Numerical Calibration of Tensile and Compressive Failure of Bio-Epoxy Foam Core for Explicit Analysis using a Simplified Testing Approach

Research conducted within the EU funded project: r-LightBioCom

Andrew Harrison / 08.07.2025

German Aerospace Center (DLR) - Institute of Vehicle Concepts (FK)

Funded by the European Union

Funded by the European Union under Grant Agreement Project No 101091691. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. The European Union cannot be held responsible for them."

r-LightBioCom Summary

Project summary and goals

Andrew Harrison, andrew.harrison@dlr.de

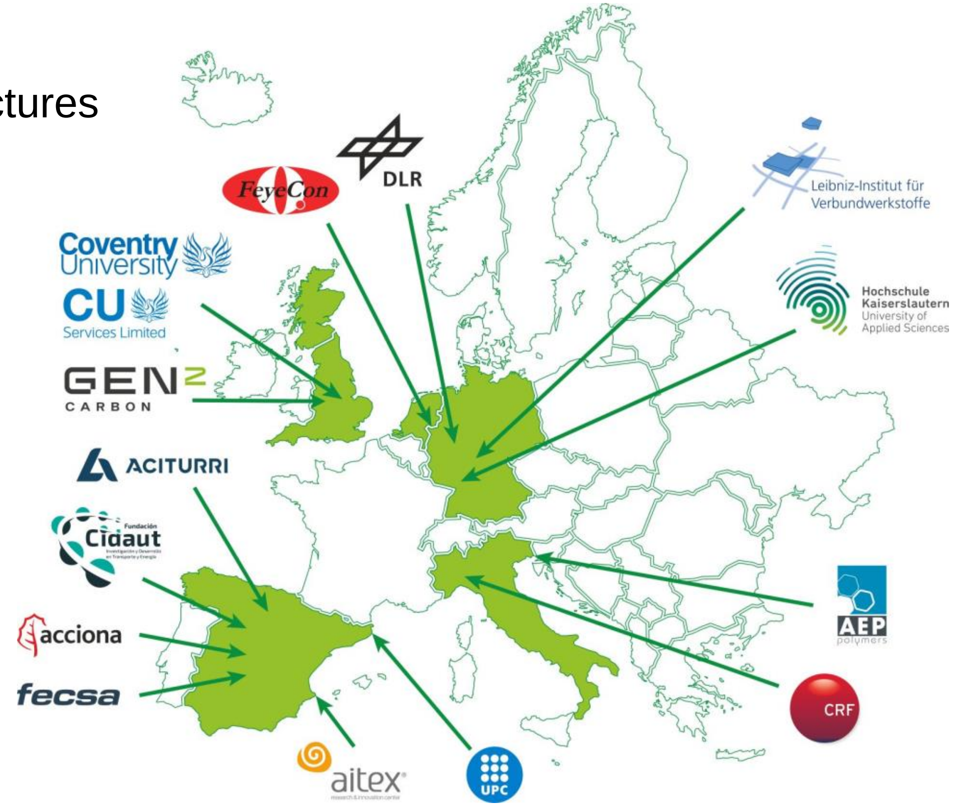
Funded by
the European Union

r-LightBioCom Overview

New bio-based and sustainable **R**aw Materials enabling Circular Value Chains of High Performance **Light**weight **BioCom**posites

Topic:	HORIZON-CL4-2022-RESILIENCE-01-11 Advanced lightweight materials for energy efficient structures
Type of action:	Research and Innovation Action (RIA)
Partners:	15 partners
Coordinator:	AITEX
Start date:	01/01/2023
End date:	30/06/2026
Project no.:	101076868

https://cordis.europa.eu/project/id/101091691



Andrew Harrison, andrew.harrison@dlr.de

Funded by the European Union

r-LightBioCom

r-LightBioCom Concept

Project Summary

New materials and technologies

Development of **new bio-based resins, additives, and formulations** for HPC

New HPC components based on sustainable textile products and bio-resins

New **fast curing technologies** for r-LightBioCom's HPC family

Sustainable-by-design framework

Development of **new recycling technologies** for resin and fibre components

Life cycle assessment (LCA)

optimization framework for composite modelling , sustainability and validation

Use case validation

Validation of r-LightBioCom composites in use cases: Automotive, infrastructure, aeronautics

Andrew Harrison, andrew.harrison@dlr.de

Funded by the European Union

Research Group Overview

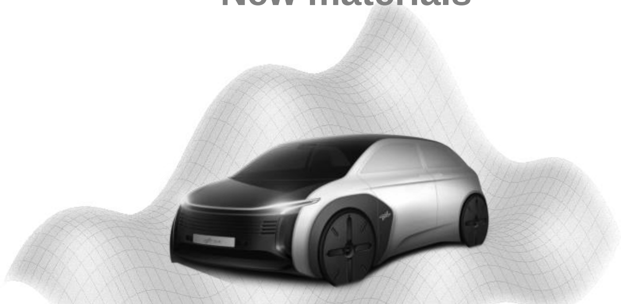
Structural optimization and integrated safety

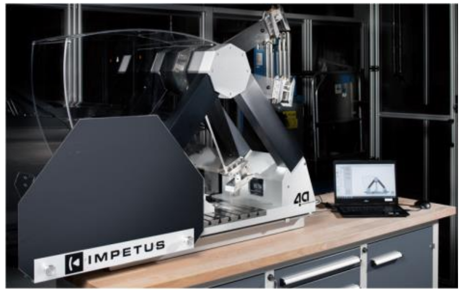
Integrated safety

Material descrption

New materials

Laboratory for automated material card calibration





Structural optimization
Integrated safety

Requirements

Optimizer

Requirements

Algorithms

New Optimization algorithms

Andrew Harrison, andrew.harrison@dlr.de

Funded by
the European Union

r-LightBioCom

R-LightBioCom: Methods and Tools

Creation of CEO, an optimization framework for composite modelling , sustainability and validation

Material Development

- Bio-based nanomaterials
- Bio-based resin
- Bio-based Intermediates
- Sustainable / recycled fibres
- Processing Technology
- …

Material Data

- Composition (bio-content)
- Mechanical Characterization
- Physical Characterization
- Chemical Characterization
- Environmental Durability
- Flammability
- …

Material Databank

- Material Data
- Production Data
- Characterization Data
- Ecological Footprint
- Production Costs

Coupled Ecological Optimization (CEO) Framework

- Numerical Material representation
- Automated Processes
- Use-case (application) description
- Material Databank

METHODS & TOOLS
for a standardised, holistic sustainable high-performance composite design, modelling and systematic optimization

