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Calibration and Validation of Epoxy Adhesive Joints: Evaluation of LAW36 and LAW59 in Radioss

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#ANTEC26

Applus+ DatapointLabs Applus+ RESCOLL

Company Overview

Applus+ Group

Applus+ is a global leader in inspection, testing and certification. Driven by our passion for progress and technological development, we'll keep moving towards a more sustainable future alongside our customers; re-enforcing our mission and company motto: **Together beyond standards.**

26,000+
People

€ 2,058M
Revenue

65+
Countries in all continents

Accredited
By main international entities

Energy & Industry Division

€ 1,084M revenue | 16,000+ personnel

Laboratories Division

€ 264M revenue | 2,589 personnel

Automotive Division

€ 392M revenue | 4,300 personnel

IDIADA Division

€ 331M revenue | 3,158 personnel

Company Overview

Applus+ DatapointLabs

ITHACA, NY
USA

OVERVIEW OF DATAPOINTLABS

Experience

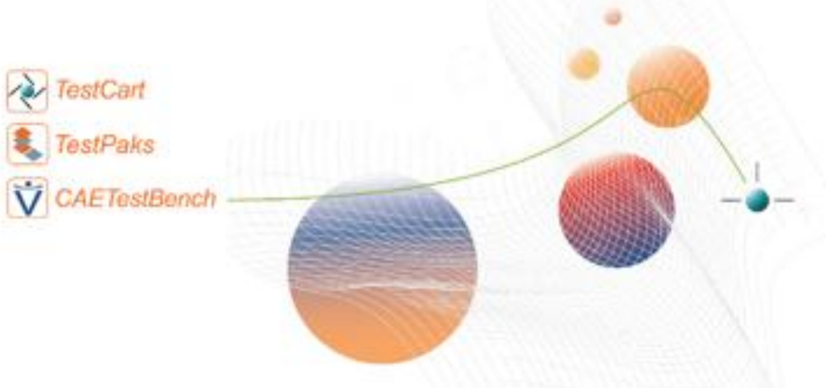
- +30 years of experience in materials testing and characterization
  - ISO 17025:2017 accredited, operating on an end-end digital platform
  - Nadcap accredited [Aerospace / Defense] (Metallic/Non-Metallic Materials Testing)

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 (elevated/cryogenic, heat aging, moisture conditioning, weathering, fluid exposure, in-vivo)
- Characterize non-linear and post-yield behavior, dynamic situations (drop, crash, impact), hyperelasticity (rubber, foams), time-based behavior (creep, stress relaxation, viscoelasticity)



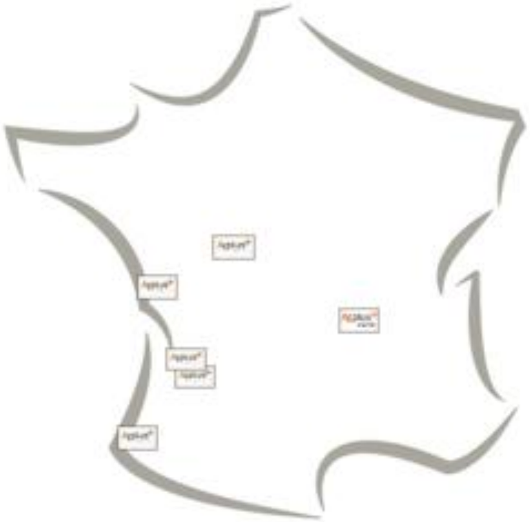
Nadcap
Administered by PRI
ACCREDITED
Certificate# 17231205927
Non Metallic Materials Testing

ISO
ISO 17025

https://www.datapointlabs.com/

Company Overview

Applus+ Rescoll



TESTING | INNOVATION STUDIES | PRODUCTS

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 (Radioss)

