

Mechanical Tests for Foldcore Base Material Properties

CompTest 2008

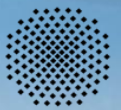
Composite Testing & Model Identification

20 – 22 October 2008

Dayton, Ohio, USA

Sebastian Fischer, Klaus Drechsler
Universität Stuttgart
IFB – Institut für Flugzeugbau
70569 Stuttgart, Germany

Sebastian Kilchert, Alastair Johnson
German Aerospace Center DLR
Institute of Structures and Design
70569 Stuttgart, Germany



Mechanical Tests for Foldcore Base Material Properties

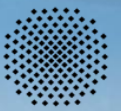
The work presented in this publication was performed within the scope of the EU-FP6-Project “Cellular structures for impact performance” (CELPACT)

Objectives:

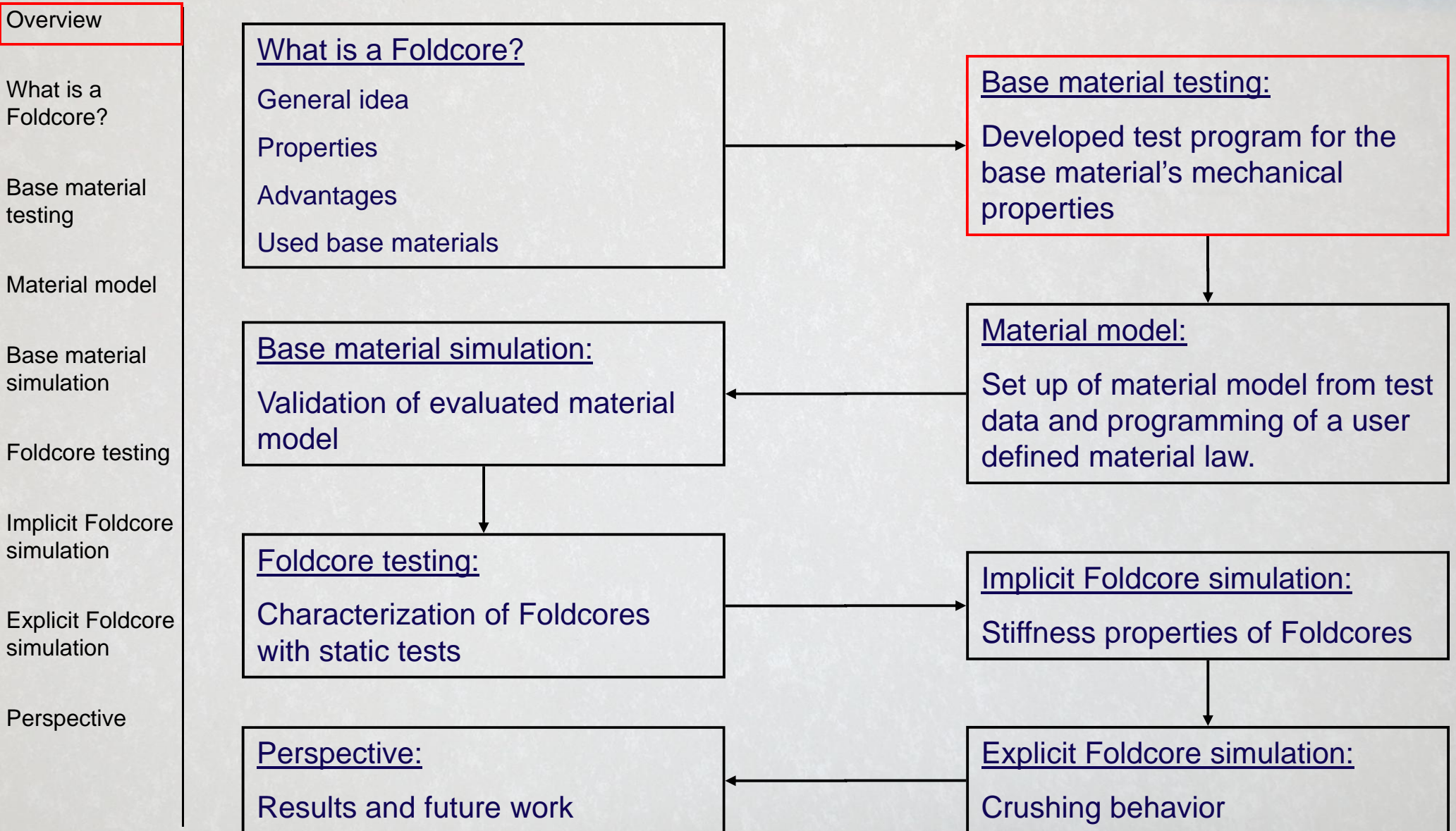
Investigate the material behavior of resin impregnated aramid fiber paper, which is used as base material for Foldcore production.

Develop a test program for resin impregnated aramid fiber paper which allows the identification of all relevant parameters.

Set up a material model for resin impregnated fiber paper which can be implemented in a FE-program.



Overview



Overview

What is a Foldcore?

Base material testing

Material model

Base material simulation

Foldcore testing

Implicit Foldcore simulation

Explicit Foldcore simulation

Perspective

What is a Foldcore?
General idea
Properties
Advantages
Used base materials

Base material testing:
Developed test program for the base material's mechanical properties

Material model:
Set up of material model from test data and programming of a user defined material law.

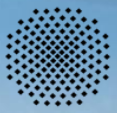
Base material simulation:
Validation of evaluated material model

Foldcore testing:
Characterization of Foldcores with static tests

Implicit Foldcore simulation:
Stiffness properties of Foldcores

Explicit Foldcore simulation:
Crushing behavior

Perspective:
Results and future work

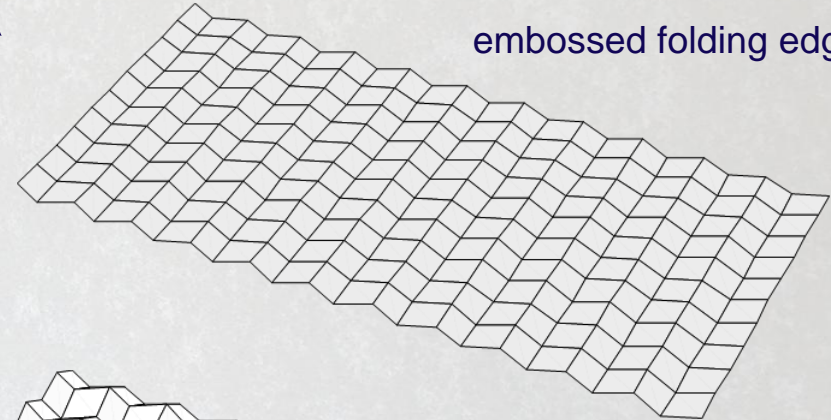


General Idea

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective

Fold a **planar** base material into a **three-dimensional** structure!

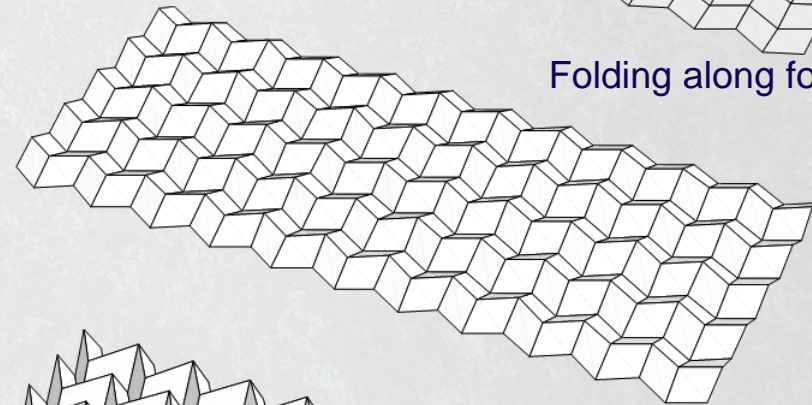
Planar base material with embossed folding edges



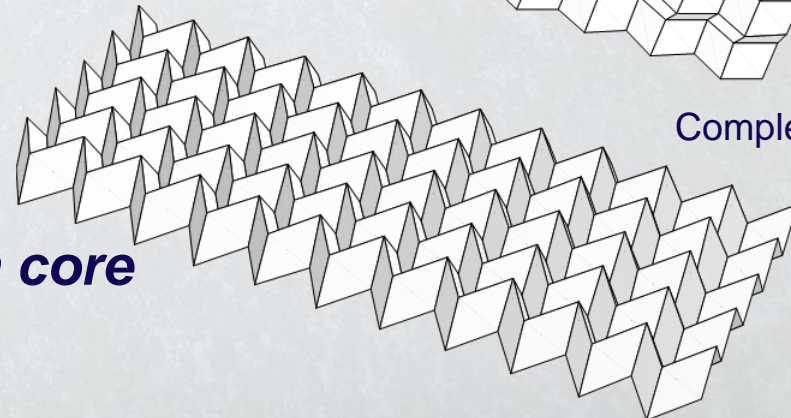
Use a **variety** of base materials, like:

- Thin metal sheets
- Plastic foils
- Paper-like materials
- Preimpregnated fiber materials

Folding along folding edges

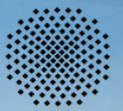


Complete Foldcore



Get a **structural sandwich core**





Mechanical Properties of Foldcores

→ **High strength and stiffness to weight ratios**

→ **Adjustable** mechanical properties due to unit cell geometry and base material

Overview

What is a Foldcore?

Base material testing

Material model

Base material simulation

Foldcore testing

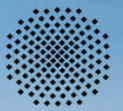
Implicit Foldcore simulation

Explicit Foldcore simulation

Perspective



Height:	15 mm
Compression strength:	1 MPa
Weight of sample:	9.5 g



Unit Cell Design

→ Unit cell geometry can be adjusted to boundary structure ***without*** additional ***mechanical finishing***

Overview

What is a Foldcore?

Base material testing

Material model

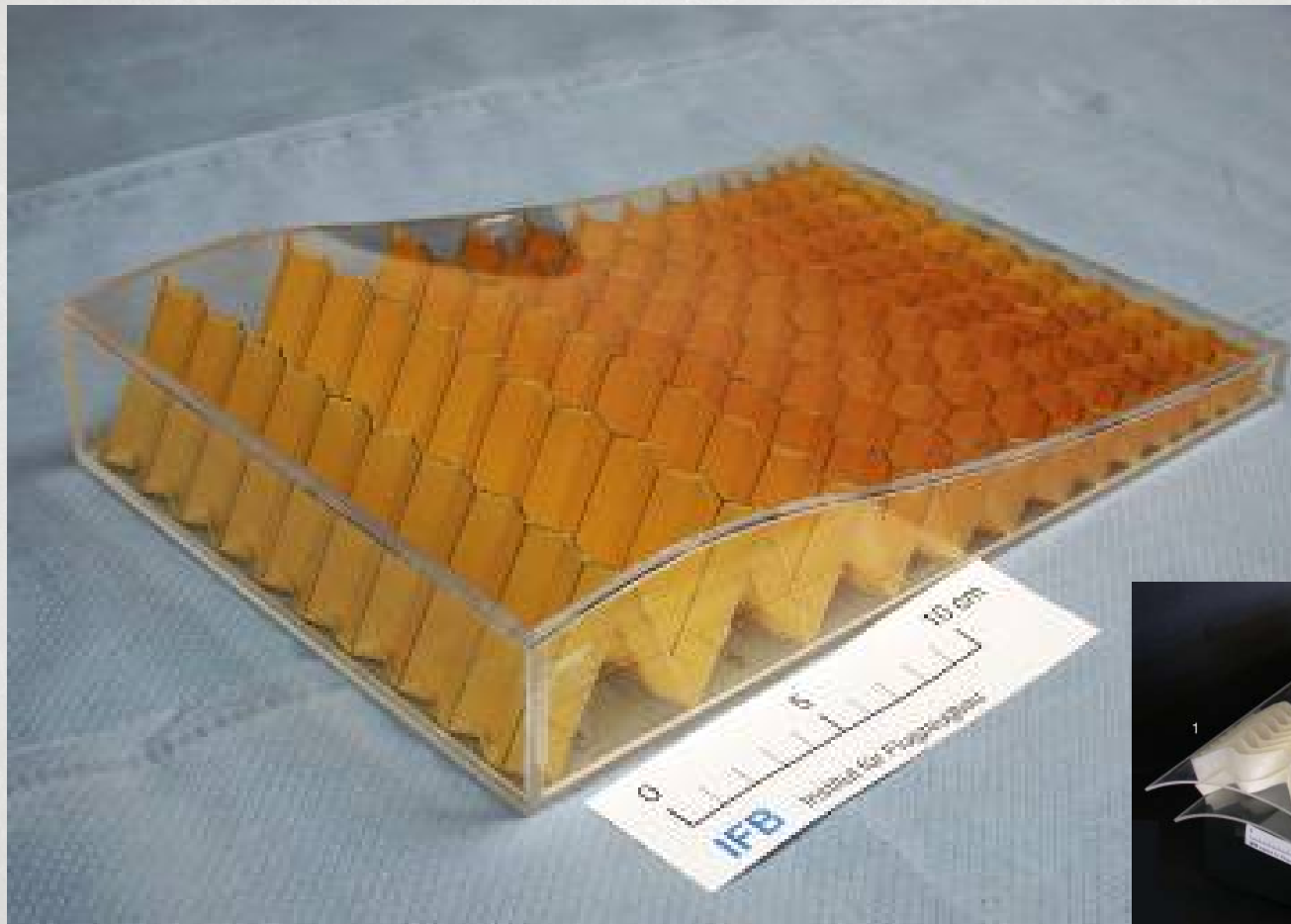
Base material simulation

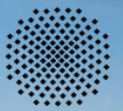
Foldcore testing

Implicit Foldcore simulation

Explicit Foldcore simulation

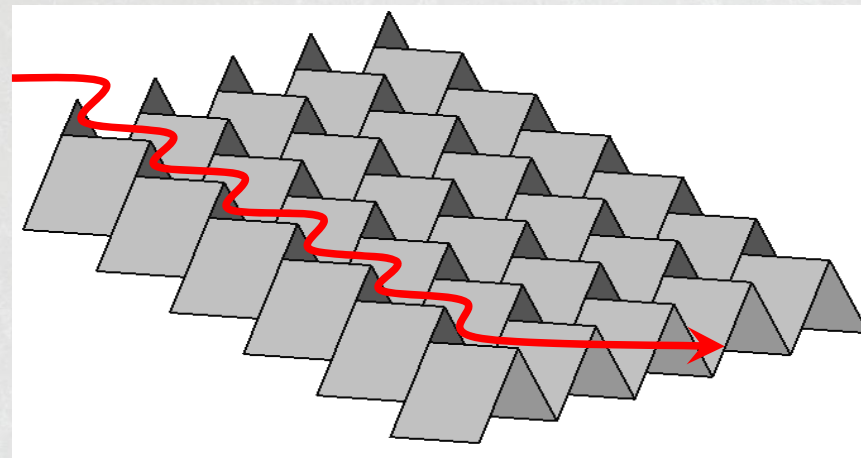
Perspective



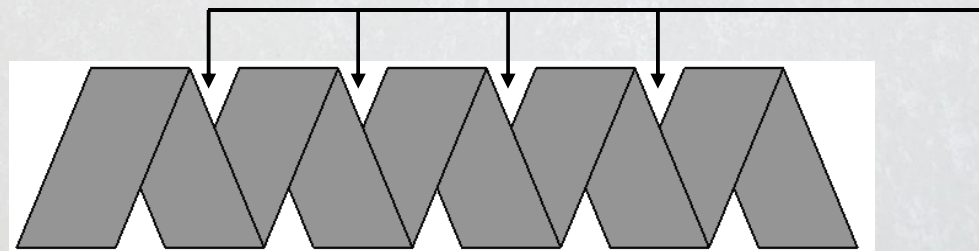


Multifunctional Aspects

→ Open channels in the core give the possibility for **venting**, fluid transport, active heating or cooling, ...
without using additional substructure



Principle of venting the Foldcore through open channels



- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective



Continuous Production

Overview

What is a Foldcore?