Andrew Harrison, andrew.harrison@dlr.de

Funded by the European Union

r-LightBioCom

Methods and Tools

Characterisation Process

Andrew Harrison, andrew.harrison@dlr.de

Funded by
the European Union

Methods and Tools: Automated Material Characterization Process

Process Chain

Materials

- (Fiber Reinforced) Plastics
- Lightweight Metals
- Foam - / Core Materials
- …

Pendulum

Coupon tests

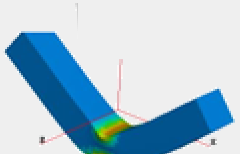
Test results

Quasi-static coupon tests

Conditioning

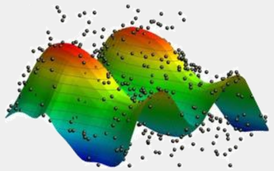
Automated Material card generation depending on conditioning

Simulation



LS-DYNA©
Pam-Crash©

Optimization



Experimental material characterization

Automated material card calibration

Funded by the European Union

Methods and Tools: Automated Material Characterization Process

General Process flow for Foam

Import compression data

Quasi-Static and Dynamic

↓

Generate Parameter Model for response curve

4a Foam Model for main characteristics	Johnson-Cook Strain rate dependency

↓

Run surrogate optimisation method

Sampling DOE	Meta-model generation	Optimisation: FE-Solver response to Test-response

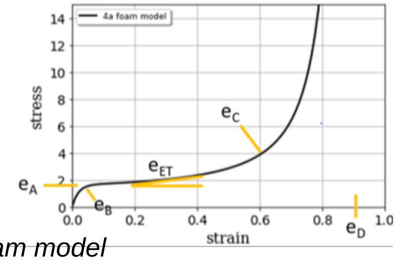
↓

Validation Simulation

↓

Export material card and validation report

$$e_A \cdot \left(1 + e_{ET}\cdot\varepsilon_{el} - e^{\frac{-\varepsilon_{el}}{e_B}}\right) \cdot \frac{e^{\frac{e_D}{e_D - (\varepsilon_{el})^{e_C}}}}{e}$$



4a engineering foam model

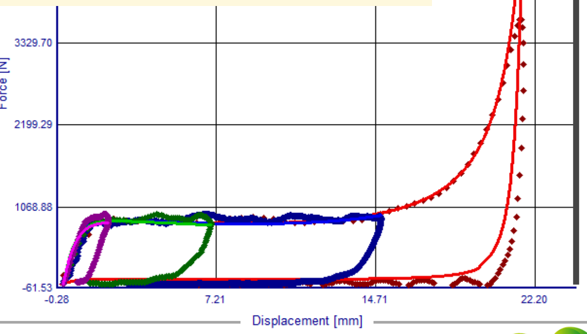
$$1 + \frac{1}{V_P}\cdot\log\left(\frac{\max(\dot{\varepsilon},\ V_{\dot{\varepsilon}})}{V_{\dot{\varepsilon}}}\right)$$

Johnson-Cook Rate Dependency

***MAT_083 (FU_CHANG_FOAM)**

Experiment

Simulation



LS-DYNA

Methods and Tools: Automated Material Characterization Process

Material Implementation into automated process: LS-DYNA availability

MAT063: Crushable Foam

- Model for foams which undergo large deformations
- Multiple different yield surface formulations
- Non-reversable deformation
- No strain-rate behavior

MAT057: Low Density Foam

- Model for highly compressible low density foams. Mainly applied in seat cushions and Side Impact Dummies. Could possibly be applied to foams like aerogels.
- Rate effects are optional and are defined through a relaxation function. This model also includes hysteretic unloading.

MAT163: Modified Crushable Foam

- This material is an extension of MAT063, with the addition of strain-rate behavior
- Definition of tables of yield stress vs volumetric strain curves
- Non-reversable deformation
- Based on yield surface formulation

MAT026: Honeycomb

- Model dedicated to modeling honeycomb and foam materials with anisotropic behavior. This is done by defining elastoplastic behavior for all normal and shear stresses, which are fully uncoupled.
- Optional rate effects defined through a load curve.

Methods and Tools: Automated Material Characterization Process

Material Implementation into automated process: via VALIMAT *(4a engineering)* - User-Defined Material Card

```
<?xml version="1.0" encoding="UTF-8"?>

<matcard xmlns="urn:4a:impetus:matcard"
 xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
 xsi:schemaLocation="urn:4a:impetus:matcard matcard.xsd"
name="*MAT_LOW_DENSITY_FOAM (*MAT_057)" A_MAT_TYPE_ELASTI
<matcard cases>
<matcard vars>
<matcard output>
<damage cases>
<damage vars>
<damage output>
</matcard>
```

- Encoding information
- Comments
- XML Schema Definition
- Variables for the whole material card
- Specific case definition
- User defined case variables
- What is written into the material.inp file
- Damage specific cases & variables
- What is written into the material.inp file

Generates input for Parameter Optimization

Mechanical Testing

Set-up and Input to Paramter Model

Andrew Harrison, andrew.harrison@dlr.de

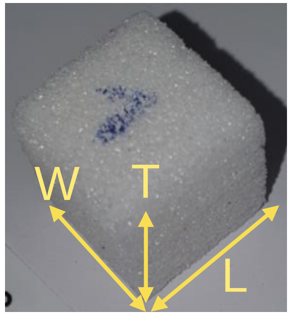
Funded by
the European Union

Mechanical Testing

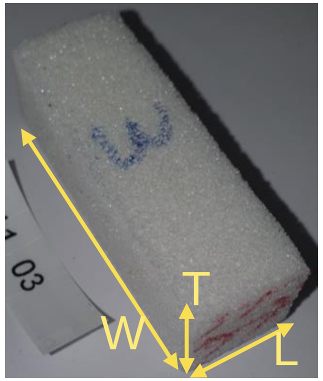
Specimen and Test set-up

Provided by: Leibniz Gemeinschaft, Leibniz-Institut für Verbundwerkstoffe

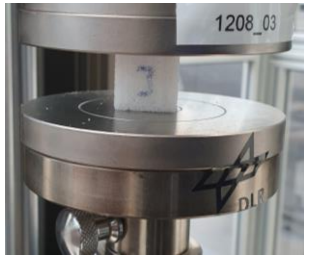
Bio-Epoxy Foam (developed by IVW in r-LightBioCom)