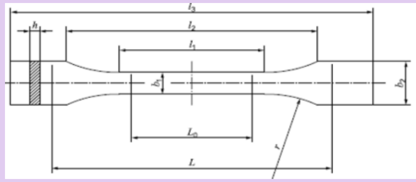
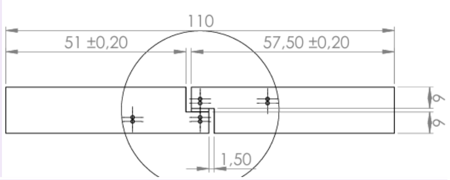
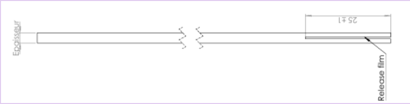
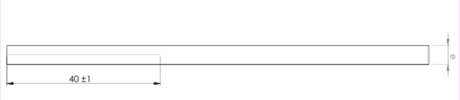
LAW36: PLAS_TAB

- 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

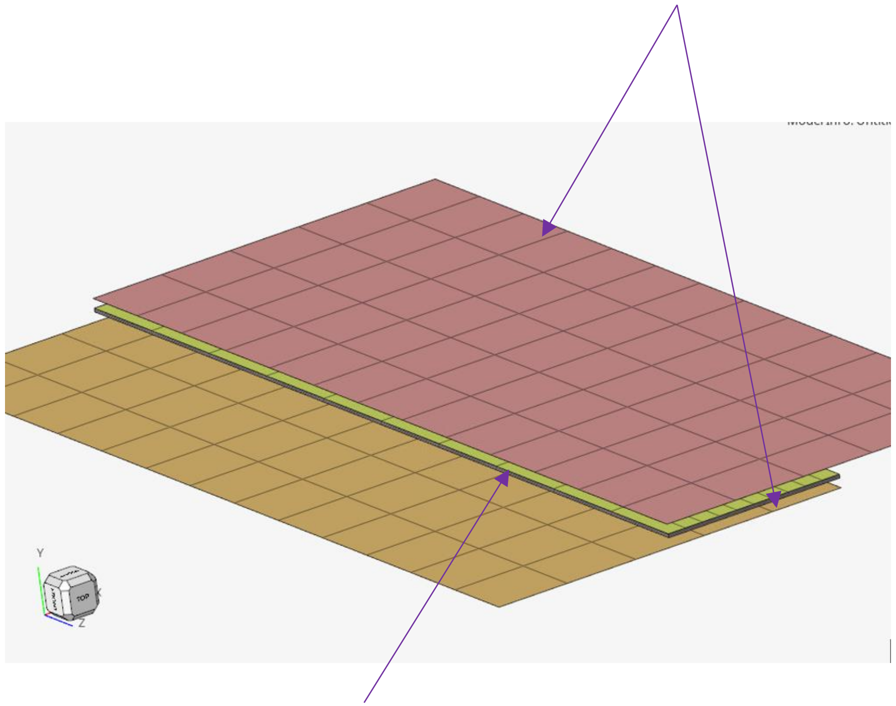
Test Name	Test Geometry	Standard	Material Parameters	Description
Bulk Tensile Test		ISO 527-2	Young Modulus Poisson's Ratio Hardening Curves	Resistance to elastic deformation and transverse contraction in tension
Thick Adherent Shear Test (TAST)		ISO 11003-2	Shear strength Tangential Hardening Curves	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