Base material testing

Material model

Base material simulation

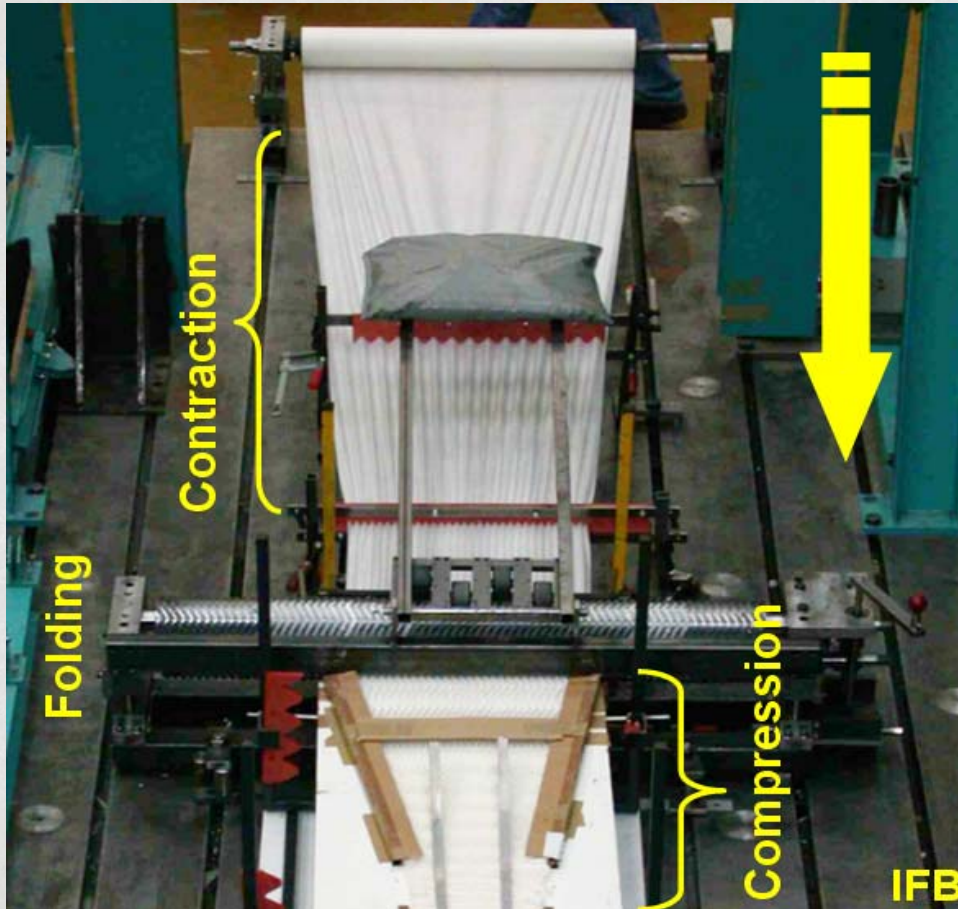
Foldcore testing

Implicit Foldcore simulation

Explicit Foldcore simulation

Perspective

→ Production in a continuous *process* is possible



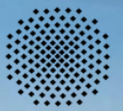
Prototype of Folding Machine

Proof of concept done with Folding Machine:

→ Foldcores can be manufactured continuously and therefore cheaply



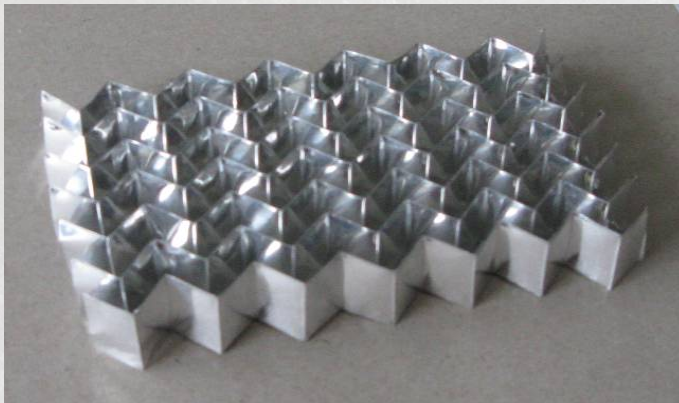
Continuously produced Foldcore



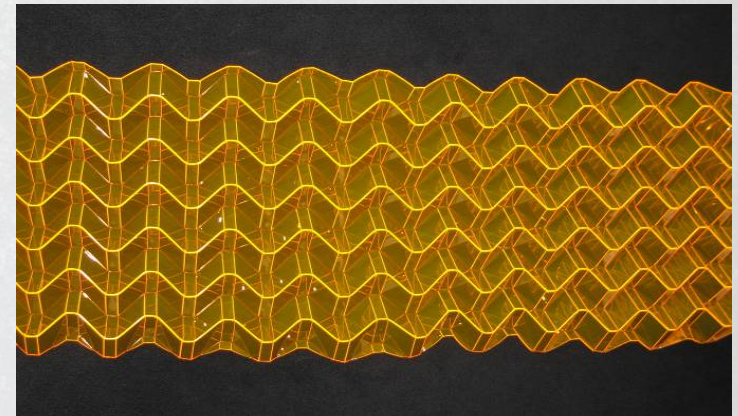
Base Materials

→ The production technology is open to a variety of different base materials

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective



Aluminum foils



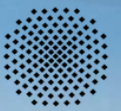
Plastic foils



Resin impregnated paper-like materials

Here: aramid fiber paper, impregnated with phenolic resin

→ **actual standard base material**



Aramid fiber paper – Standard Base Material

Overview

What is a Foldcore?

Base material testing

Material model

Base material simulation

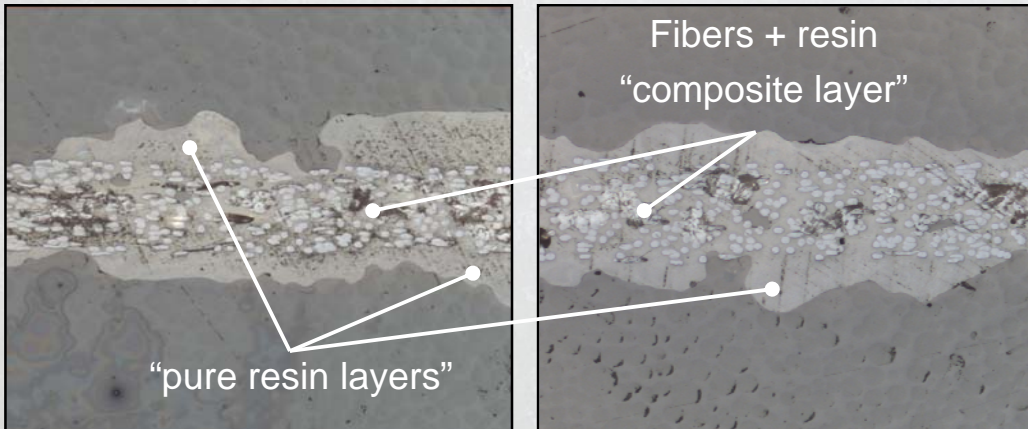
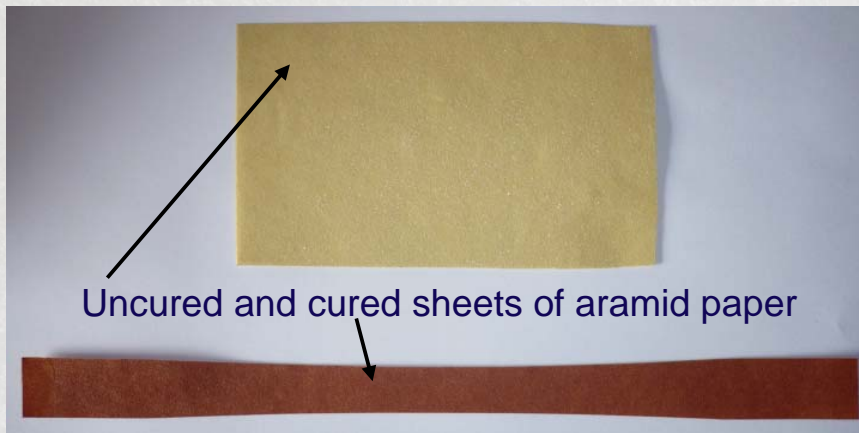
Foldcore testing

Implicit Foldcore simulation

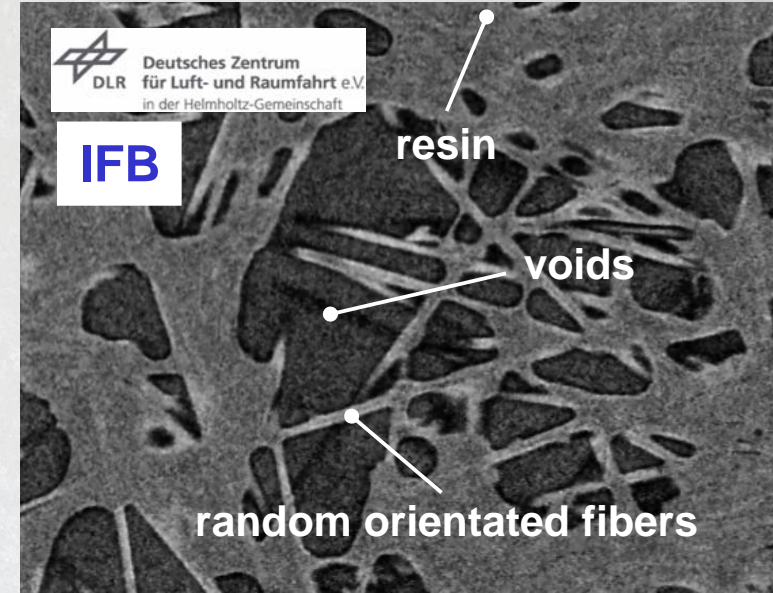
Explicit Foldcore simulation

Perspective

Microscopic and macroscopic views on resin impregnated aramid fiber paper



Polished cut image of aramid paper

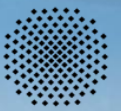


CT image of aramid paper

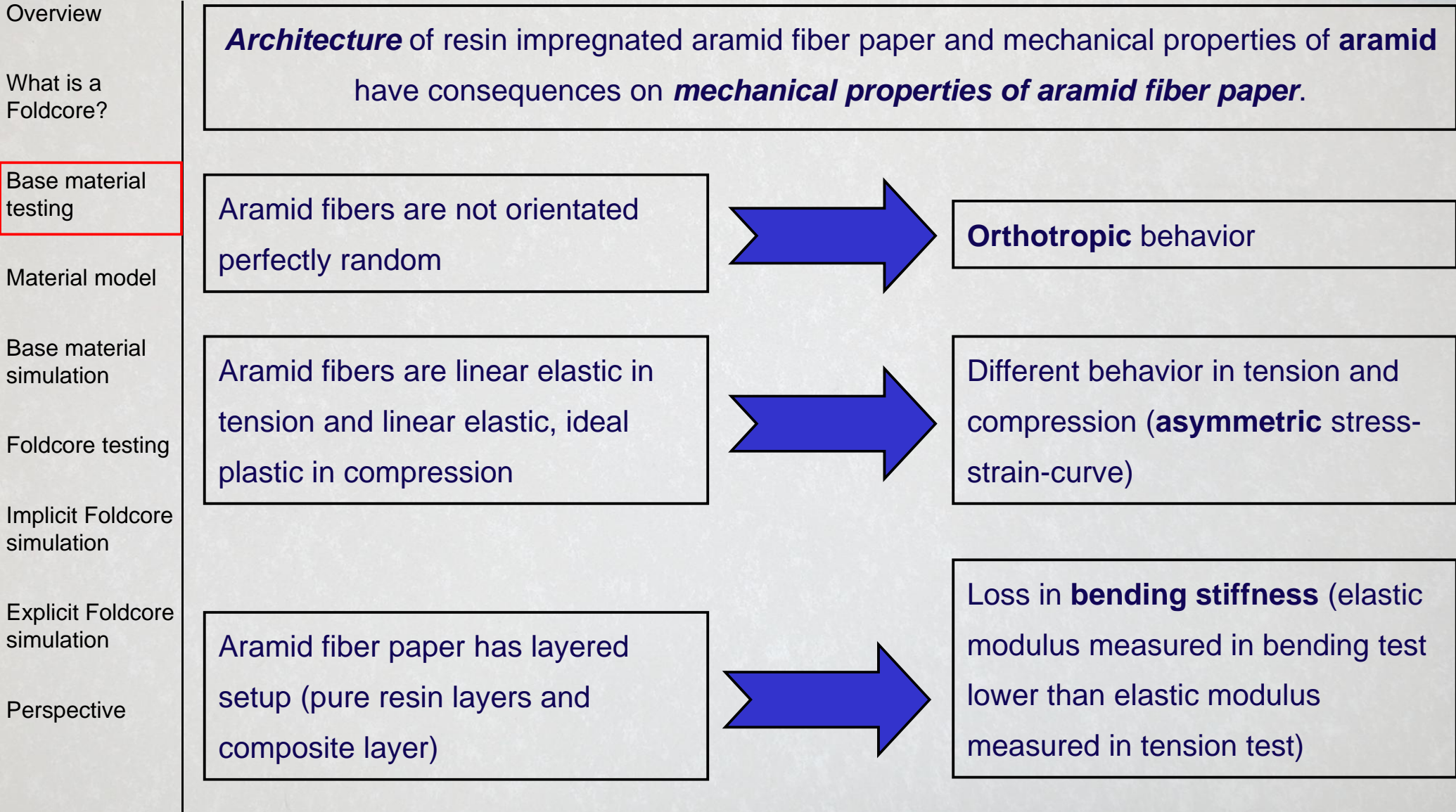
(CT image taken at DLR Stuttgart by Raouf Jemali)