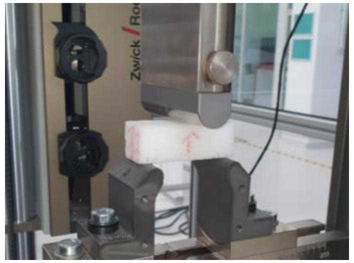


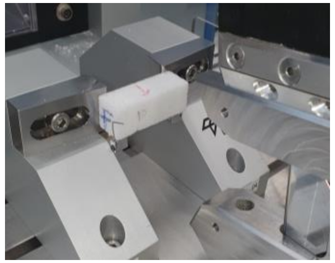
Compression Specimen
- Length: 20mm
- Width: 20mm
- Thickness: 20mm



3-Point bending Specimen
- Length: 20mm
- Width: 60mm
- Thickness: 20mm







Test Type	Speed(s) (m/s)	Fin radius (mm)	Support Radius (mm)	Support Distance (mm)
Compression	9.9E-6, 1, 2.5, 3	-	-	-
3-Point Bending	3.3E-6, 0.5, 1, 1.5	QS: 10 DYN: 5	QS: 5 DYN: 2	50

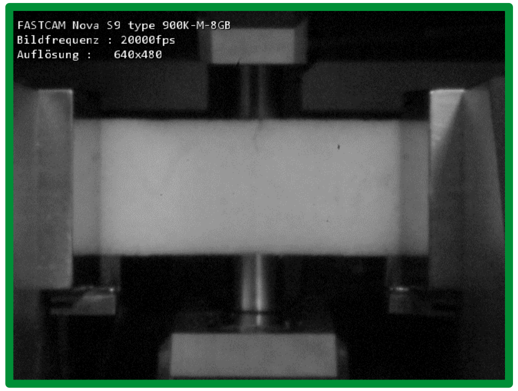
Funded by the European Union

Mechanical Testing

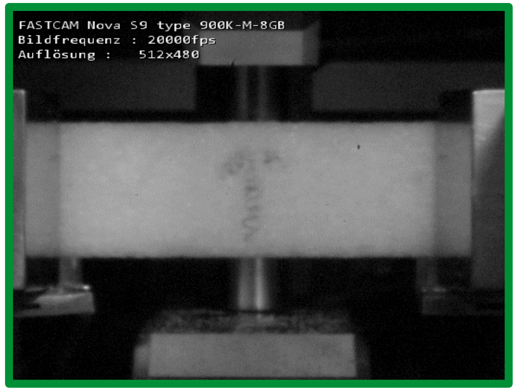
Results Overview: Dynamic

3-Point Bending Test (IMPETUS)

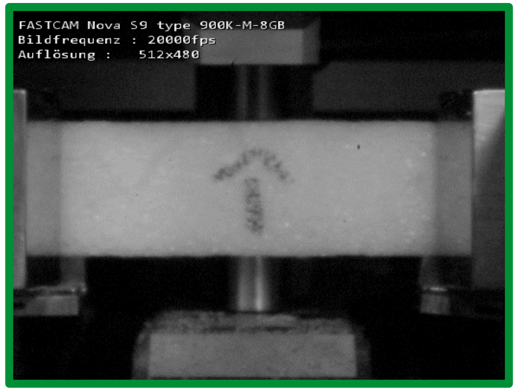
0.5 m/s



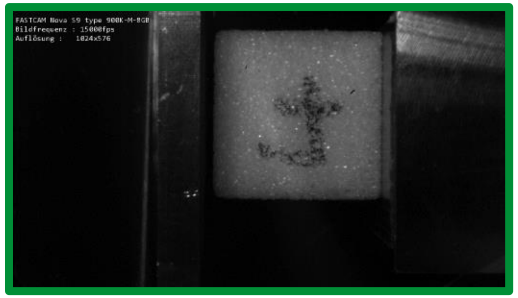
1 m/s



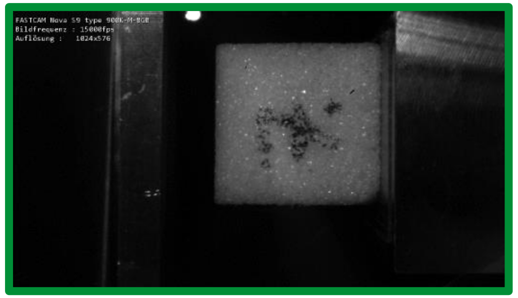
1.5 m/s



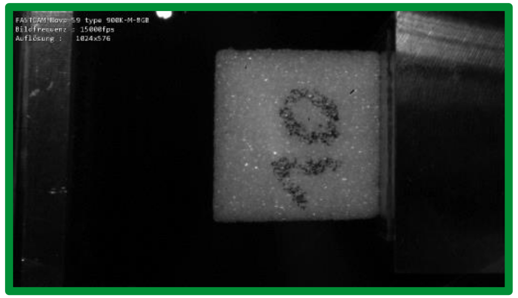
Compression Test (IMPETUS)



