STRATEGY AND GLOBAL PARAMETERS

- Finite Element simulations performed using the Radioss explicit solver
- Adhesive layers modeled with 3D solid elements (8 node hexahedral elements TYPE43)
- Metallic substrate modeled with shell elements to reduce computational cost
- Mesh refinement applied in the adhesive layer2–3 elements through the adhesive thickness
- Coarser mesh in substrates
- Adhesive behavior described using:
  - LAW36
  - LAW59 + FAIL
- TIED Contact between adhesive and substrates
- Displacement-controlled loading used in all simulations
- Quasi-static conditions ensured by low loading rates and energy balance checks



NUMERICAL MODELING APPROACH

LAW36: Elasto-plastic tabular model



- Elastic parameters from the highest strain-rate curve
- Power law fitting when possible
- Extrapolation beyond min. and max. strain-rates
- Strain-rate filtering activated

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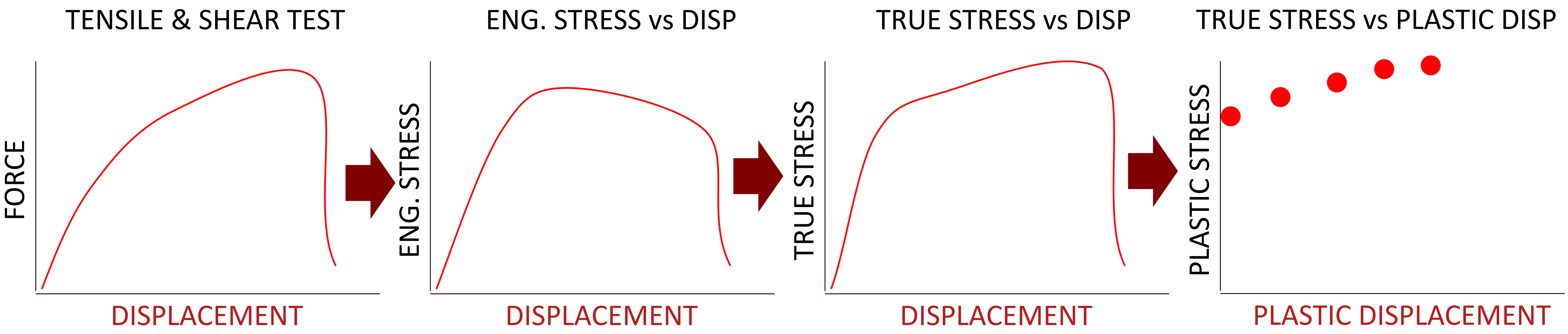
NUMERICAL MODELING APPROACH

LAW36: Elasto-plastic tabular model



- Elastic parameters are per unit of length (Preferable to add a Butt Joint Tensile test to obtain these data)
- Icomp flag set to 0: symmetrical elasto-plastic behavior in compression
- Strain-rate filtering activated

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NUMERICAL MODELING APPROACH

LAW 59 Failure model

- Multidirectional failure (coupled failure formulation)
- Calibration of both criteria:
  - Displacement criteria

$$\underbrace{\left|\frac{\bar{u}_N}{\bar{u}_{\max N}}\cdot\alpha_N\cdot \mathrm{f}_N\left(\dot{\bar{u}}_N\right)\right|^{\exp_N}}_{\text{TENSILE TEST}}+\underbrace{\left|\frac{\bar{u}_T}{\bar{u}_{\max_T}}\cdot\alpha_T\cdot \mathrm{f}_T\left(\dot{\bar{u}}_T\right)\right|^{\exp_T}}_{\text{SHEAR TEST}}>1 \quad (1)$$

  - Energy criteria

$$\overbrace{\left(\frac{En}{EN_{\max}}\right)^{N_n}}+\overbrace{\left(\frac{Et}{ET_{\max}}\right)^{N_t}}>1 \qquad (2)$$