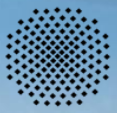


breaking edge

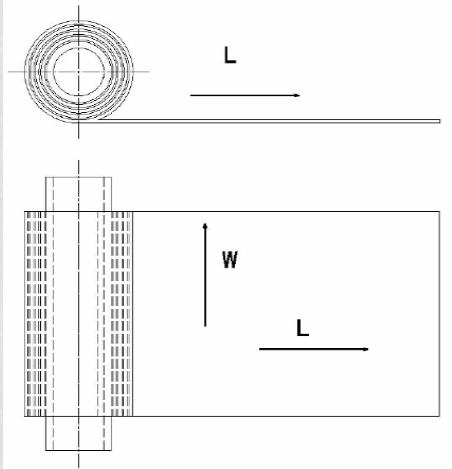
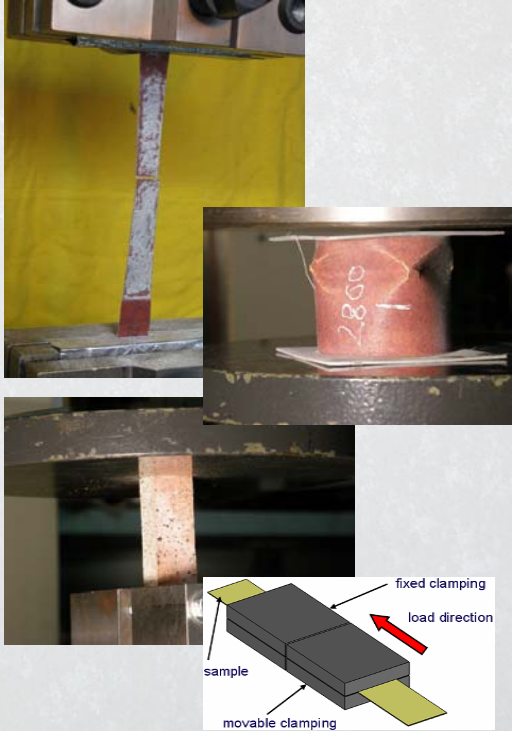
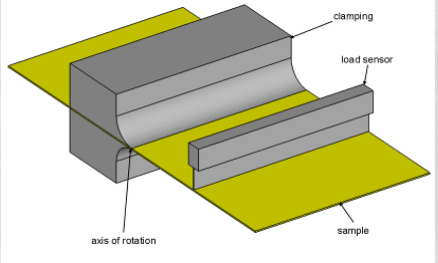
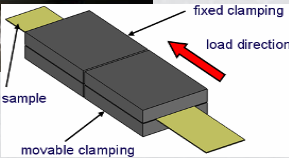


Aramid fiber paper – Standard Base Material





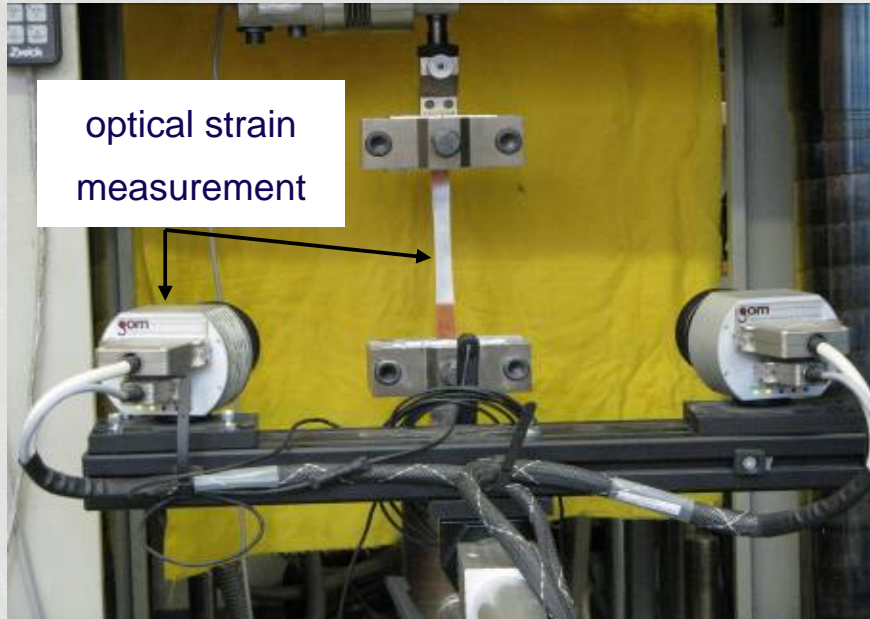
Overview over Test Program for Base Material

Overview	Orthotropic behavior	Different behavior in tension and compression	Loss in bending stiffness
What is a Foldcore?			
Base material testing	Tests in both preferred directions	Tension and compression tests	Bending test
Material model	<p>Preferred directions are defined by direction of rolling of aramid fiber paper</p>  <p>L: longitudinal paper direction W: transverse paper direction</p>		
Base material simulation			
Foldcore testing			
Implicit Foldcore simulation			
Explicit Foldcore simulation			
Perspective			



Tension Test

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective

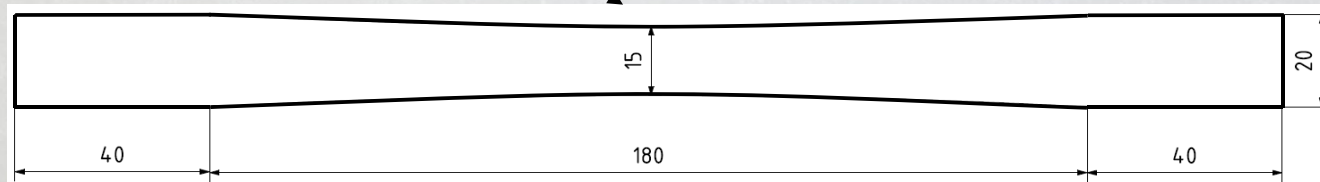


test setup

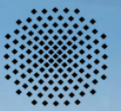


Broken test specimen

Sample is waisted, cap stripes are unnecessary

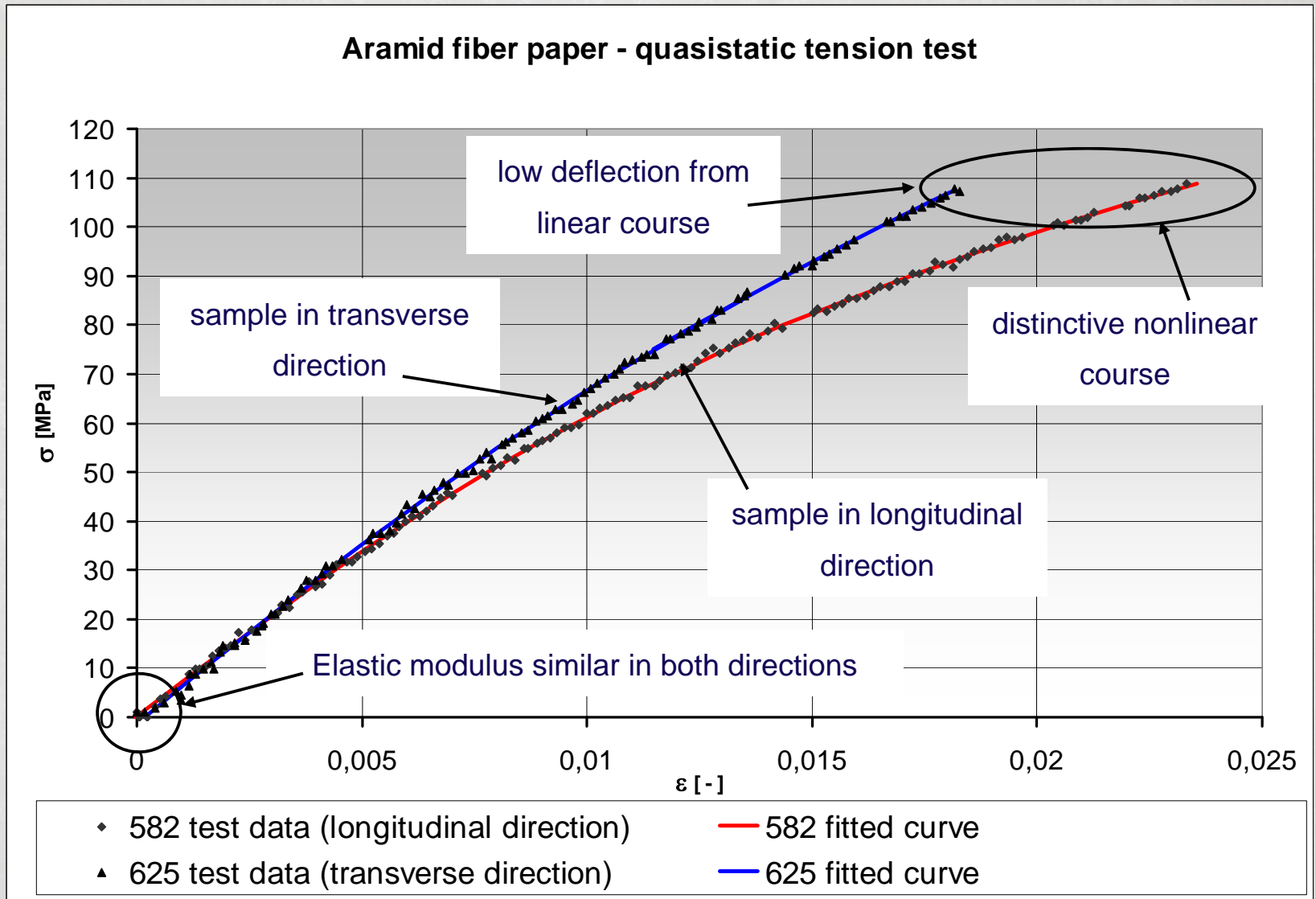


Geometry of tension test sample



Tension Test, continued

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective



Typical stress-strain curves



Compression Test – Cylinder Test

Overview

What is a Foldcore?

Base material testing

Material model

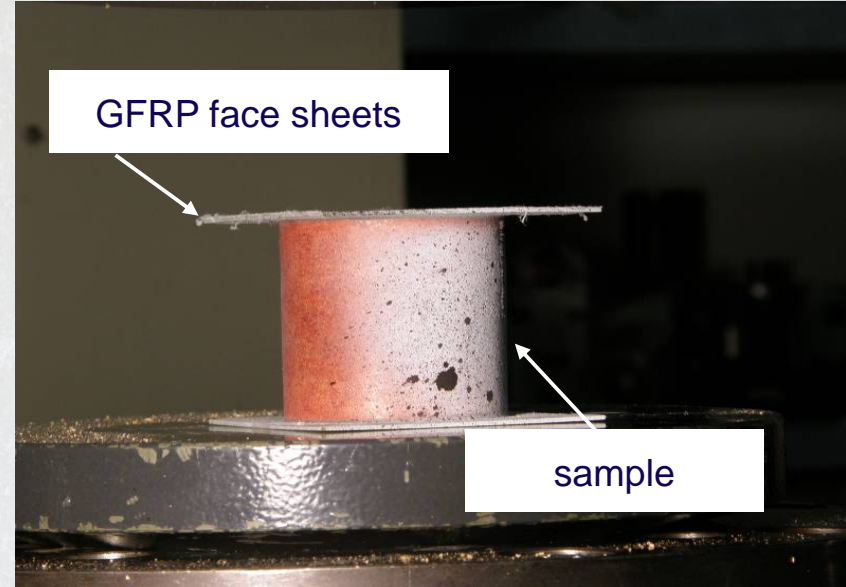
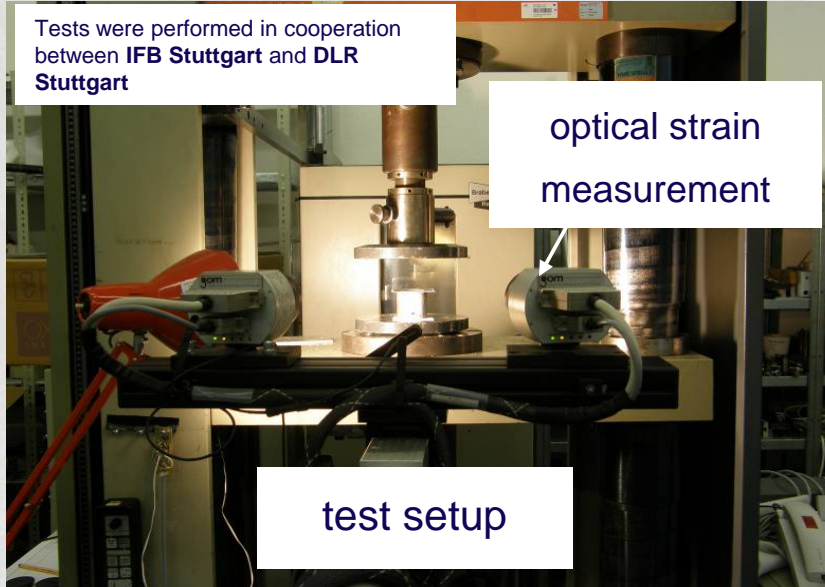
Base material simulation