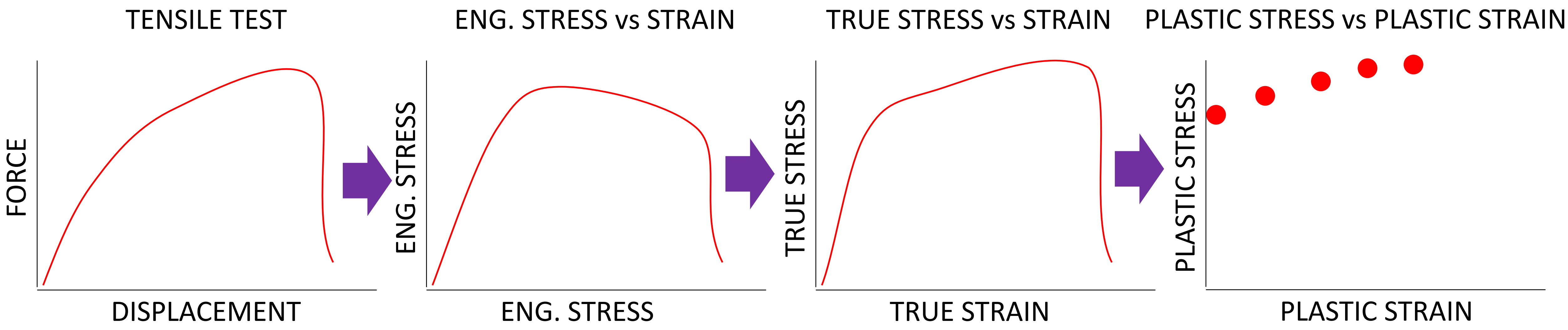
Modeling Strategy and Global Parameters

- 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



Model Calibration Strategy

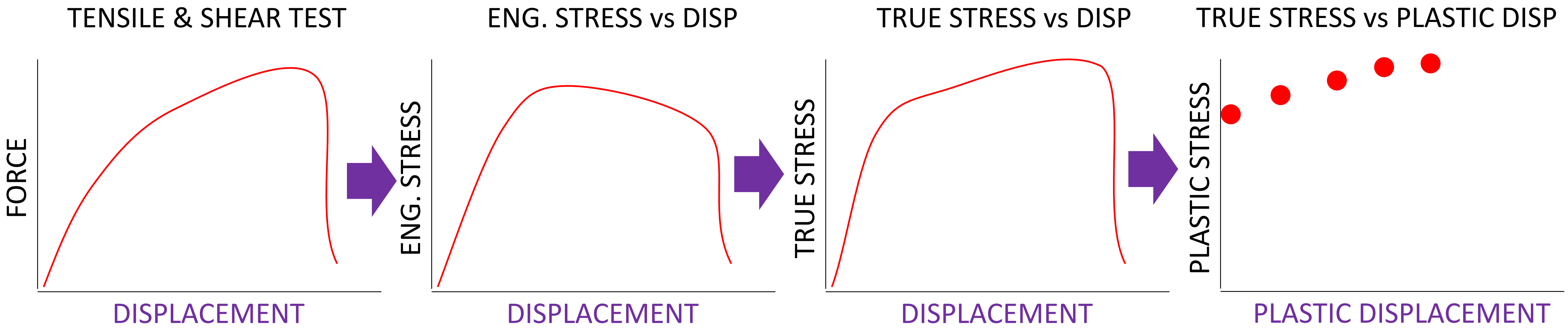
LAW36: Elasto-plastic tabular model



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

Model Calibration Strategy

LAW59: Connection material 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