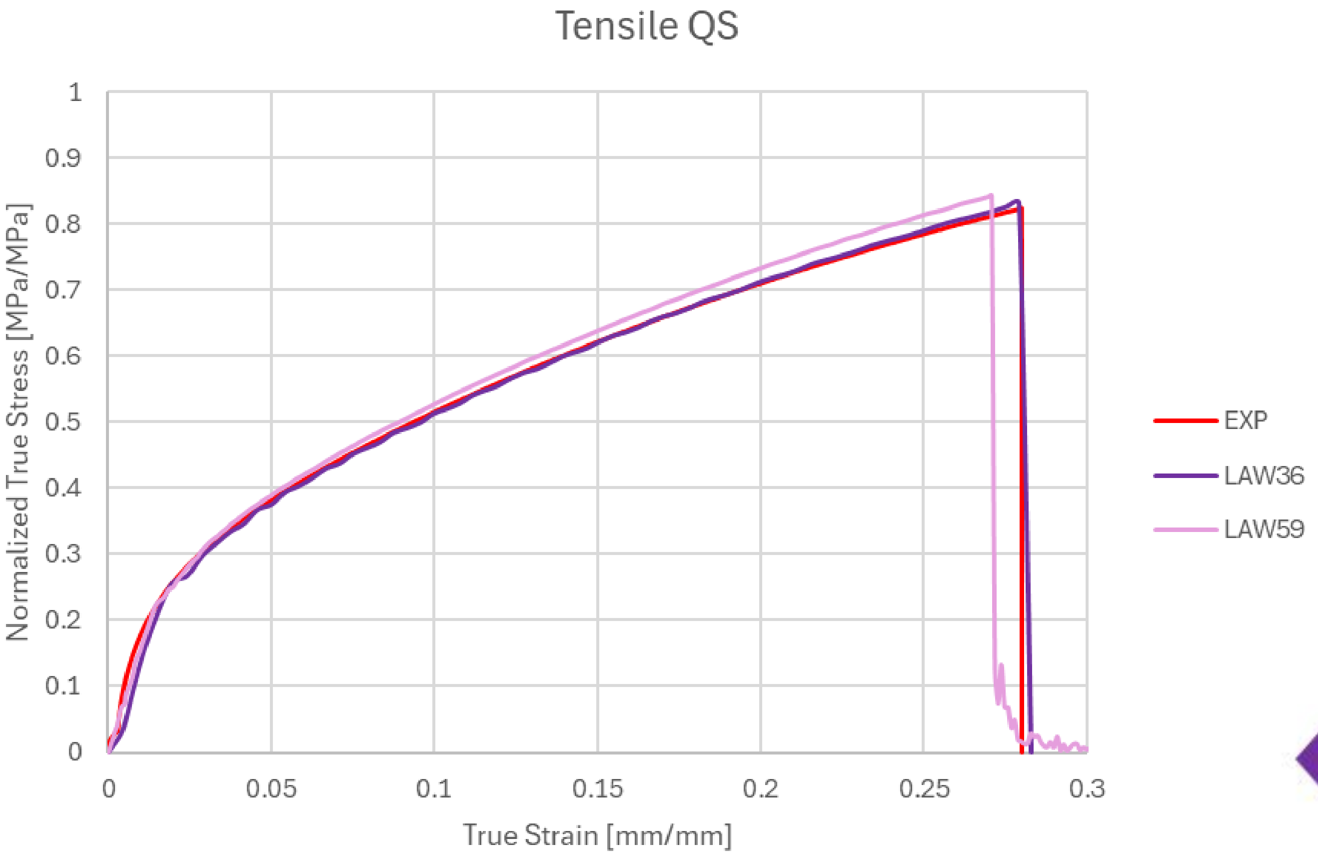
ITERATIVE ALGORITHM REQUIRED

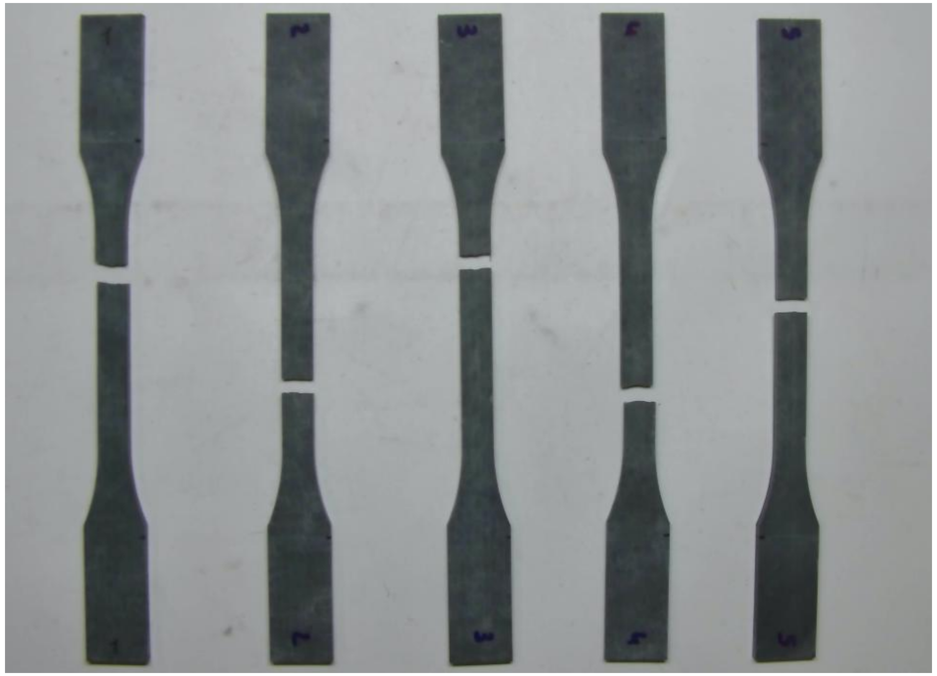
- Softening

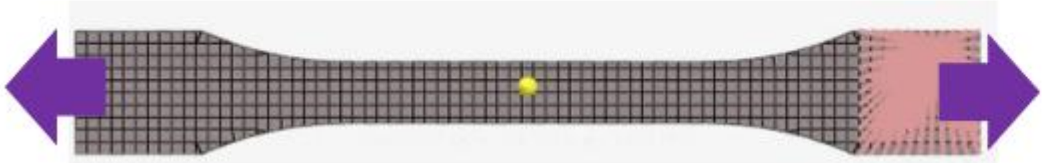
$$\boldsymbol{\sigma}=\boldsymbol{\sigma}\left(1-\frac{D}{T_{\max}}\right)^{N_{soft}} \qquad (3)$$