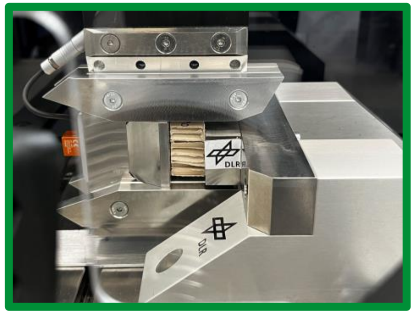
1 m/s



2.5 m/s



3 m/s



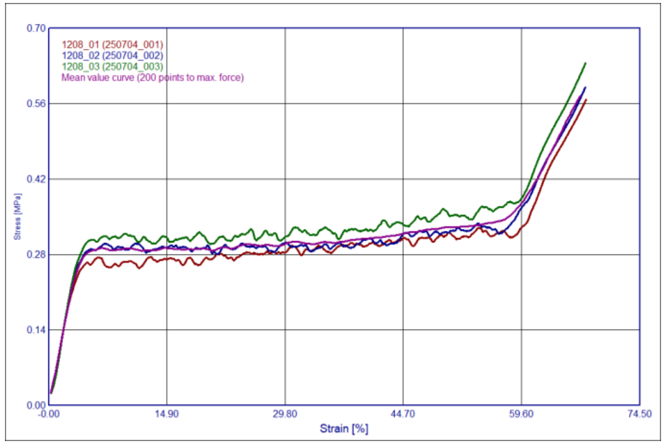
Andrew Harrison, andrew.harrison@dlr.de

Funded by
the European Union

r-LightBioCom

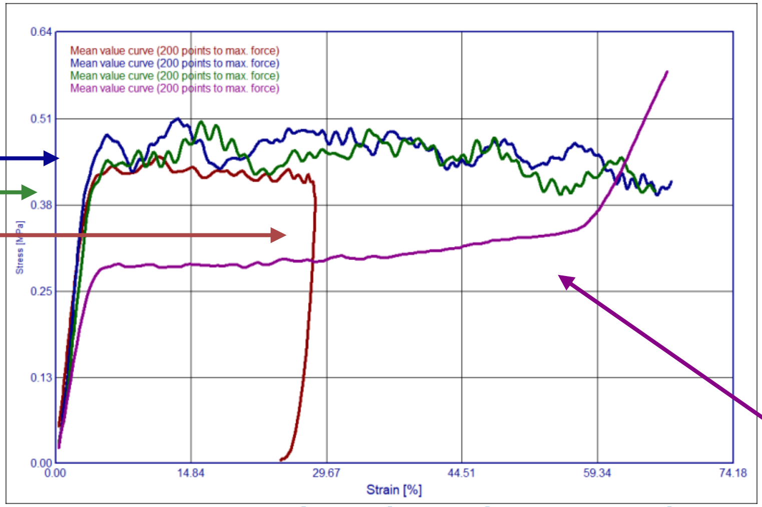
Mechanical Testing

Results Overview

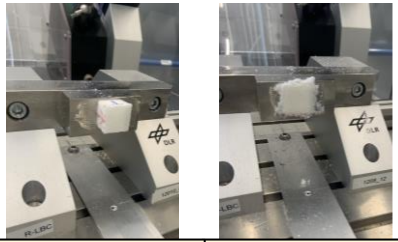


Quasistatic compression

Dynamic (pendulum) response



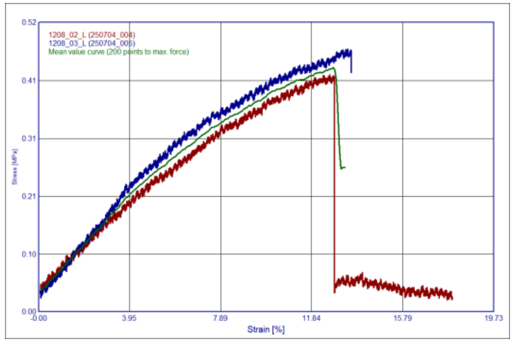
Compression (varying rates)



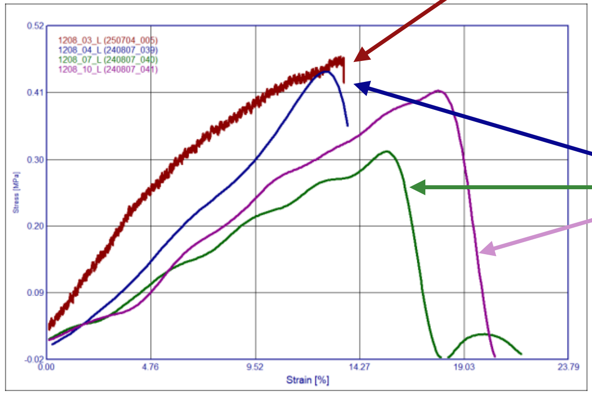
Pre-test	post-test

Quasistatic (UPM) response

Pre-test	post-test



Quasistatic 3-pt Bending



Dynamic (pendulum) response

3-pt Bending (varying rates)

Andrew Harrison, andrew.harrison@dlr.de

Funded by the European Union

r-LightBioCom

Numerical Calibration

Bio-Epoxy Foam using MAT_163

Andrew Harrison, andrew.harrison@dlr.de

Funded by
the European Union

16

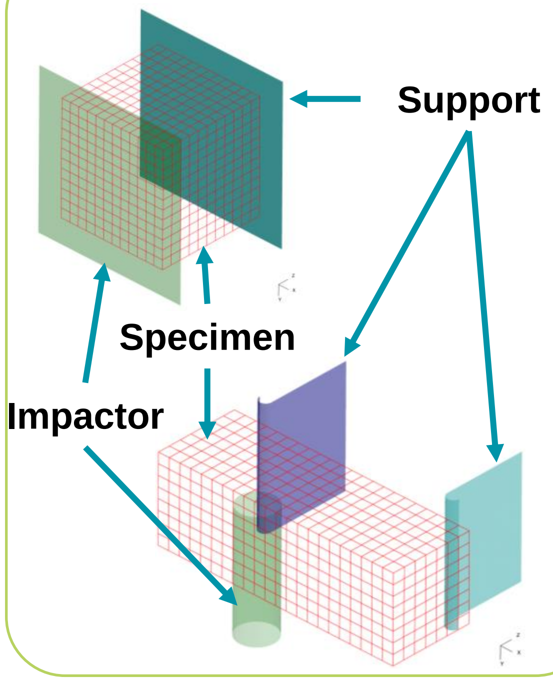
Numerical Calibration

Calibration process for compression and 3-point bending

Finite Element Input:

- 3mm Solid element
- ELFORM = 2
  - Fully Integrated solid element
- Initial velocity (V_0) for dynamic tests
- Pescribed motion (V) for quasistatic tests
- Simplified Test representation
- Time-scaling (quasistatic only)

Optimization Model



Parameter identification stages:

- Quasistatic compression curve only, using 4a Foam Model
- Integrate dynamic compression curves for rate effects (Johnson-Cook)
- Use design variables with small variance for tensile failure criterion with Bending cases
- Failure and damage parameters for compression
- Validation simulation