Model Calibration Strategy

LAW59: FAILURE MODEL

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

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

TENSILE TEST SHEAR TEST

  - Energy criteria

TENSILE TEST SHEAR TEST

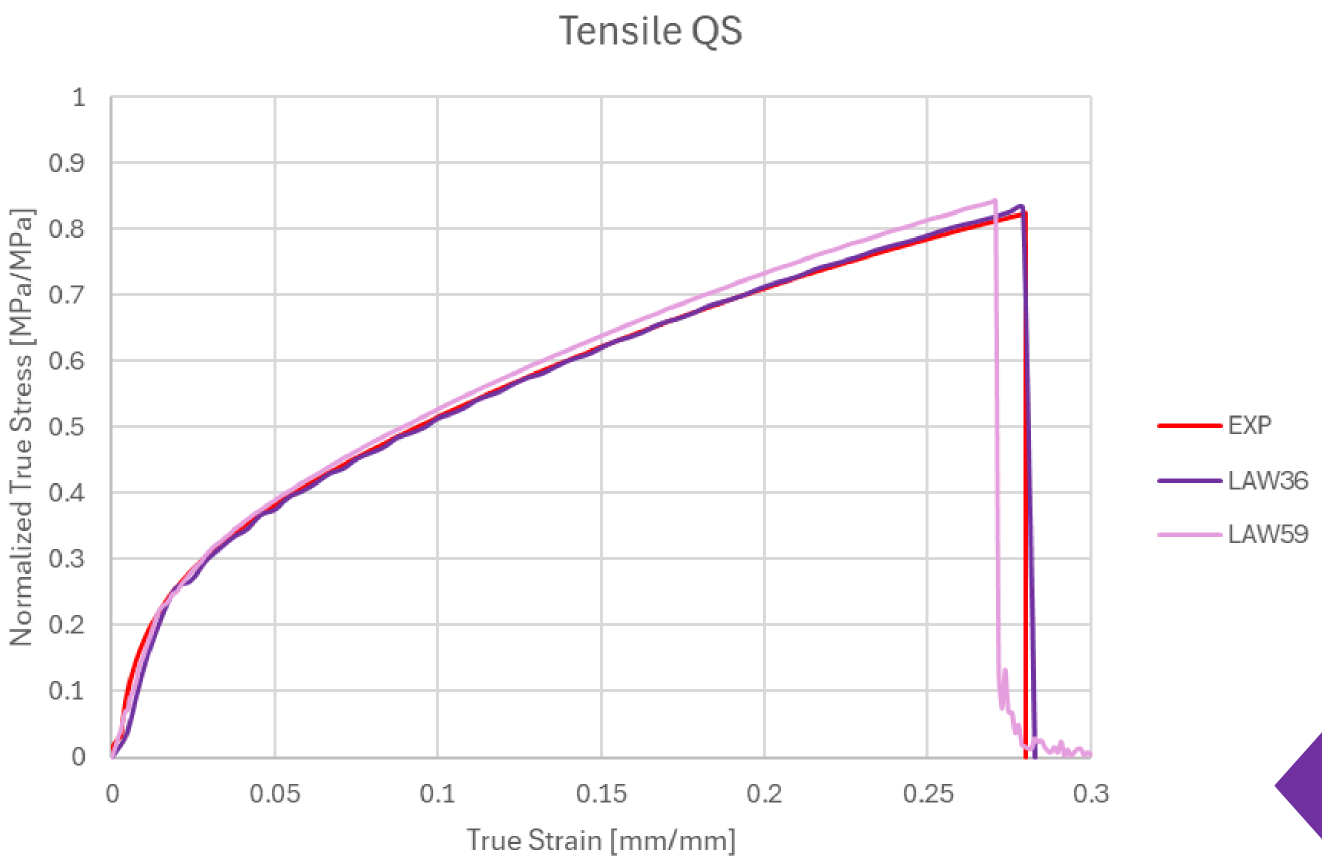
$$\left(\frac{En}{EN_{\max}}\right)^{N_n}+\left(\frac{Et}{ET_{\max}}\right)^{N_t}>1 \quad (2)$$