Foldcore testing

Implicit Foldcore simulation

Explicit Foldcore simulation

Perspective

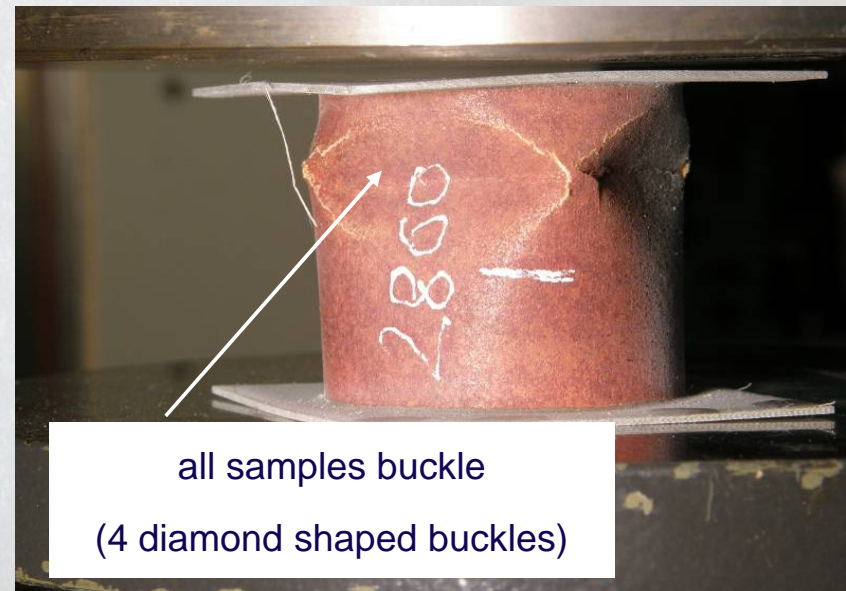


A cylindrical sample was used:

diameter = 52.25 mm

height = 50 mm

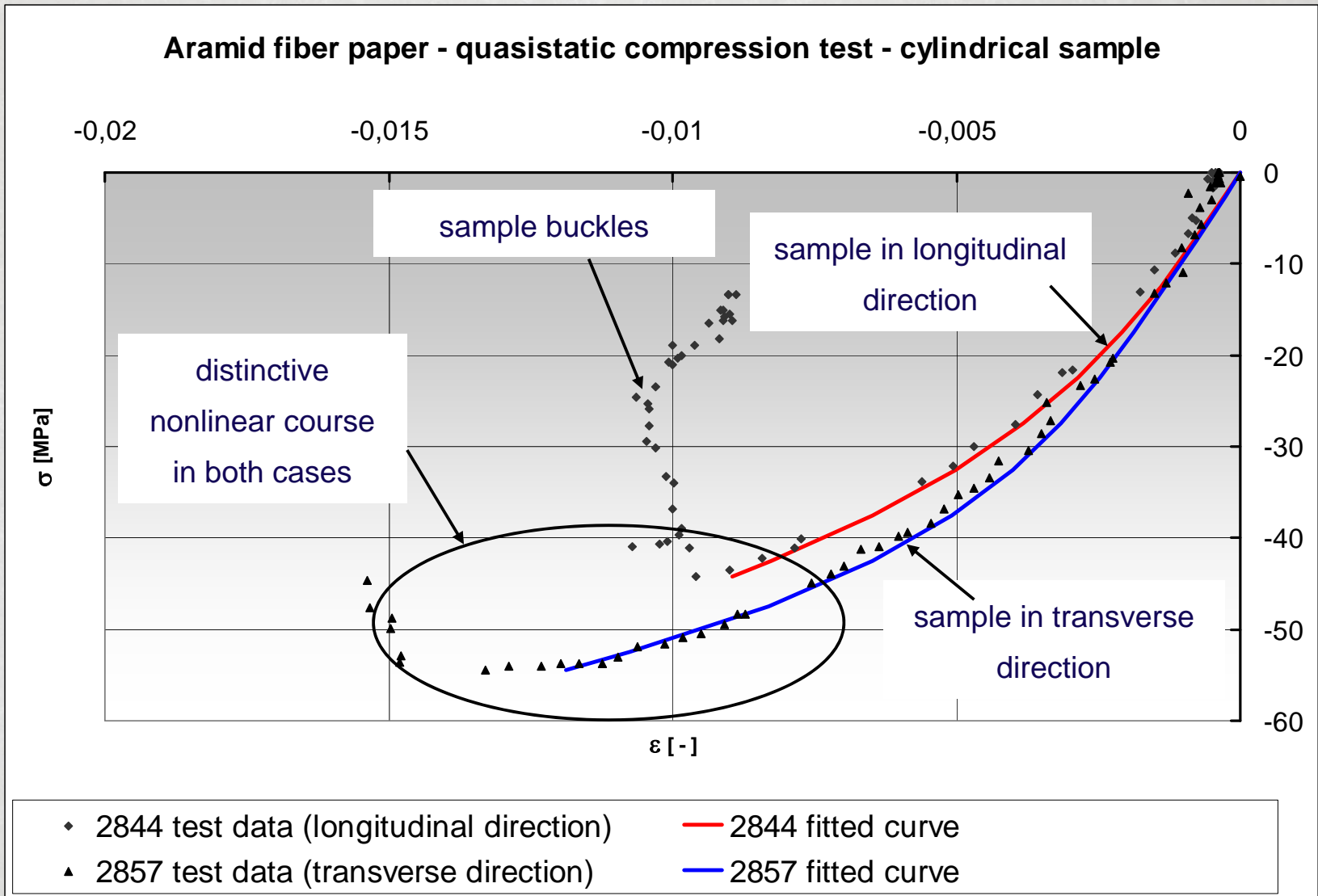
Due to buckling failure, material strength could not be determined. Elastic constants could be measured.





Compression Test – Cylinder Test, continued

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective



Typical stress-strain curves



Compression Test – Block Test

Overview

What is a Foldcore?

Base material testing

Material model

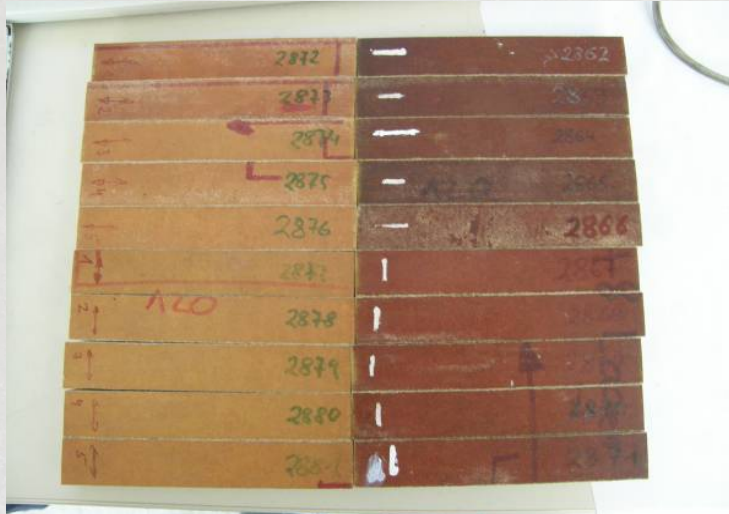
Base material simulation

Foldcore testing

Implicit Foldcore simulation

Explicit Foldcore simulation

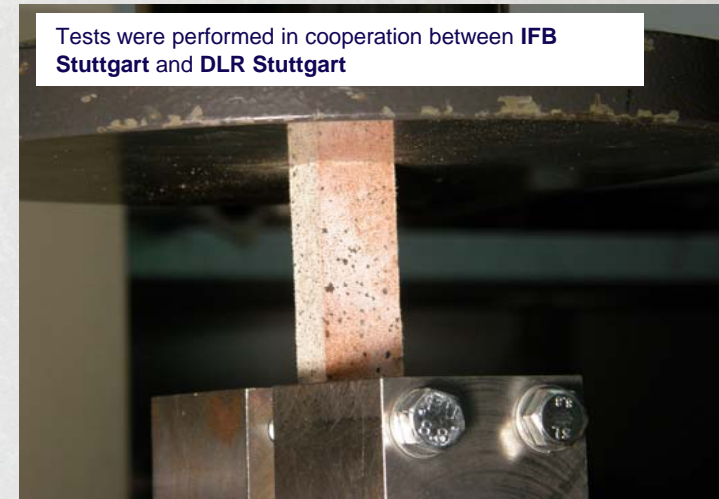
Perspective



Samples: samples

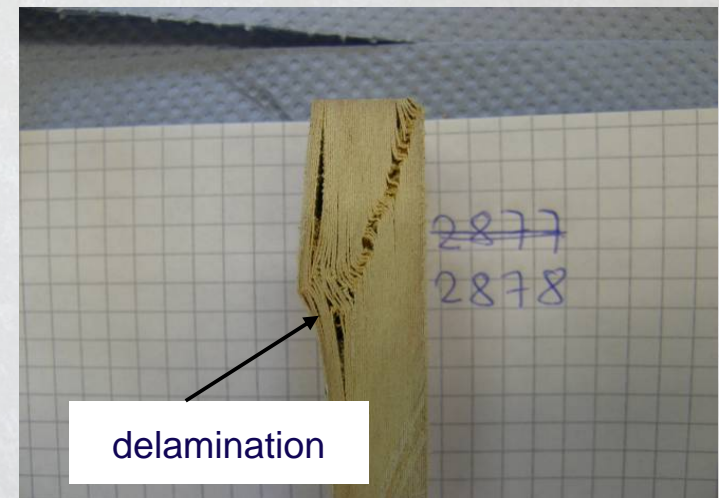
48 layers of aramid paper stacked together
 Layers stick together in curing process
 Samples cut out of aramid paper “block”.

Due to delamination failure, material strength could not be determined. Elastic constants could be measured and show good correlation to values from “cylinder test”.



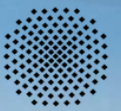
Tests were performed in cooperation between IFB Stuttgart and DLR Stuttgart

test setup



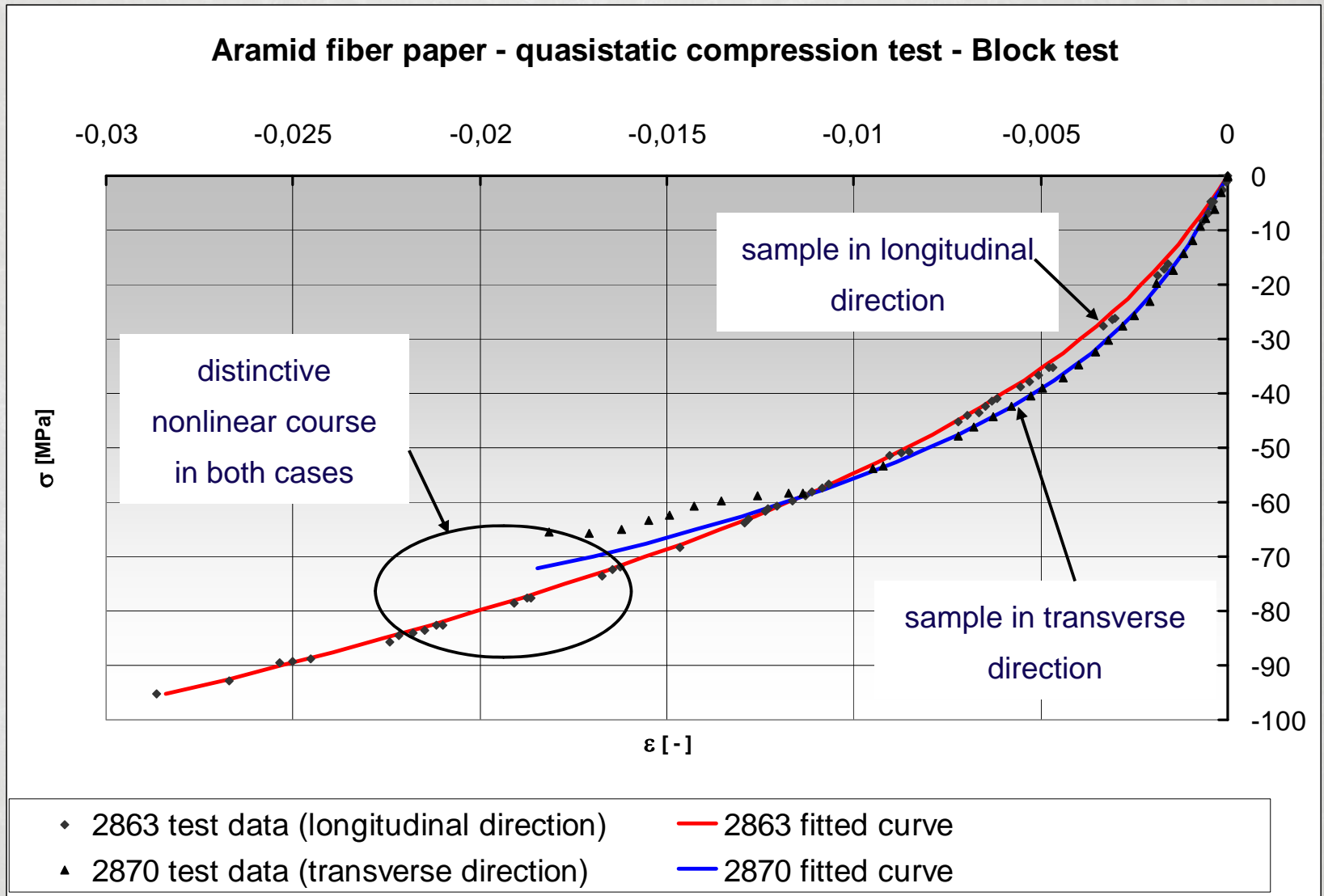
delamination

typical failure: delamination

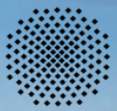


Compression Test – Block Test, continued

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective



Typical stress-strain curves



Compression Test – Strap Crush Test

Overview

What is a Foldcore?