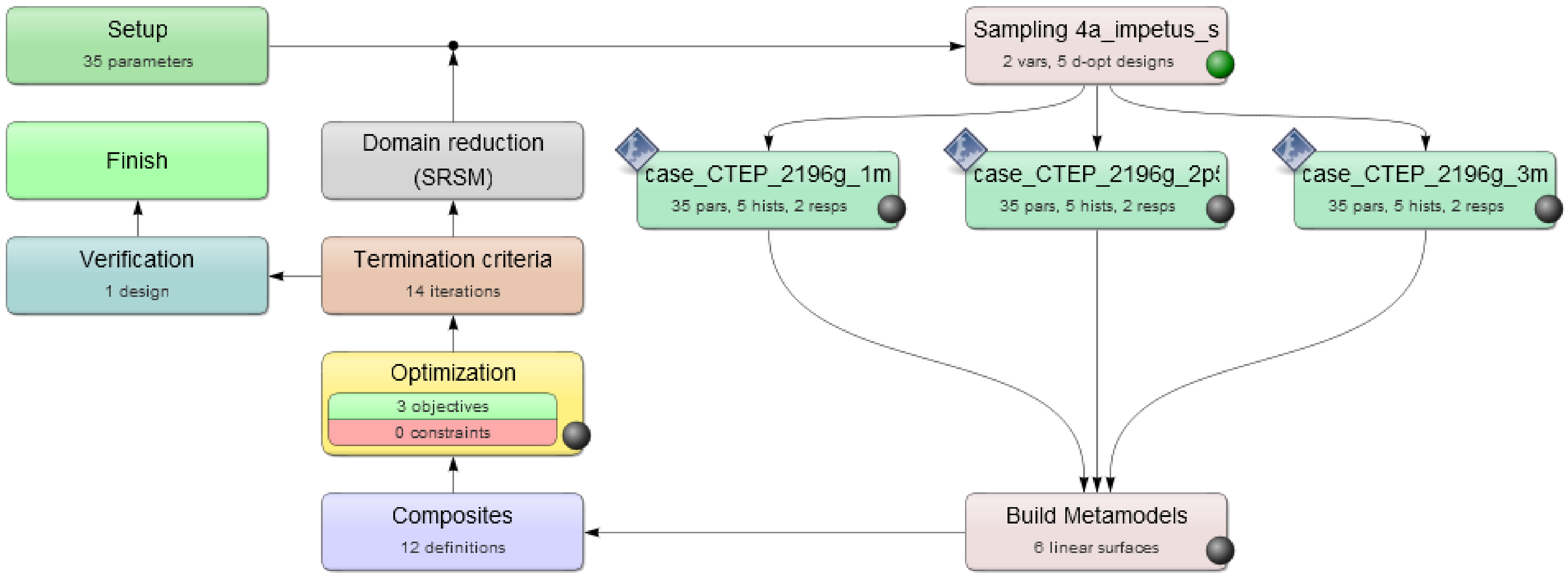
Andrew Harrison, andrew.harrison@dlr.de

Funded by the European Union

r-LightBioCom

Numerical Calibration

Classical Calibration process loop in LS-OPT

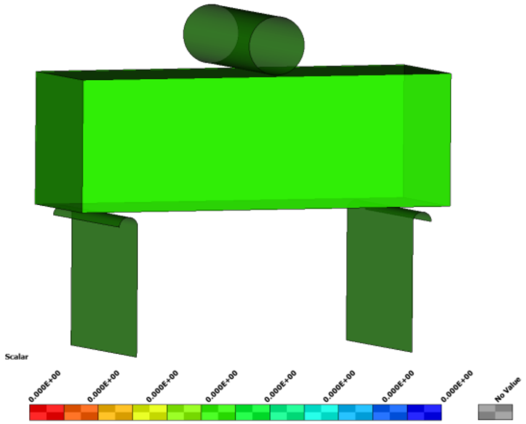


Andrew Harrison, andrew.harrison@dlr.de

Funded by
the European Union

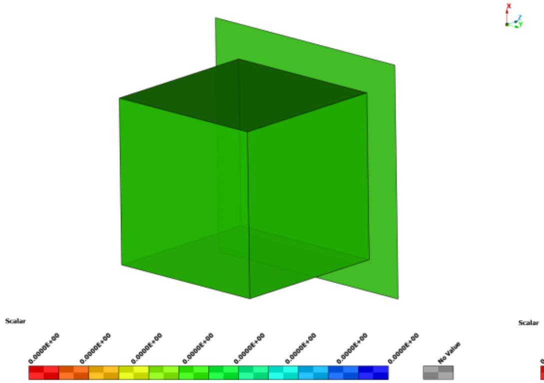
Numerical Calibration

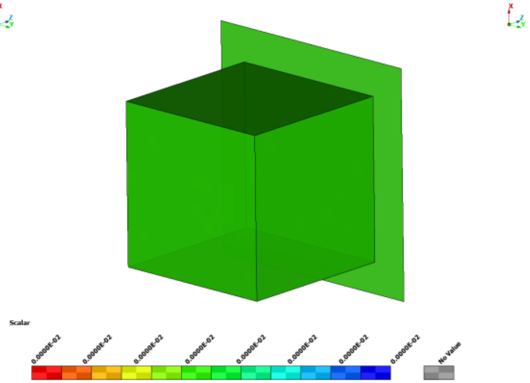
Calibration Results: LS-DYNA

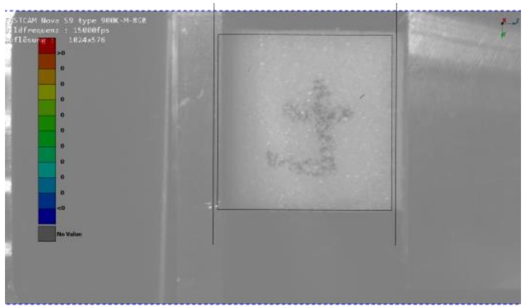


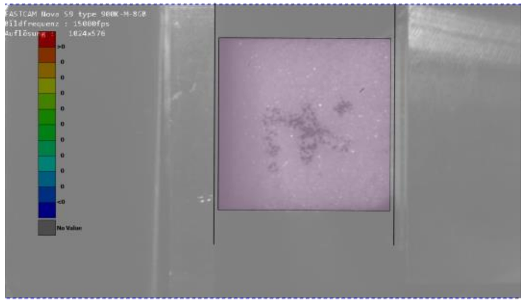
1 m/s

2.5 m/s



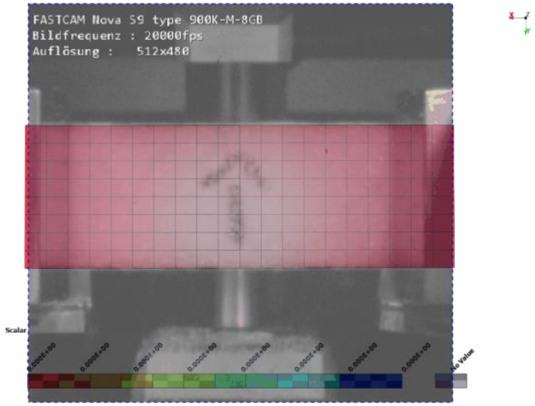






Tension failure (*MAT_ADD_EROSION), Criteria:

- maximum principal stress
- plastic strain failure criteria.