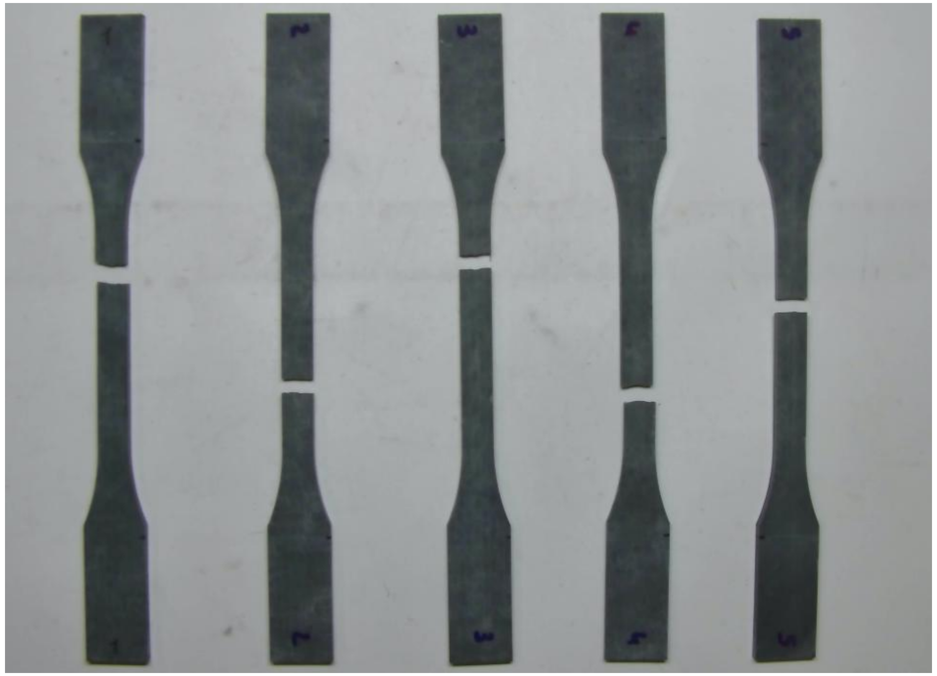
ITERATIVE ALGORITHM REQUIRED

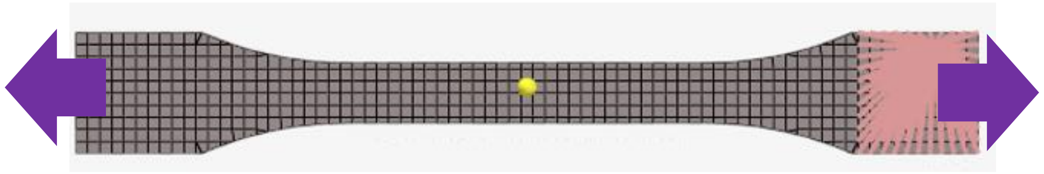
  - Softening

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

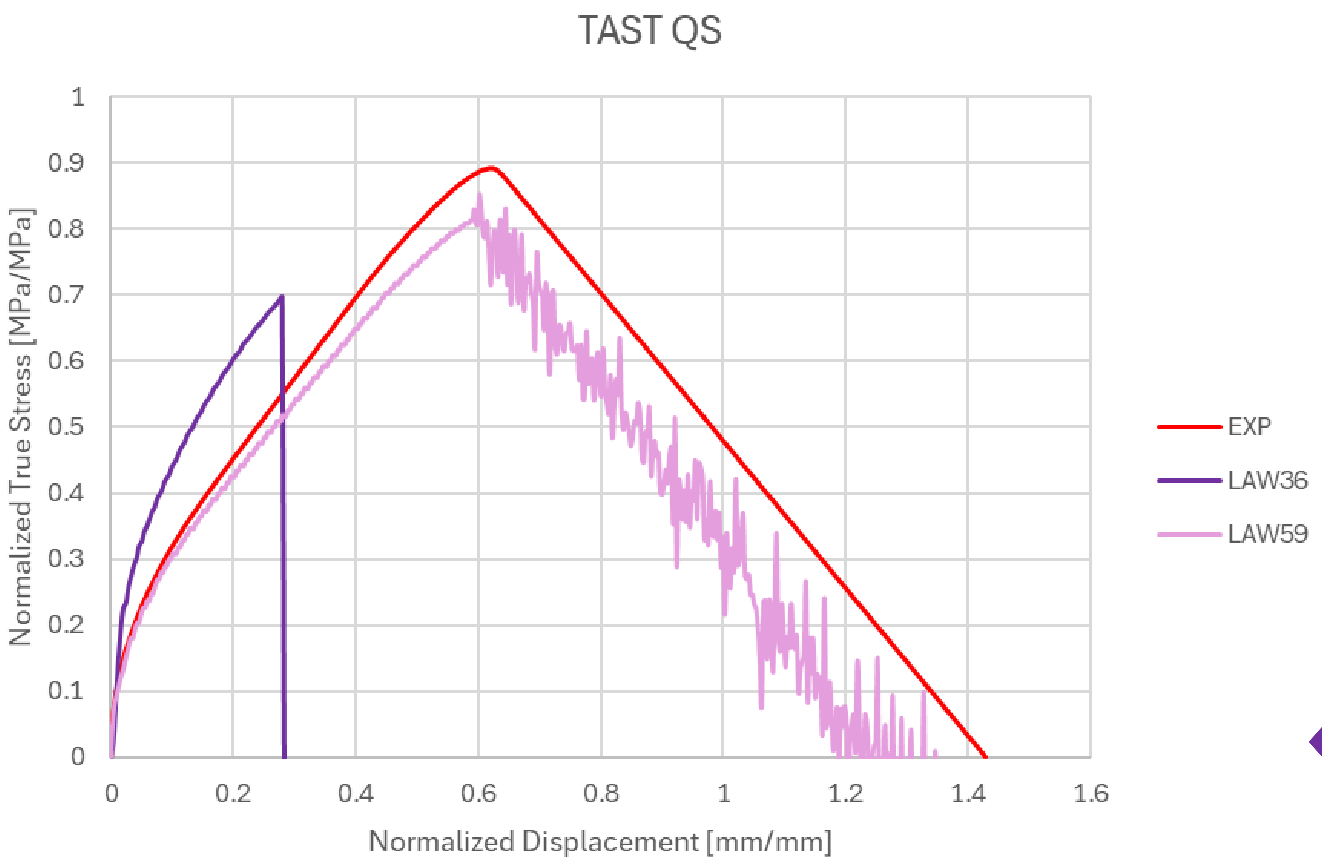
Bulk Tensile Tests

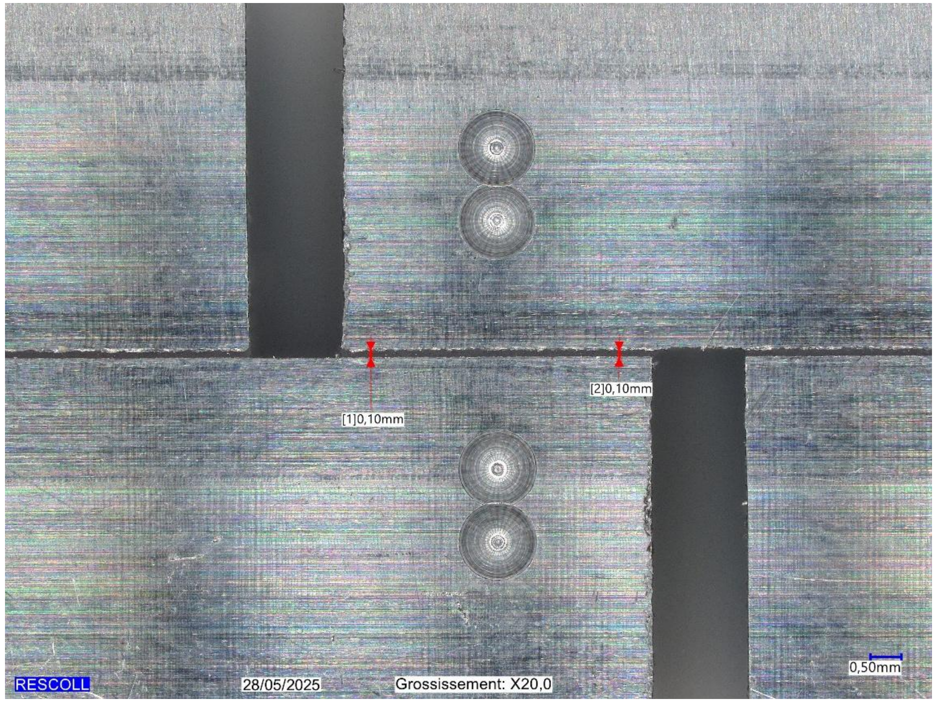


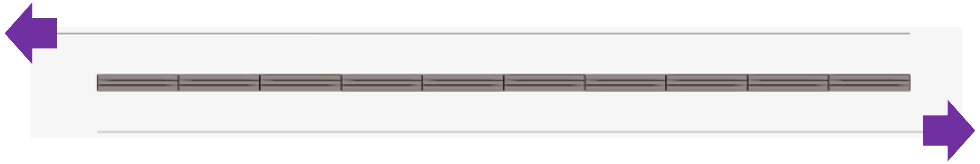