Base material testing

Material model

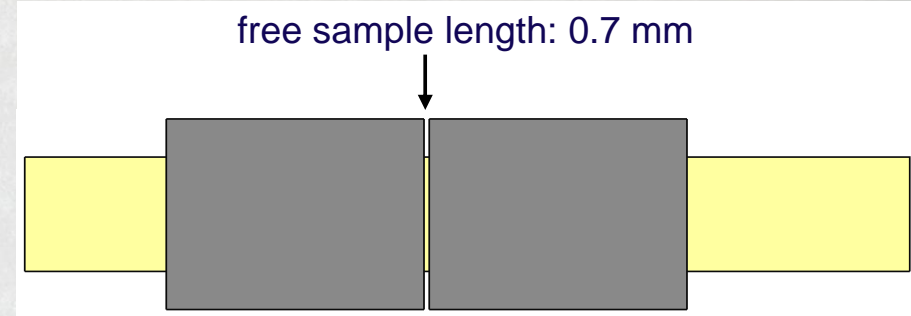
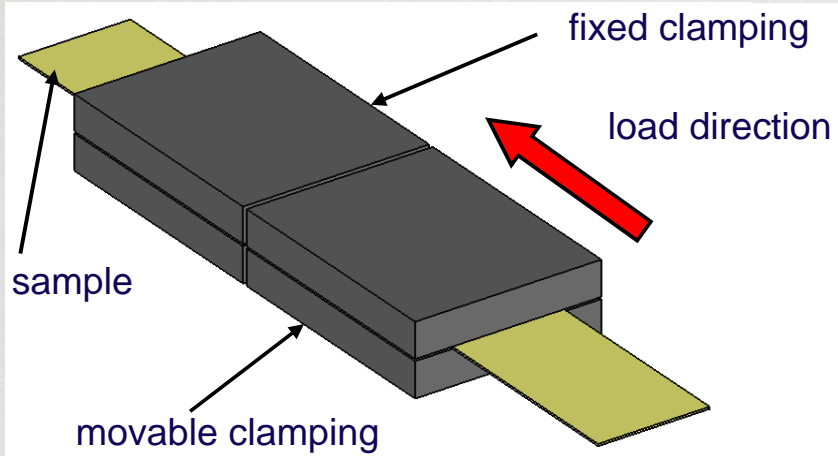
Base material simulation

Foldcore testing

Implicit Foldcore simulation

Explicit Foldcore simulation

Perspective



sketch of strap crush test

Dimensions of sample: 110 mm x 15 mm

Strap Crush Test performed with a standard test setup according to ISO 9895.

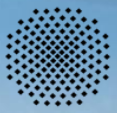
Measurement of short span compression strength

→ highest load that can be reached in compression test

Test not useful for determining elastic modulus



Samples for strap crush test



Bending Test

Overview

What is a Foldcore?

Base material testing

Material model

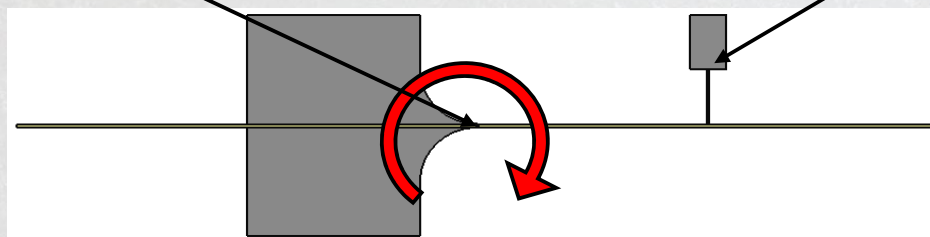
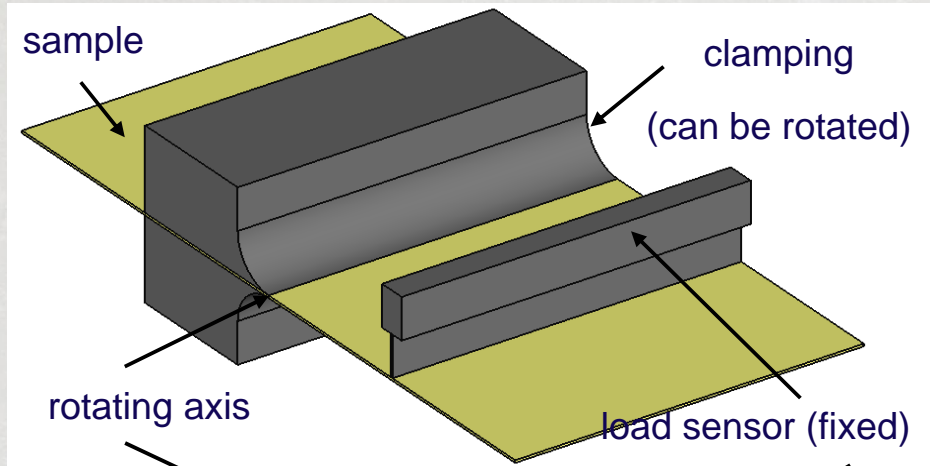
Base material simulation

Foldcore testing

Implicit Foldcore simulation

Explicit Foldcore simulation

Perspective



sketch of bending test

Dimensions of sample: 100 mm x 40 mm

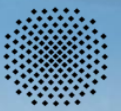


samples for bending test

Bending test performed with standard test setup according to ISO 2493

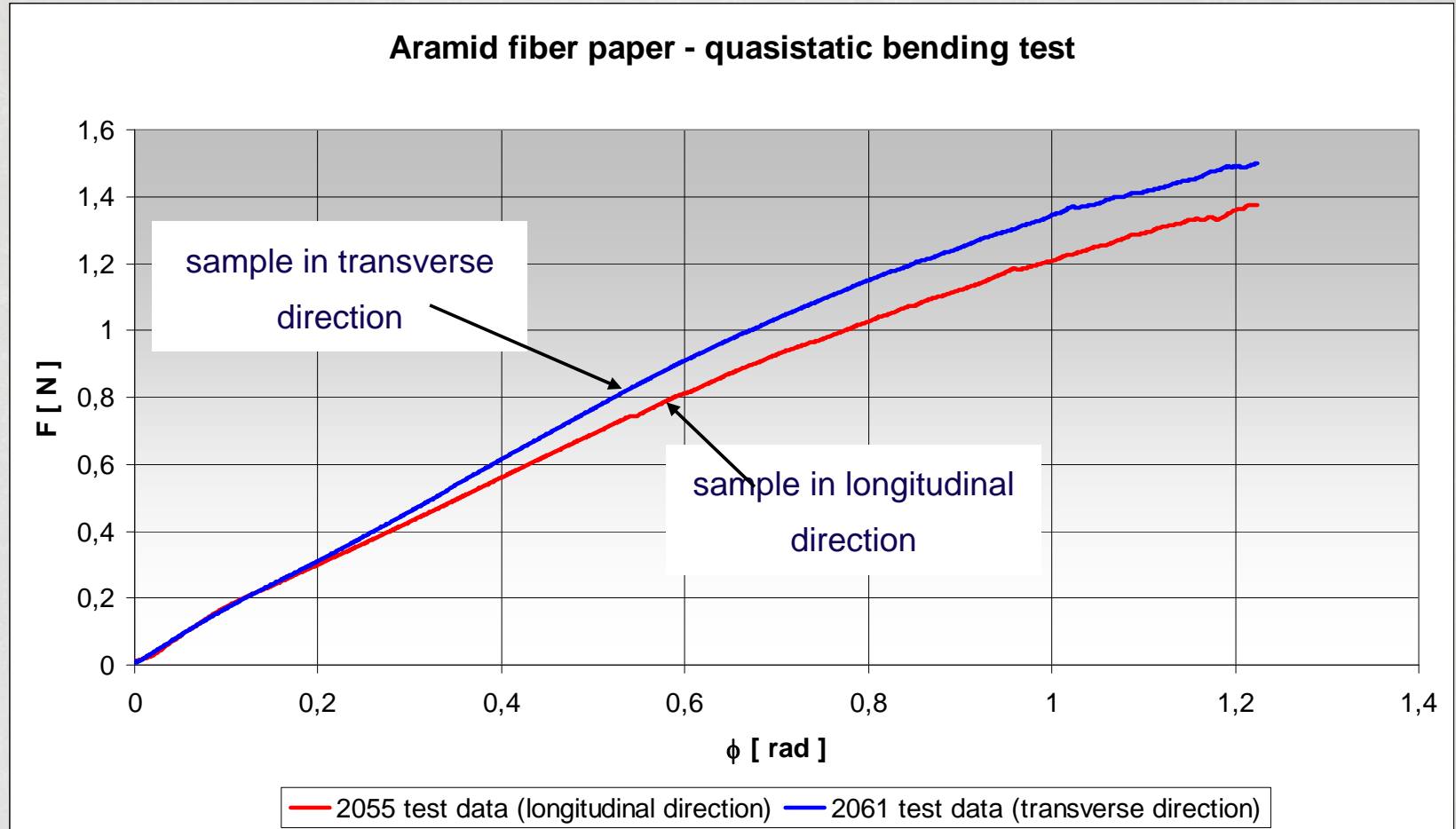
Direct result:

Bending angle – Force curve → calculation of bending stiffness / modulus



Bending Test, continued

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective



Typical Force-bending angle curves

Bending modulus calculated from test data is 4 times lower than elastic modulus from tension test!



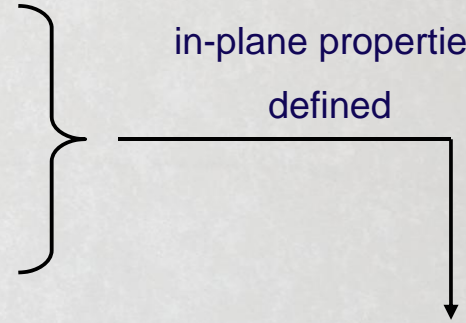
Material model – in-plane properties

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective

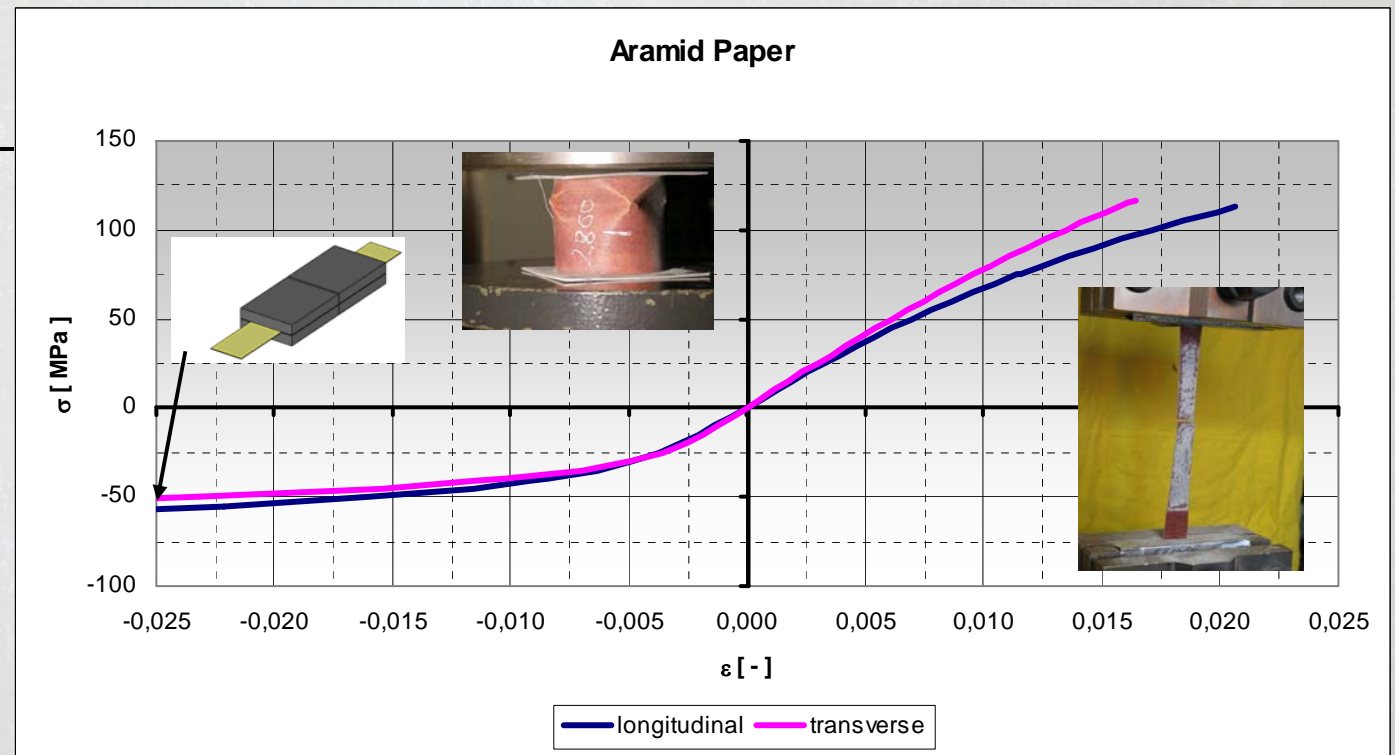
Material model is obtained by combination of all previously shown data:

- All tension data determined from tension test
- Compressive elastic properties determined with “cylinder” test
- “Block” test used as comparison to “cylinder” test
- Ultimate compression stress estimated with strap crush test

in-plane properties defined



User defined material law programmed in FORTRAN and implemented in ABAQUS





Material Model – bending properties

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective

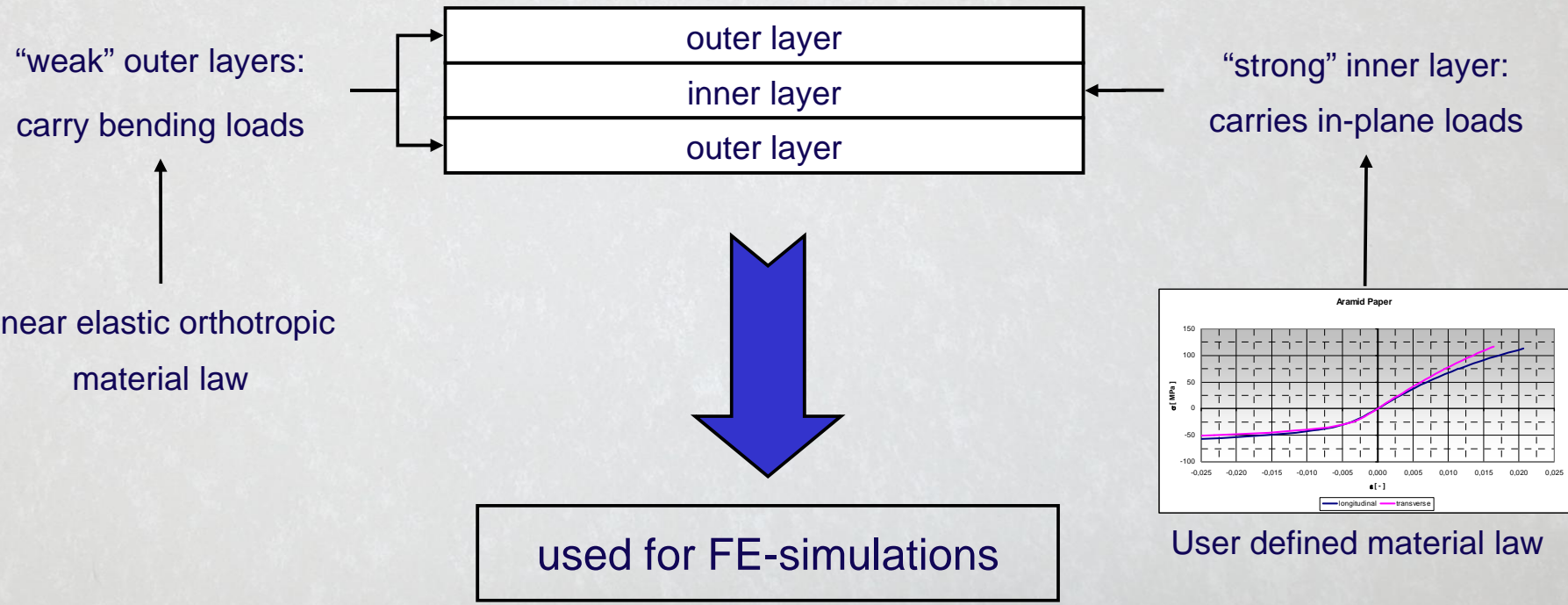
Problem:

Bending modulus lower than tensile modulus (results from non-homogeneous material distribution over the paper thickness)

Solution:

Instead of a homogeneous shell, a **composite** (layered) shell is used

S. Kilchert, A. F. Johnson, H. Voggenreiter, "Finite element modelling of phenolic resin impregnated aramid paper adopted in foldcore sandwich structures", CST 2008, Civil-Comp Press, paper 316, 2008





Simulation – recalculation of material tests

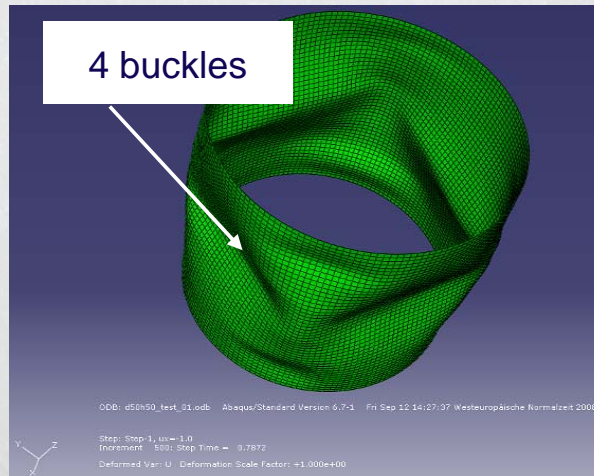
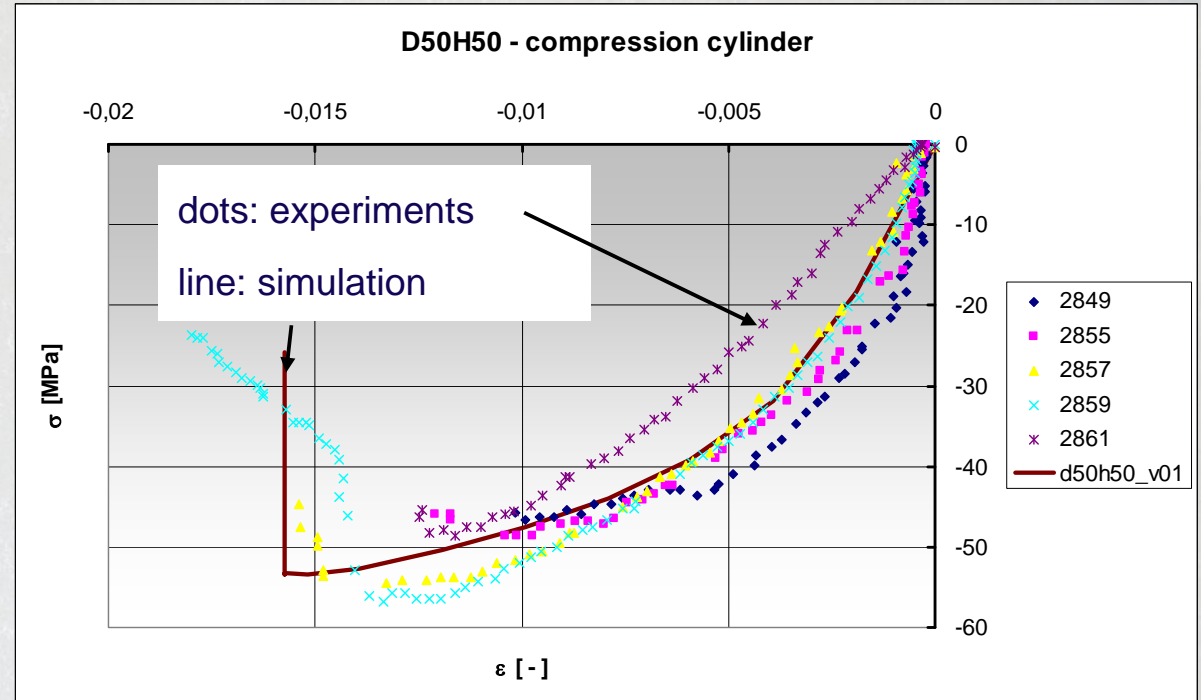
- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective

Correct number of buckles

Buckles are diamond shaped in test and simulation

Buckling stress can be determined with a deviation of less than 10 % in simulation.

Compressive stiffness of aramid paper and buckling behavior can be modeled with developed material law.





Simulation – recalculation of material tests

Overview

What is a Foldcore?

Base material testing

Material model

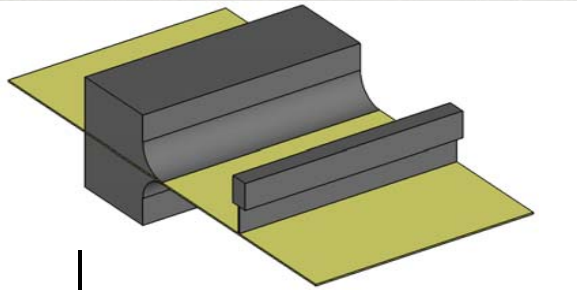
Base material simulation

Foldcore testing

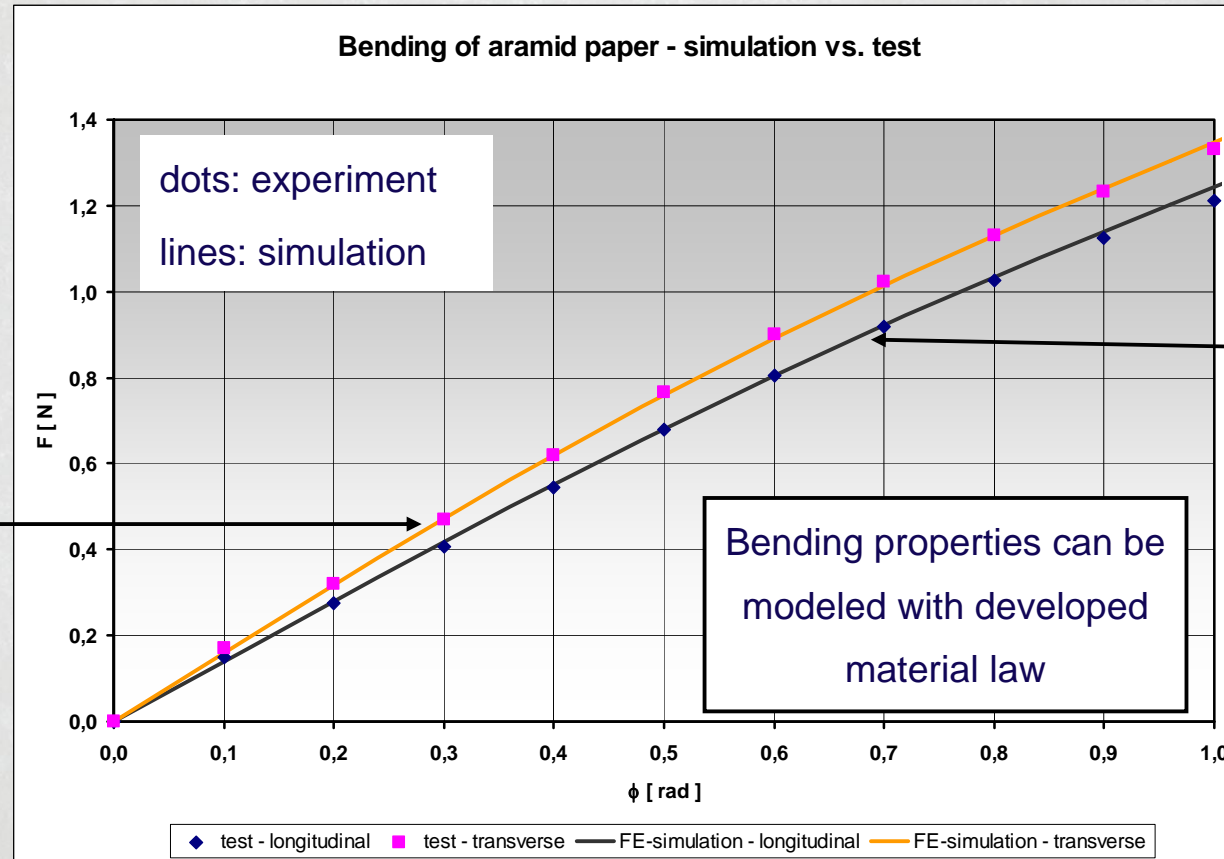
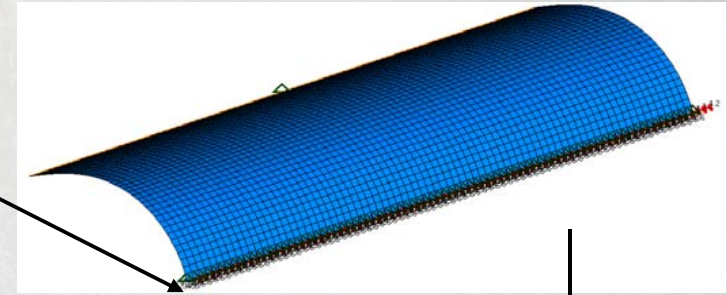
Implicit Foldcore simulation

Explicit Foldcore simulation

Perspective



Bending angle applied to FE-model, reaction force output.

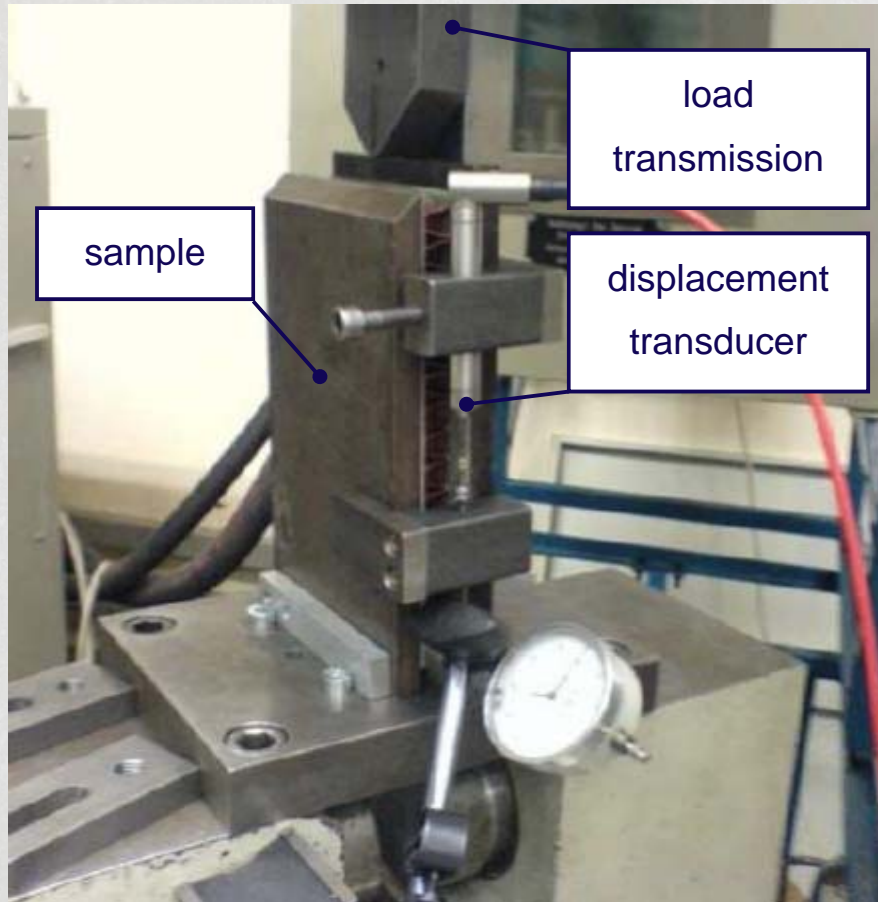




Foldcore Testing – Shear Test

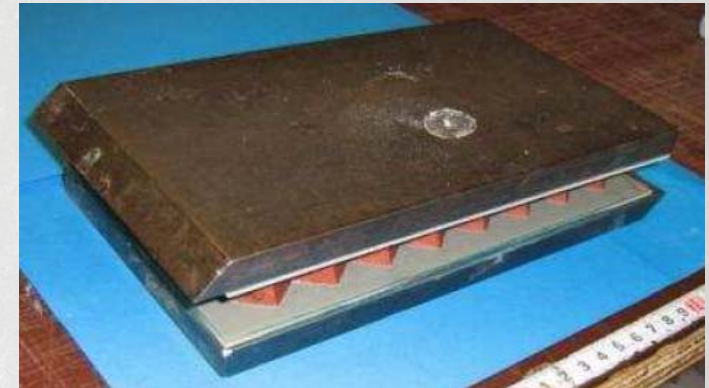
- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective

shear test

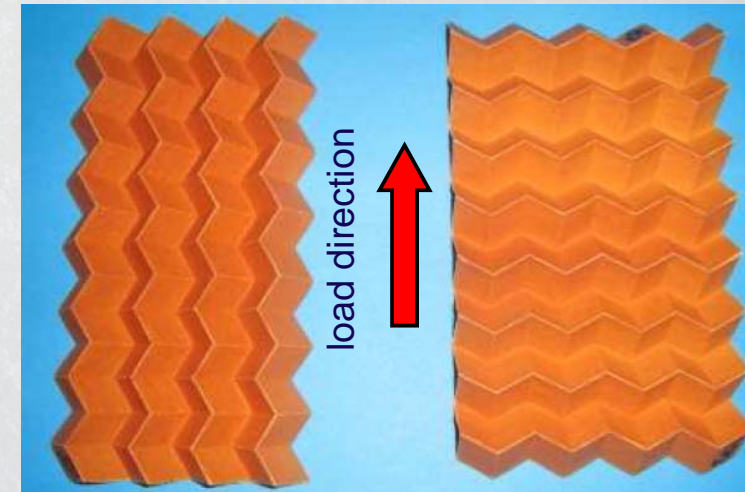


Test setup for shear test according to DIN

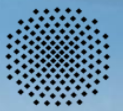
53294



Sample for shear test (shear-W).
Foldcore glued to steel plates



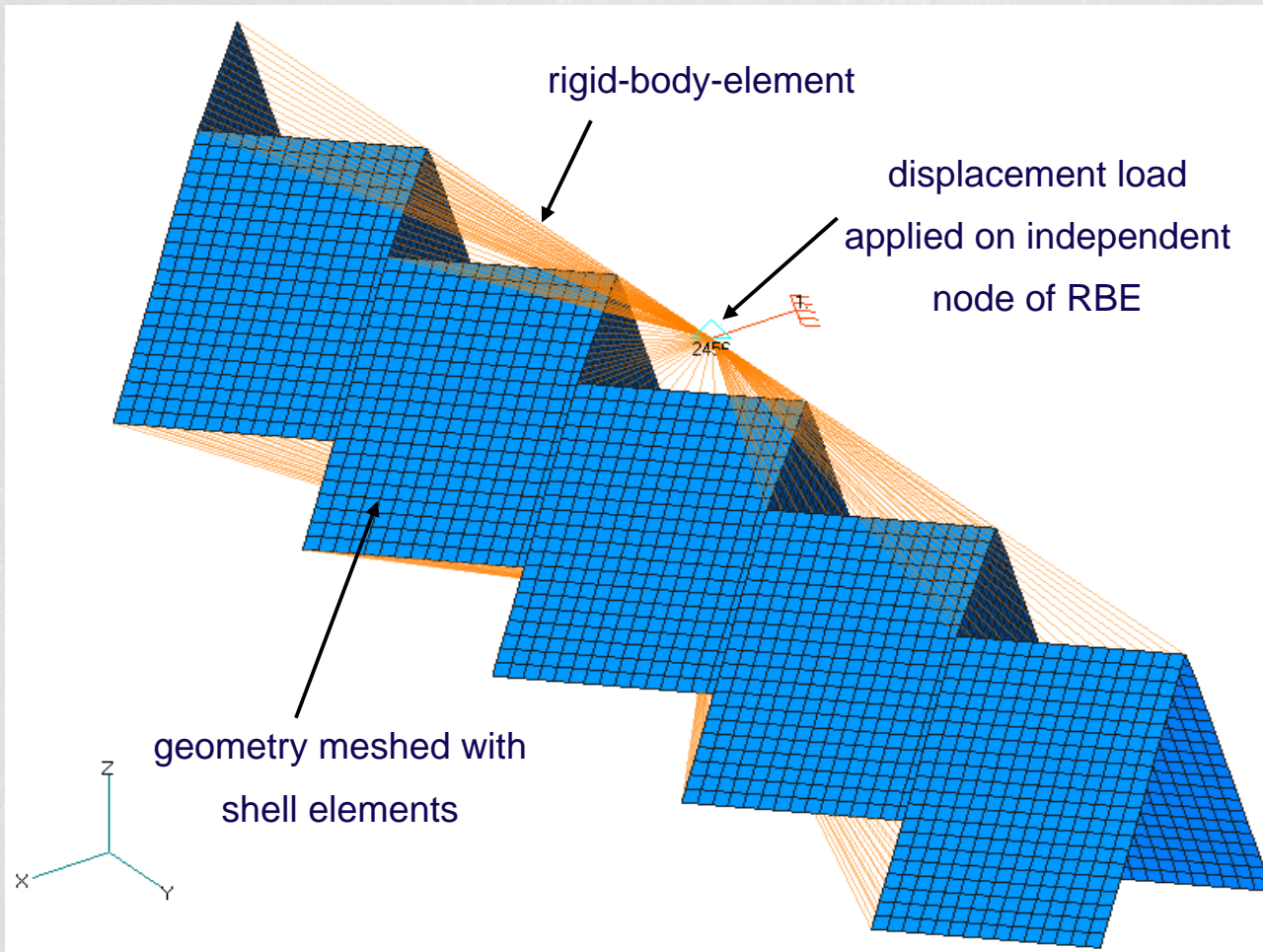
Foldcores for shear tests
left: **W**-direction, right: **L**-direction



Implicit Foldcore Simulation – recalculation of a shear test

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective

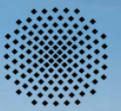
Implicit recalculated shear test



Five unit cells modeled to meet original configuration of test sample.

Upper and lower edge of model fixed with Rigid Body Elements. All displacements and all rotations fixed. Effect of the gluing is not included.

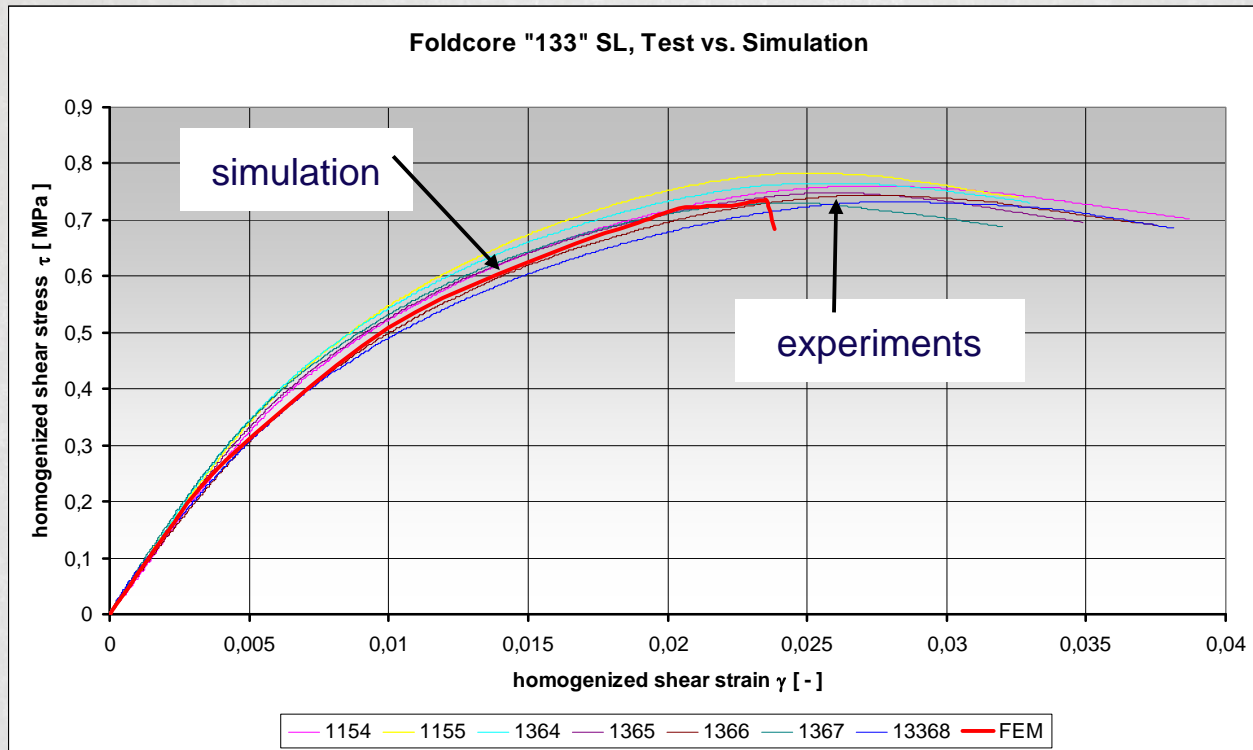
FE-model for virtual shear test



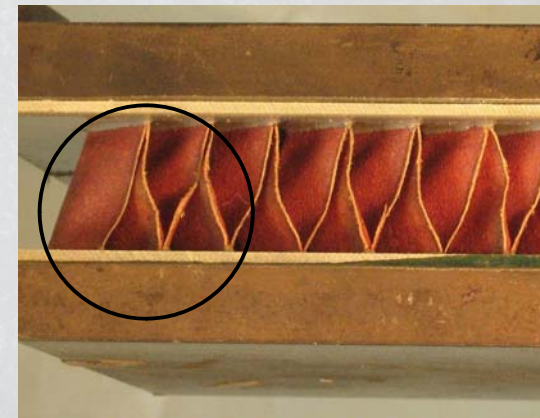
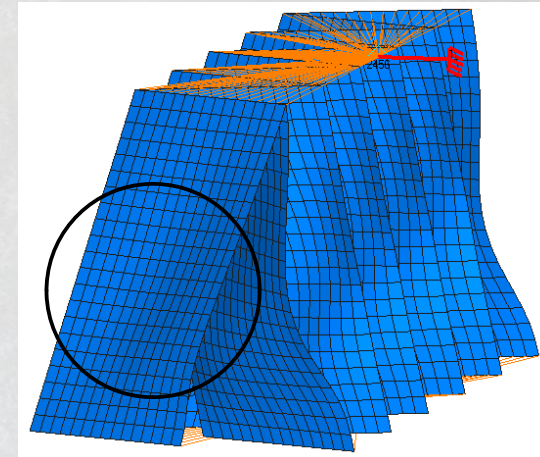
Implicit Foldcore Simulation – recalculation of a shear test

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective

Stiffness properties of the core are calculated in good agreement to the tests. Failure model is included in this simulation, maximum stress is calculated.



Test and simulation results from shear test (L-direction)

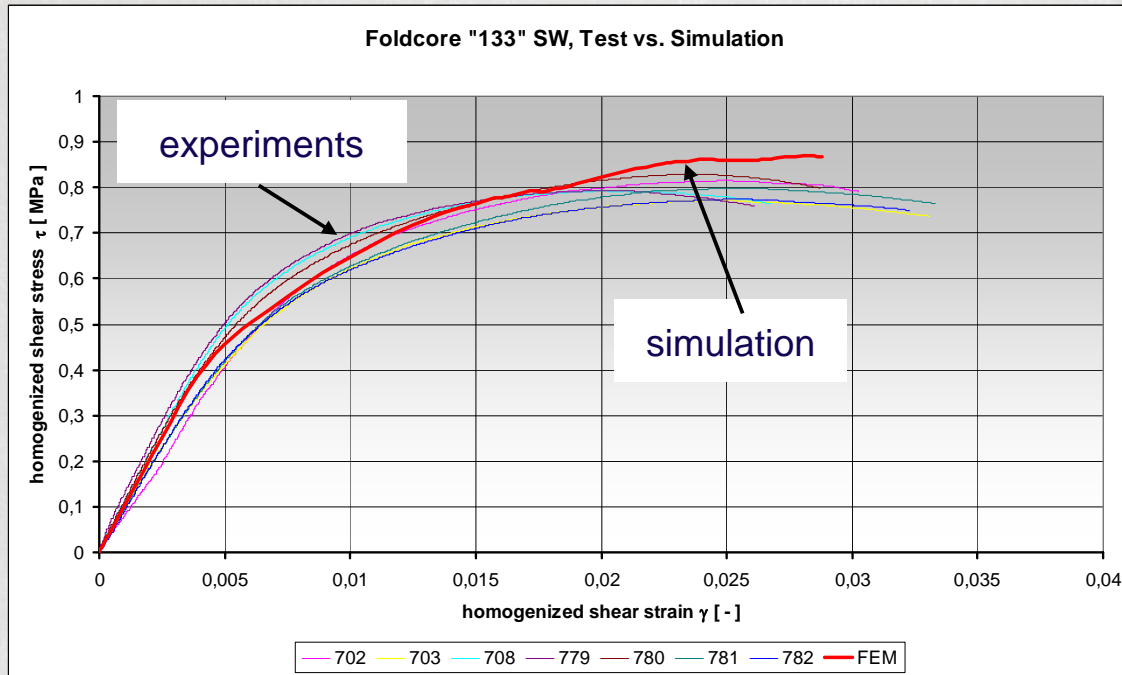




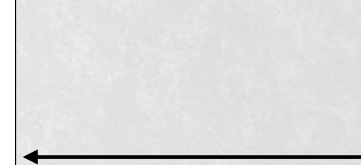
Implicit Foldcore Simulation – recalculation of a shear test

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective

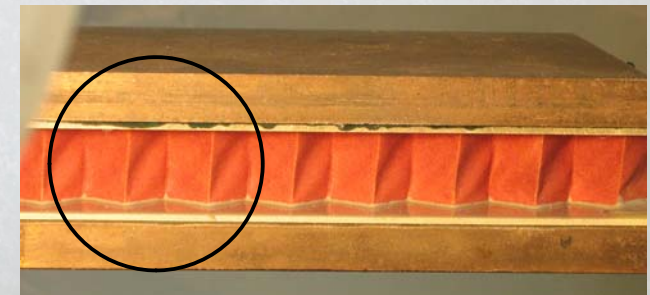
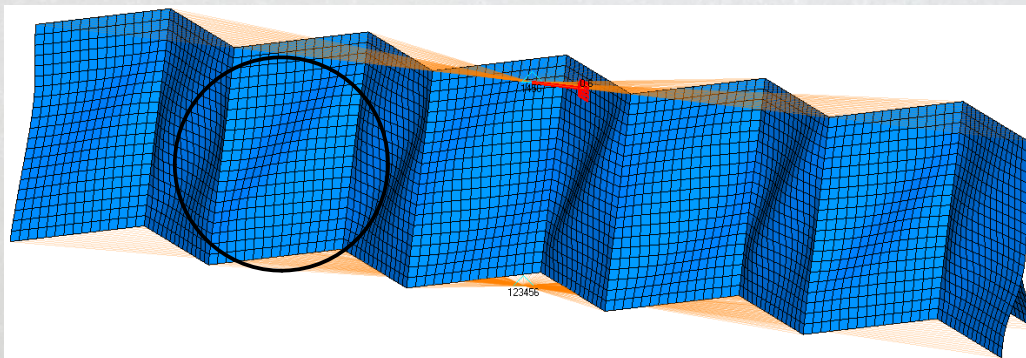
Stiffness properties of the core are calculated in good agreement to the tests. Failure model is included in this simulation, maximum stress is slightly overestimated.



Test and simulation results from shear test (**W**-direction)



Buckling behavior is simulated





Explicit Foldcore Simulation – recalculation of a shear test

Overview

What is a Foldcore?