RESULTS

Bulk Tensile Test

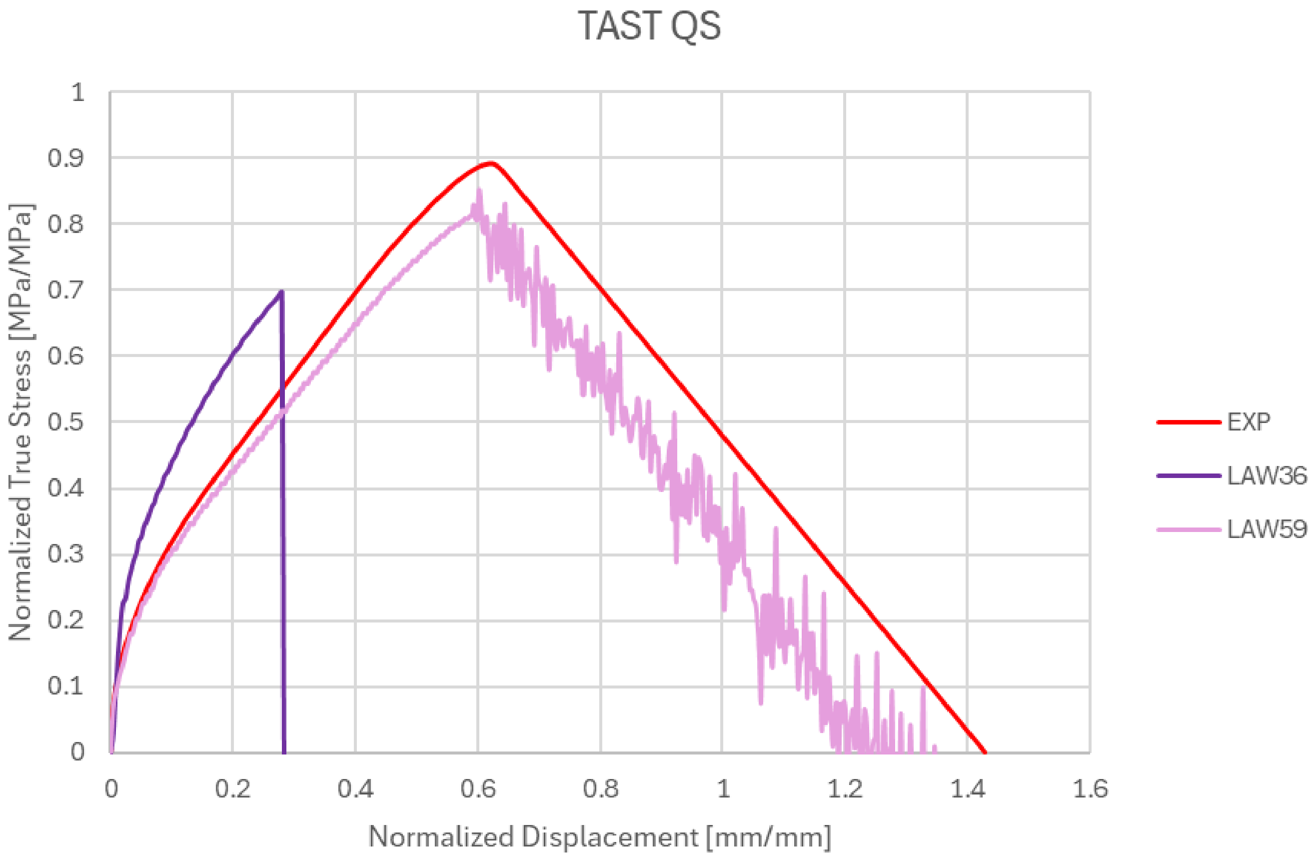


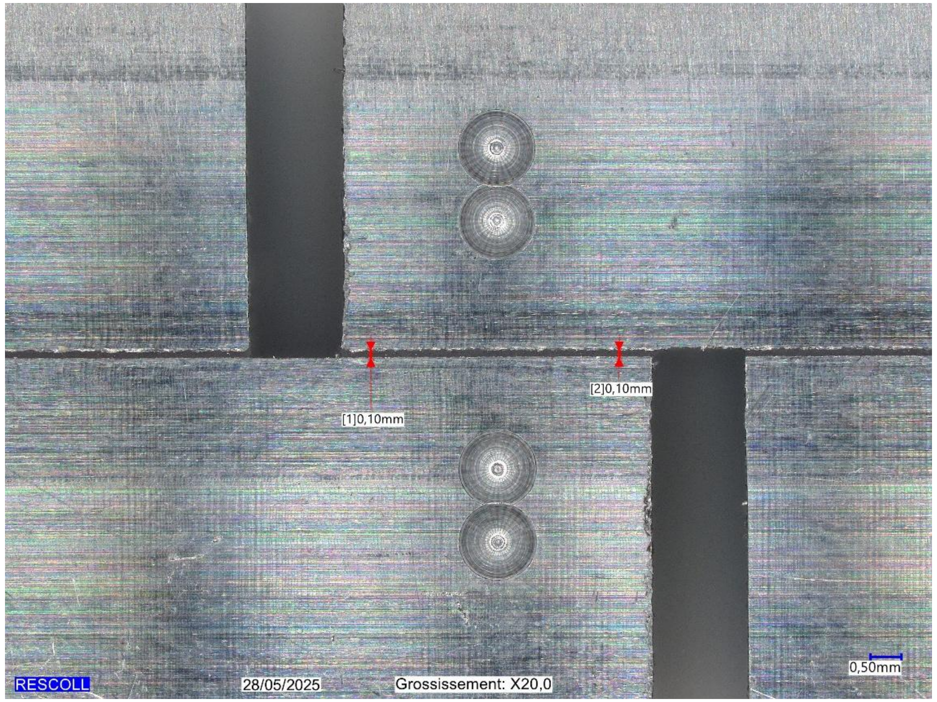


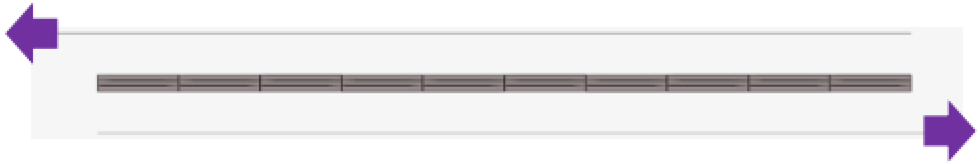


RESULTS

Thick Adherent Shear Test

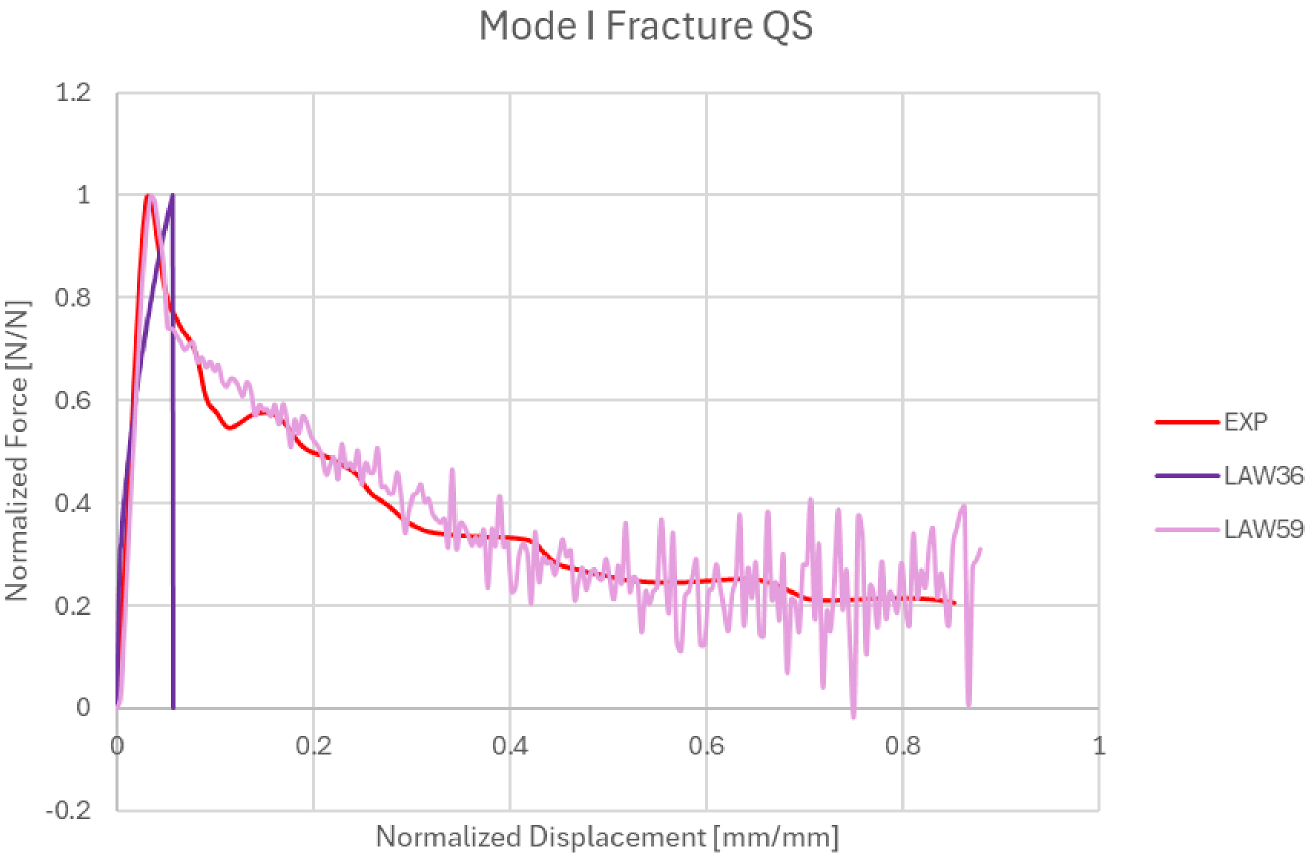


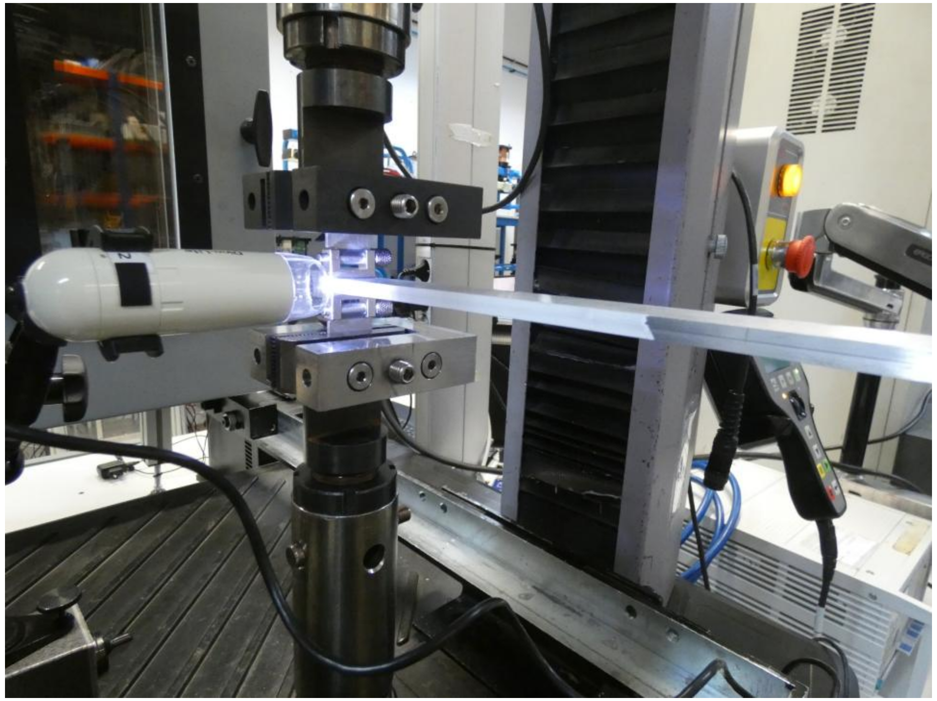


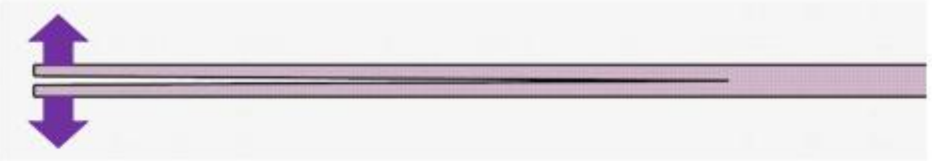


RESULTS

Mode I Fracture Toughness







DISCUISSIONS: Comparative Assessment

Correlation with Tests

- **Tensile test**
  - Both models reproduce peak load accurately
  - Similar stiffness response
- **TAST**
  - LAW36 slightly overpredicts peak load
  - LAW59 shows better agreement in post-peak response
- **Mode I Fracture**
  - LAW36 fails to reproduce measured fracture energy