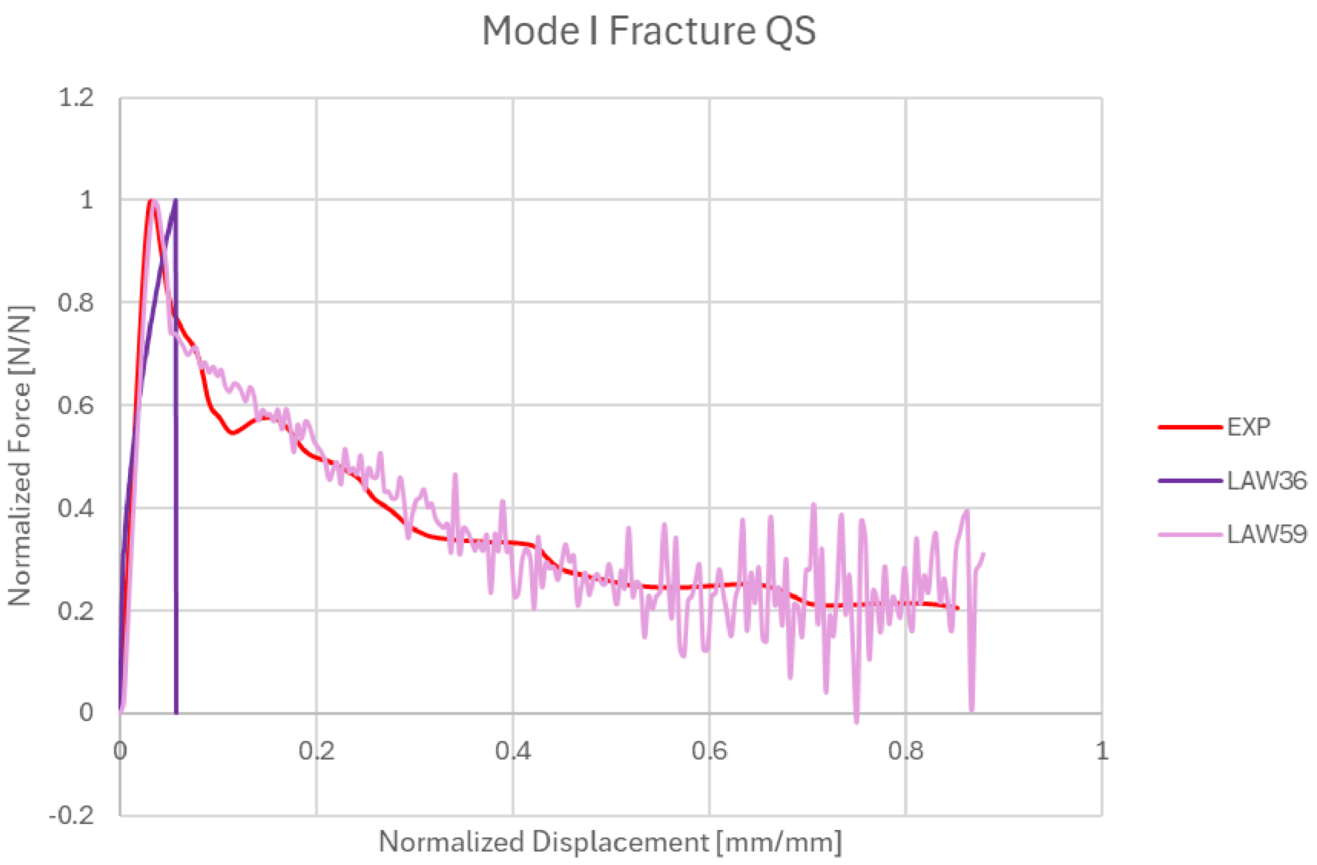
Thick Adherent Shear Test Results

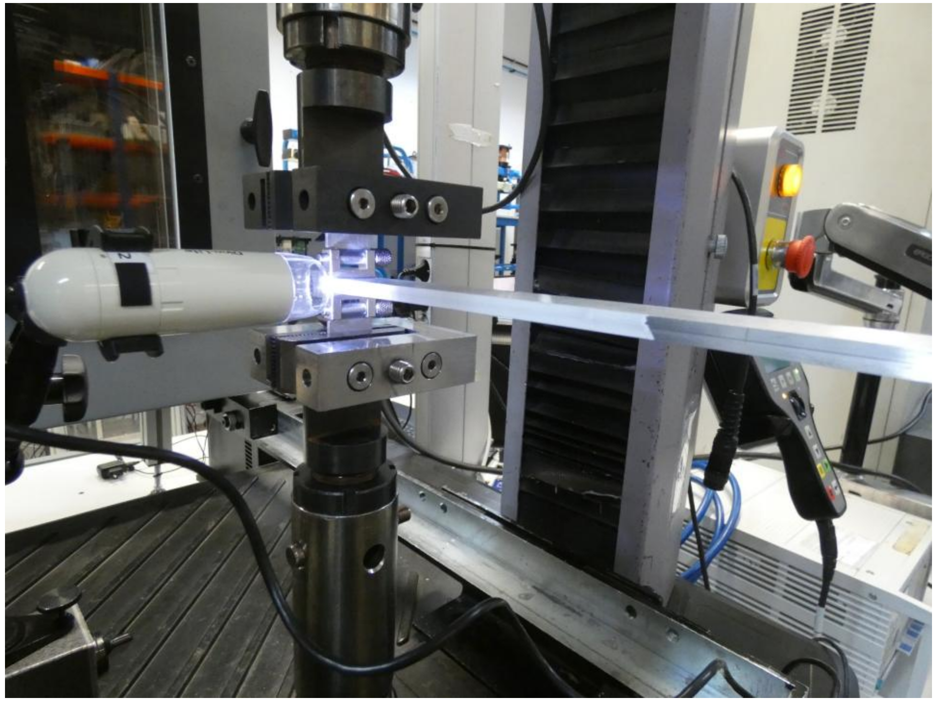


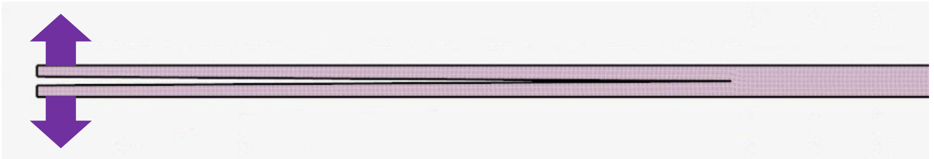




Mode I Fracture Thougness







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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