Base material testing

Material model

Base material simulation

Foldcore testing

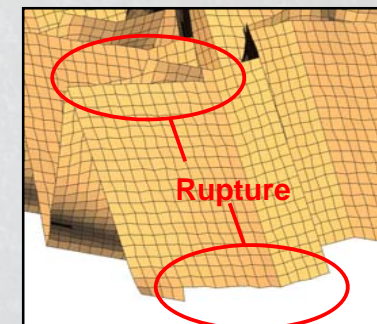
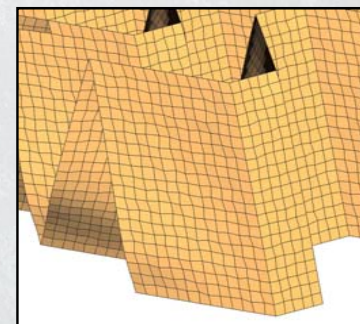
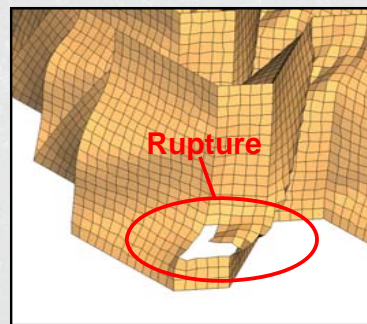
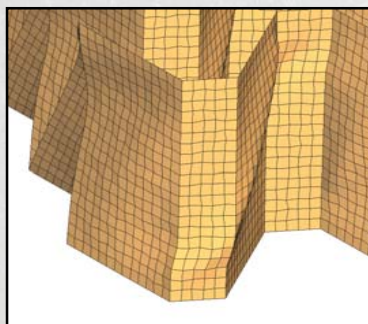
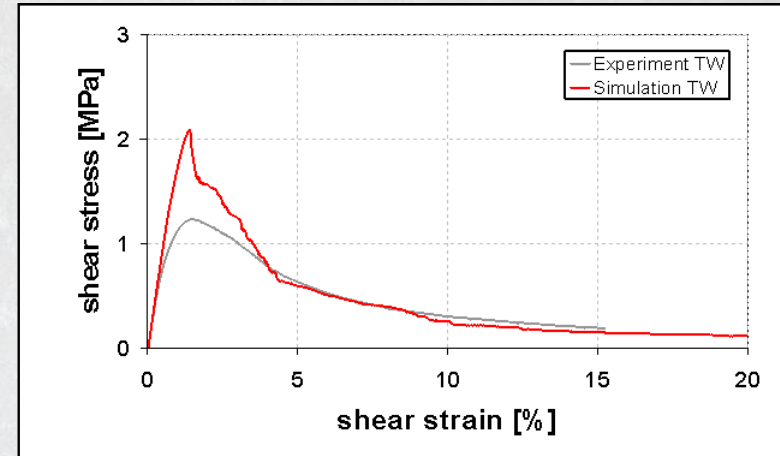
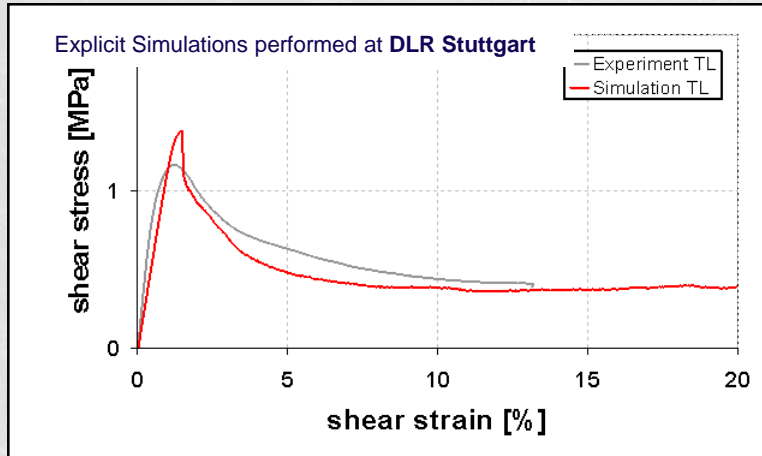
Implicit Foldcore simulation

Explicit Foldcore simulation

Perspective

Foldcore shear test

Explicit simulations performed by Sebastian Kilchert, DLR Stuttgart. See also: S. Kilchert, A. F. Johnson, H. Voggenreiter, "Finite element modelling of phenolic resin impregnated aramid paper adopted in foldcore sandwich structures", CST 2008, Civil-Comp Press, paper 316, 2008



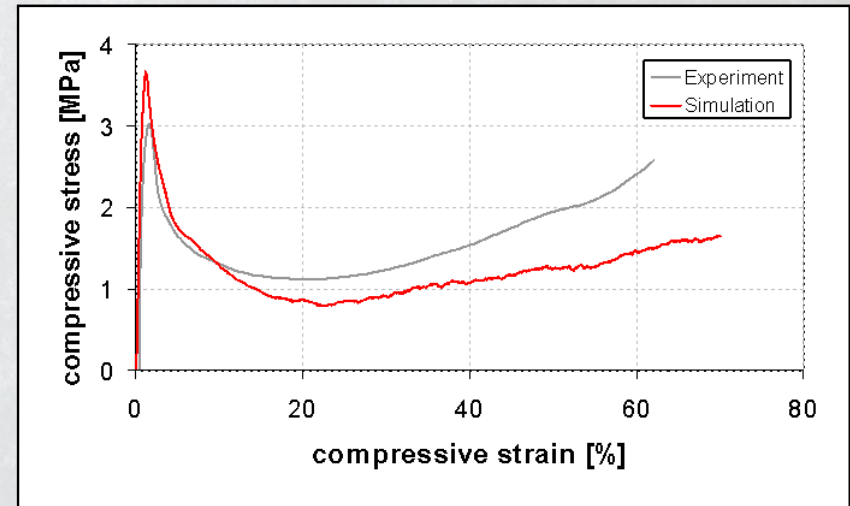
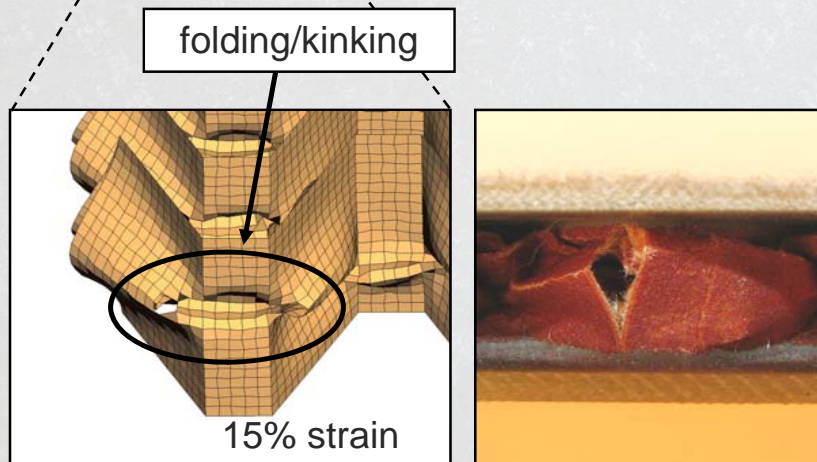
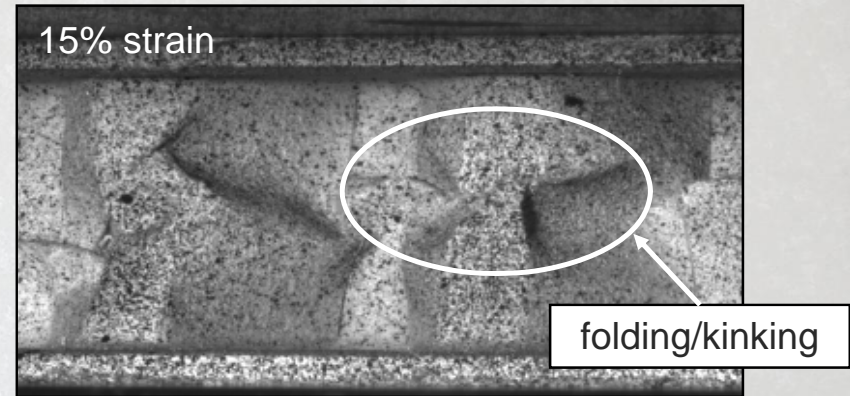
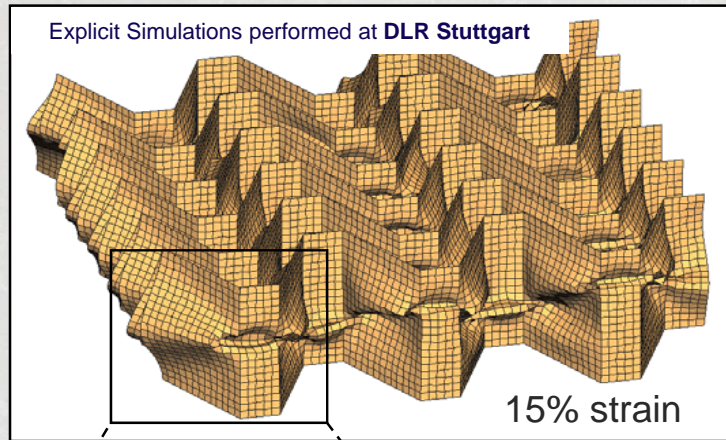
The crushing behavior of a Foldcore in a shear test has been recalculated in an explicit FE-simulation



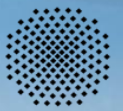
Explicit Foldcore Simulation – recalculation of a compression test

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective

Foldcore compression test



The crushing behavior of a Foldcore in a compression test has been recalculated in an explicit FE-simulation



Conclusions and Perspective

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective

Results:

A test program for the full characterization of resin impregnated aramid fiber paper has been developed.

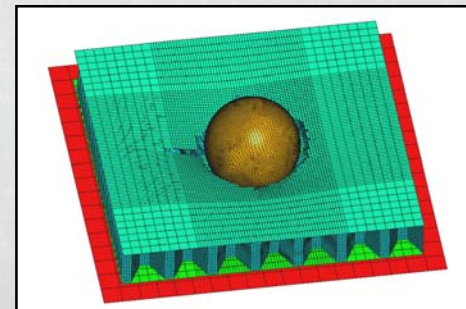
A material model for aramid paper has been extracted from test data and used for programming a user defined material law for implementation in ABAQUS.

Tests on aramid paper and on Foldcores were recalculated. Calculated results show good correlation to experimental data.

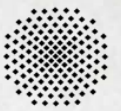
Future work:

Further validation of the material law with calculation of Foldcores with different geometries.

Calculate dynamic tests like impact tests.

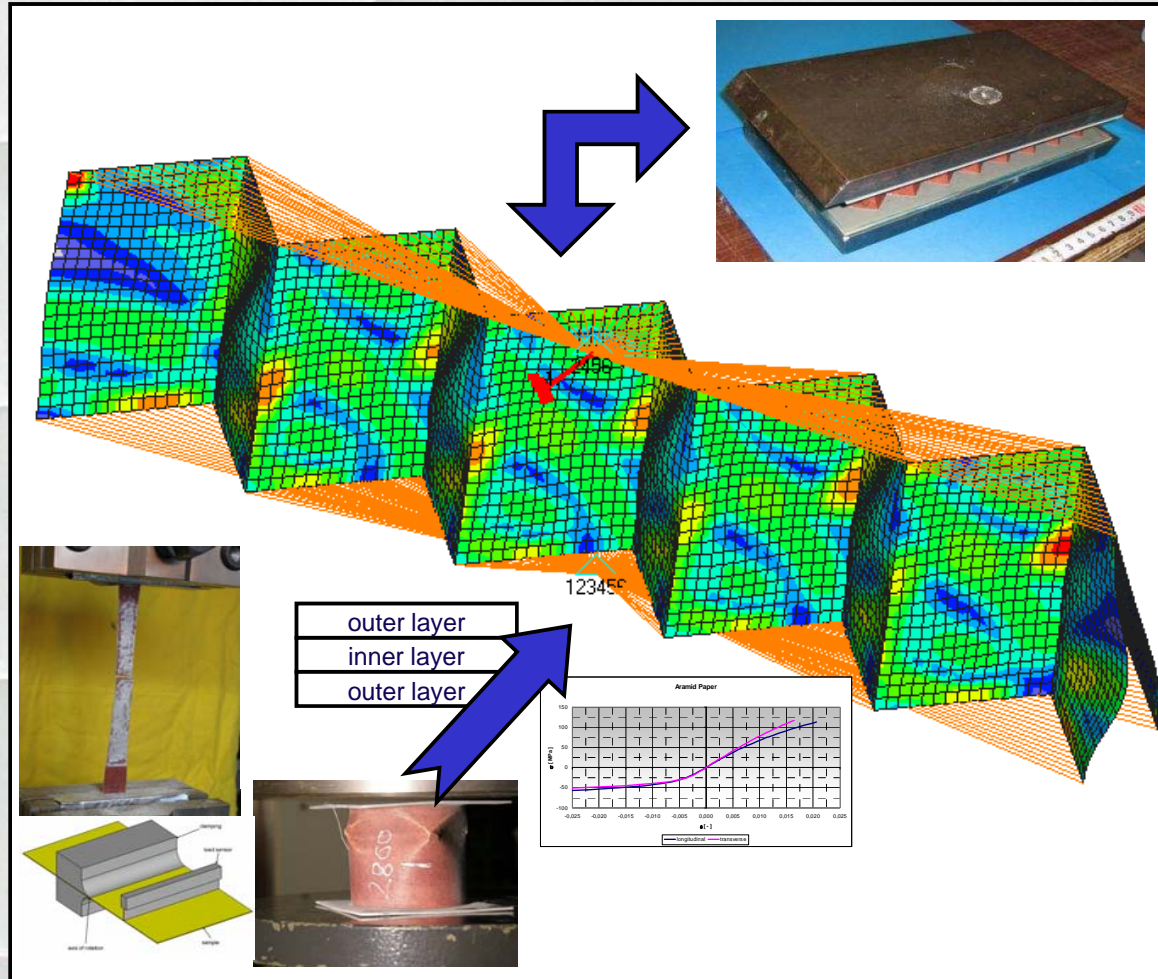


Preliminary impact simulation



Thank you very much...

- Overview
- What is a Foldcore?
- Base material testing
- Material model
- Base material simulation
- Foldcore testing
- Implicit Foldcore simulation
- Explicit Foldcore simulation
- Perspective



... for your attention!