  - LAW59 accurately matches G1c and crack growth behavior

Failure Prediction

- **LAW36**
  - Damage initiation well captured
  - Failure tends to be abrupt and localized
  - Limited capability to reproduce progressive crack growth
- **LAW59**
  - Accurate damage initiation and evolution
  - Progressive degradation observed in all loading modes
  - Realistic crack initiation and propagation in Mode I tests

DISCUISSIONS: Comparative Assessment

Predictive Capabilities

Test Condition	Law 36	Law 59
Tensile Response	Robust	Robust
Shear Response	Acceptable	Robust
Mode I Fracture	Limited	Robust

Calibration Effort

Criterion	Law 36	Law 59
Calibration Effort	Low	High
Numerical stability	High	Moderate
Mesh sensitivity	Low	High
Computational cost	Low	Moderate

DISCUISSIONS: Comparative Assessment

Summary

- **Law 36**
- Efficient and robust for strength-driven applications
- Suitable for preliminary design and global assessments

- **Law 59**
- Physically consistent fracture representation
- Superior for joint-level simulations and failure analysis
- Preferred when crack propagation and energy dissipation are critical

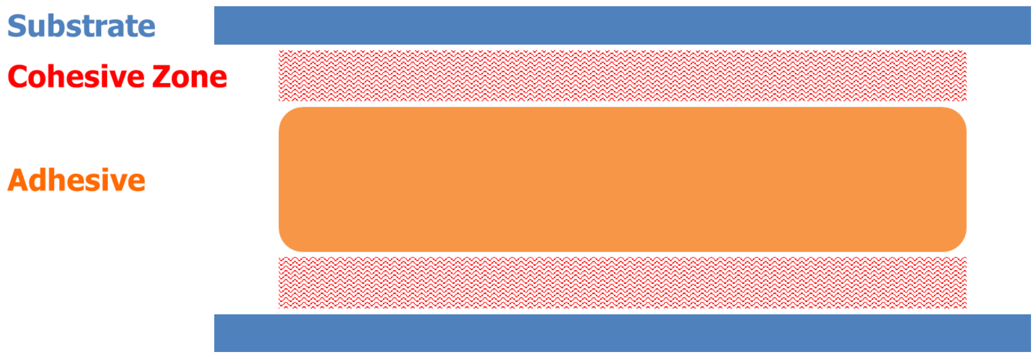
NEXT STEPS

Roadmap 2026

1. **Adhesive model + Rigid substrate + Tied connection**
   - Simple to calibrate
   - Good accuracy of the adhesive behavior
   - Failure within the adhesive

2. **Adhesive model + Substrate model + Tied connection**
   - More complex to calibrate
   - More testing needed
   - Better accuracy on the prediction of the union behavior
   - Failure within the adhesive or the substrate

3. **Adhesive model + Substrate model + Cohesive zone model**
   - More complex to calibrate
   - Best accuracy on the prediction of the union behavior
   - Failure within the adhesive, the substrate or the cohesive zone



Thank You!

Brian Croop

- CEO & Laboratory Director
- brian.croop@applus.com
- +1 607-266-0405

Barbara Leichtenstern

- Customer Relations & Business Development Manager – Europe
- barbara.leichtenstern@applus.com
- +353 86 898 0355

Daniel Campos Murcia

- CAE Engineer
- Daniel.campos@applus.com
- +34 687 117 968