- **LAW36**
- Accurate damage initiation and evolution
- Progressive degradation observed in all loading modes
- Realistic crack initiation and propagation in Mode I tests

Comparative Assessment

Predictive Capability

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

Numerical Robustness and Cost

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

Comparative Assessment

Overall Assessment

- **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

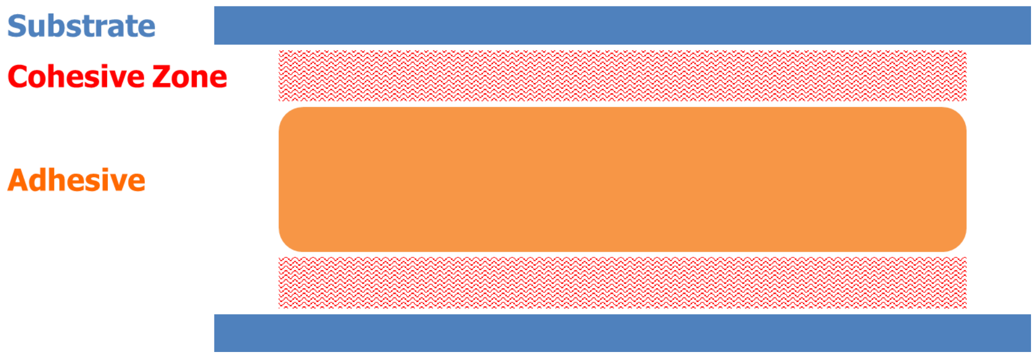
Future Work

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



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