1.5 m/s

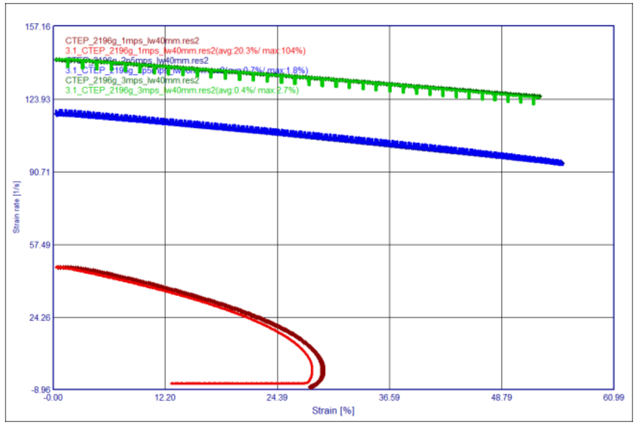
Andrew Harrison, andrew.harrison@dlr.de

Funded by the European Union

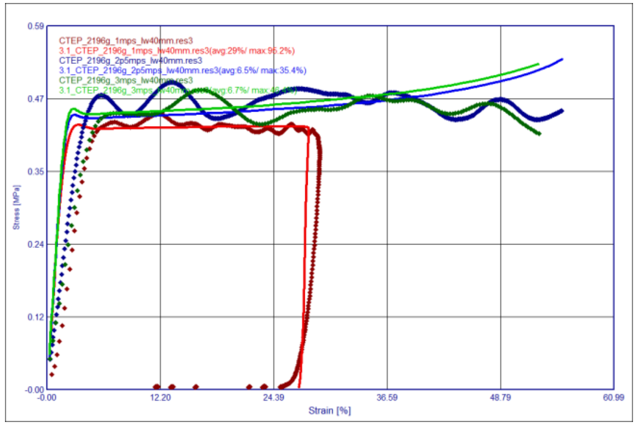
r-LightBioCom

Numerical Calibration

Calibration Results: LS-DYNA

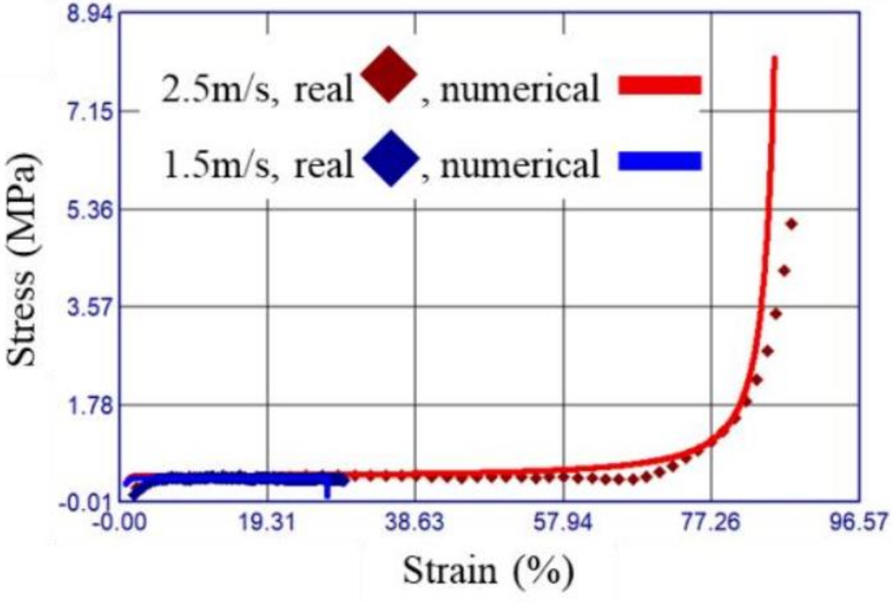


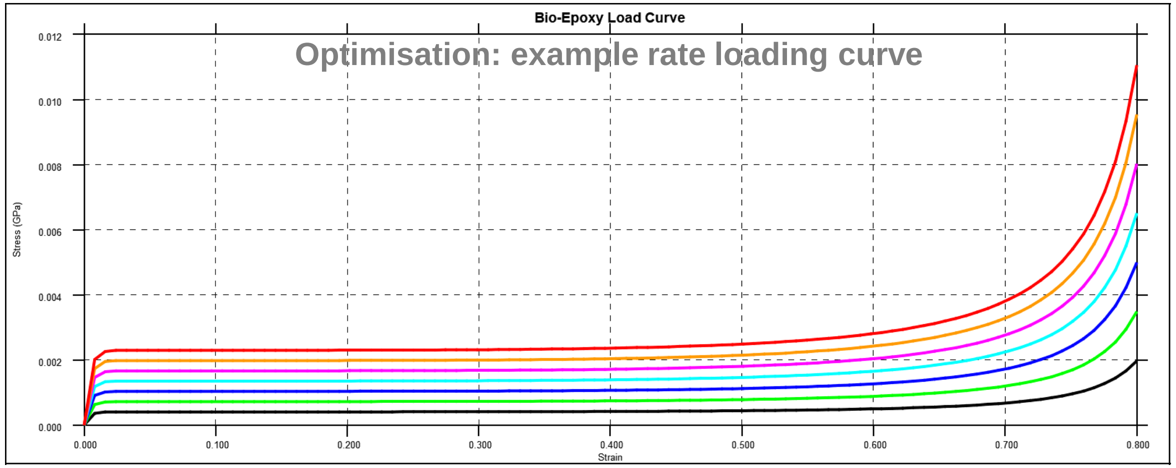
Optimisation: (MAT_163) rate curve



Optimisation: (MAT_163) σ vs. ε

Bio Epoxy Foam (MAT_063)



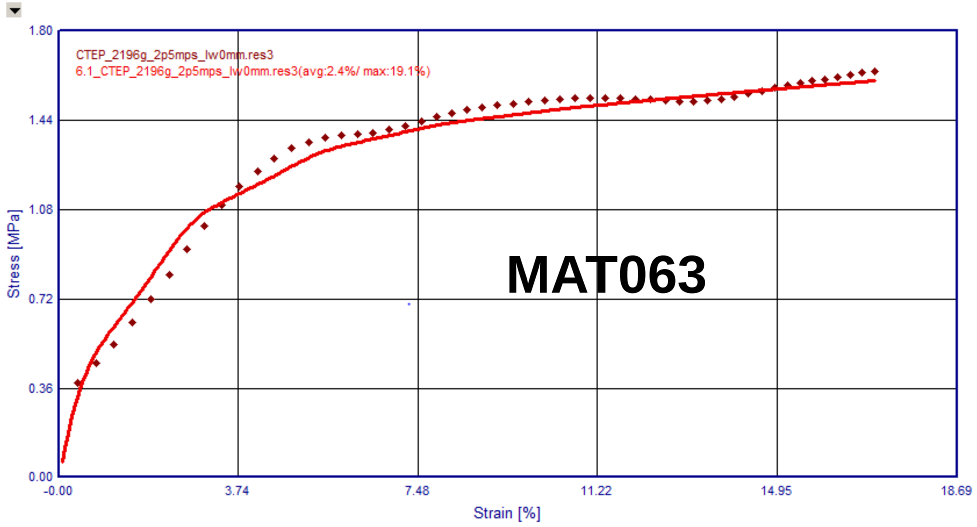


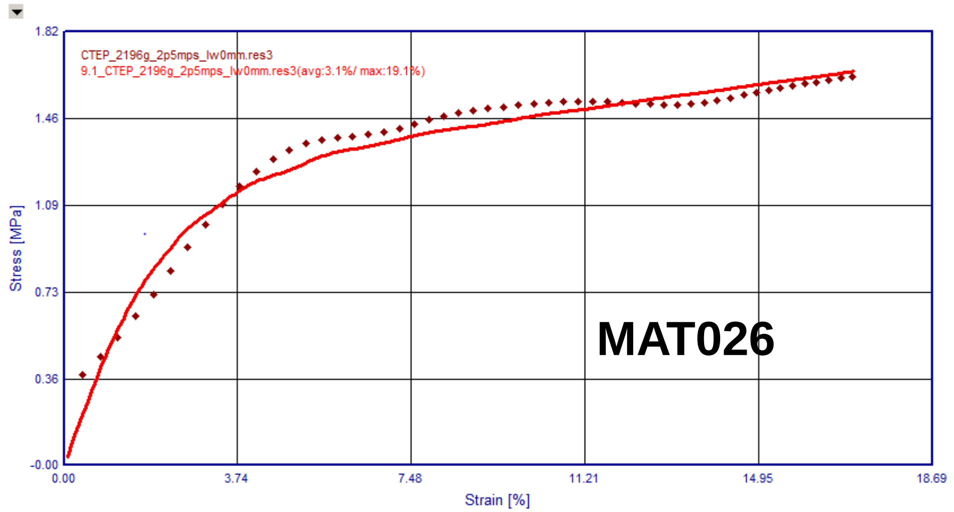
Optimisation: example rate loading curve

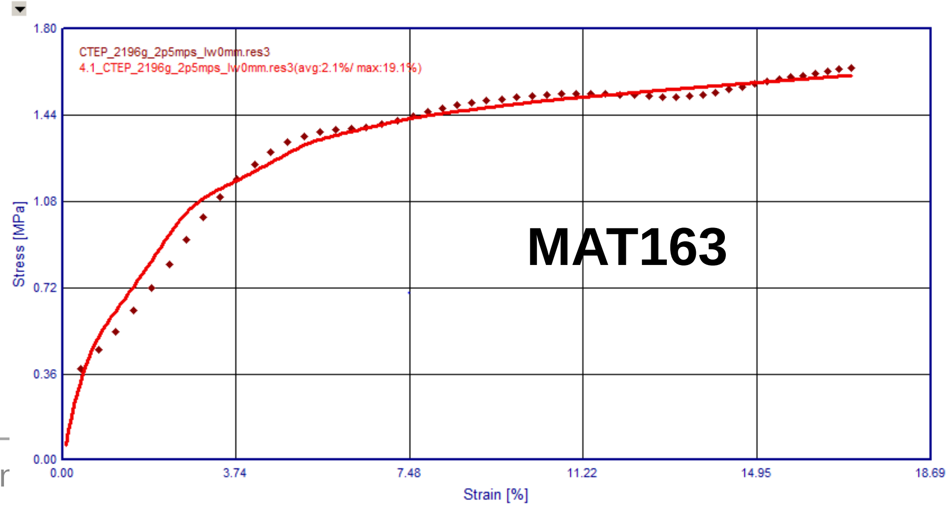
Numerical Calibration Examples

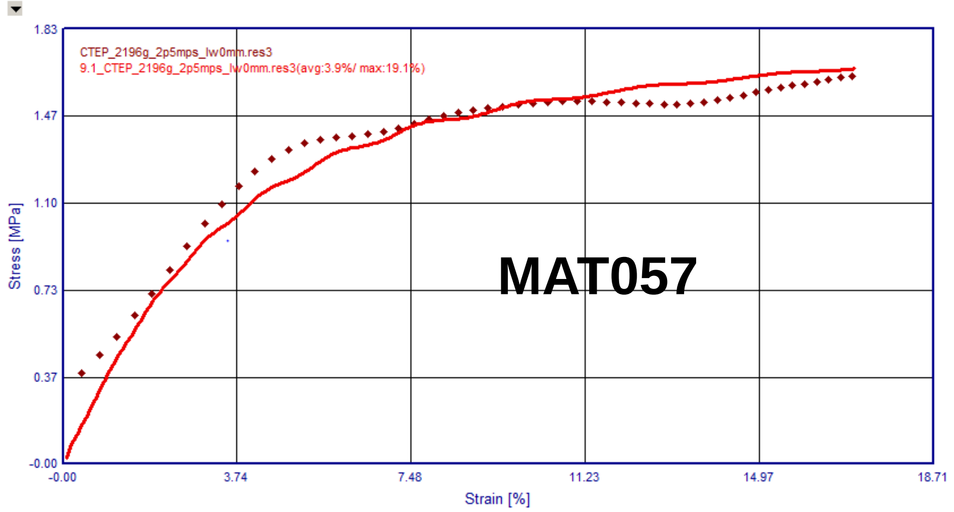
Calibration Results: LS-DYNA

2.5mps Compression Test - Covestro





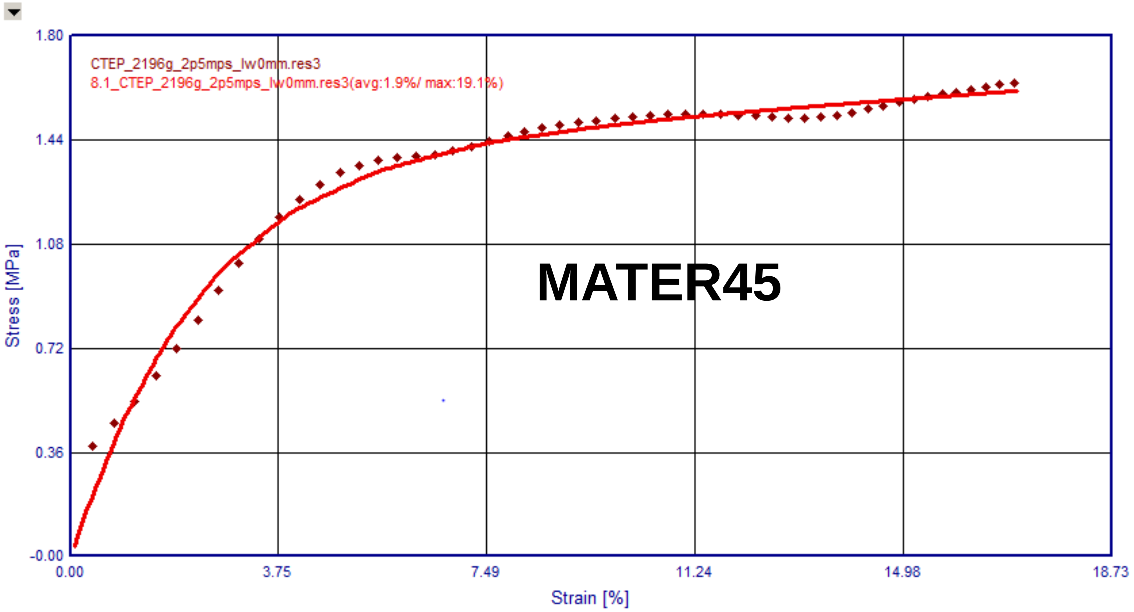


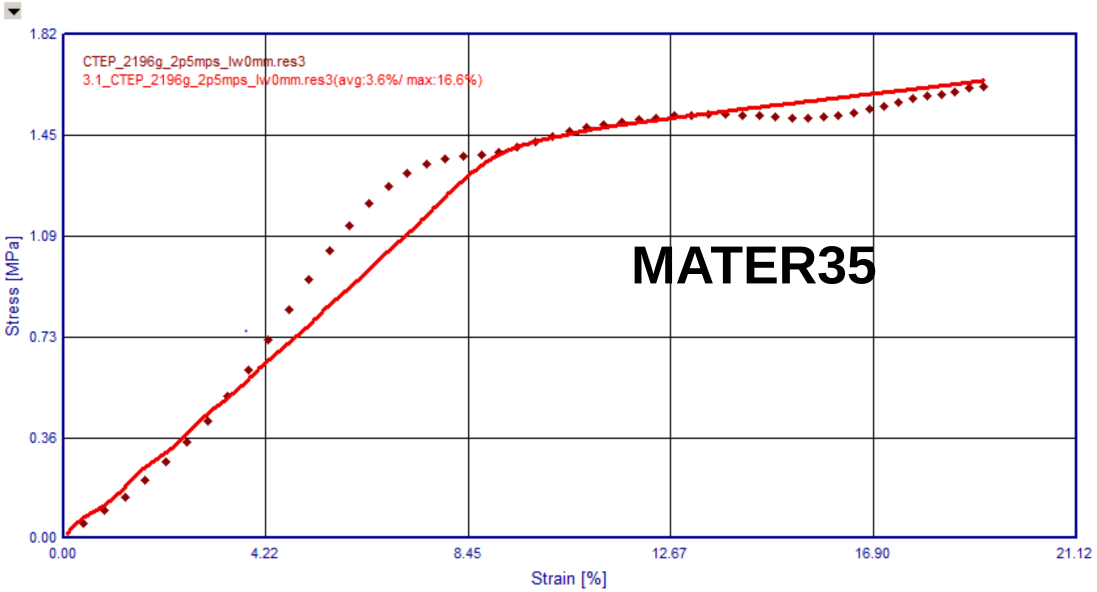


Numerical Calibration Examples

Calibration Results: VPS - PAMCRASH

2.5mps Compression Test - Covestro





Andrew Harrison, andrew.harrison@dlr.de

Funded by
the European Union

r-LightBioCom

Automated Numerical Calibration

Outlook and Next steps

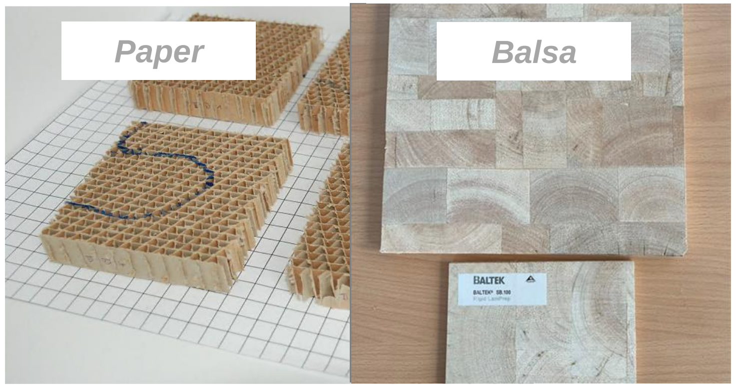
Outlook

- Good alignment between test and numerical results in each solver (LS-DYNA, PAMCRASH)
  - Material selection vital
- Simplified Characterisation approach provided enough data for key mechanical properties in crash use-cases
- Implementation of failure/erosion laws (erosion and DIEM)

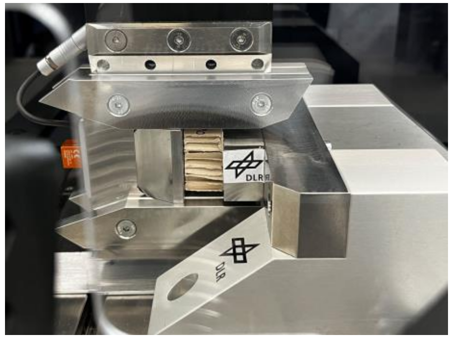
Next Steps:

- Exploring methods to ascertain key properties of core materials with less number/demanding tests
- Validating further properties of automated material calibration (e.g. Honeycomb failure)
- Generating numerical representation of r-LightBioCom core materials (Balsa, Hemp, rCF…)
- Improving robustness of ROM approach (element regularization)

Test specimens



Dynamic compression tests



Metals | Plastics

*

Funded by the European Union

*ecoinvent

r-LightBioCom

r-LightBioCom

Thank you for your attention

Project Coordinator

Aitex

Info-r-LightBioCom@dlr.de

Technical Manager

Eduardo Fages

efages@aitex.es

Dissemination Manager

Dorothea Weber

dorothea.weber@dlr.de

Visit us

Project website

www.r-LightBioCom.eu

Follow us

LinkedIn

https://www.linkedin.com/company/rlightbiocom/

Twitter

https://twitter.com/rLightBioCom

Funded by the European Union

Funded by the European Union under Grant Agreement Project No 101091691. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. The European Union cannot be held responsible for them.”