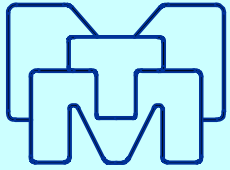


Modelling of deformability and internal structure of textile composites

Stepan V. Lomov, Ignaas Verpoest

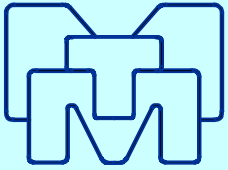
Department MTM, Katholieke Universiteit Leuven



Contents



- 1. “Micro-macro” modelling chain**
- 2. *WiseTex* textile deformability models**
 - **Compression**
 - **Biaxial tension**
 - **Shear**
- 3. Availability of experimental data**
 - **Internal geometry**
 - **Mechanical properties of yarns**
 - **Compressibility of fabrics**
 - **In-plane deformation of fabrics**



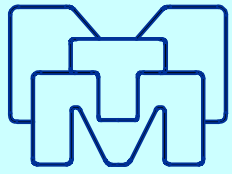
1. “Micro-macro” modelling chain

2. *WiseTex* textile deformability models

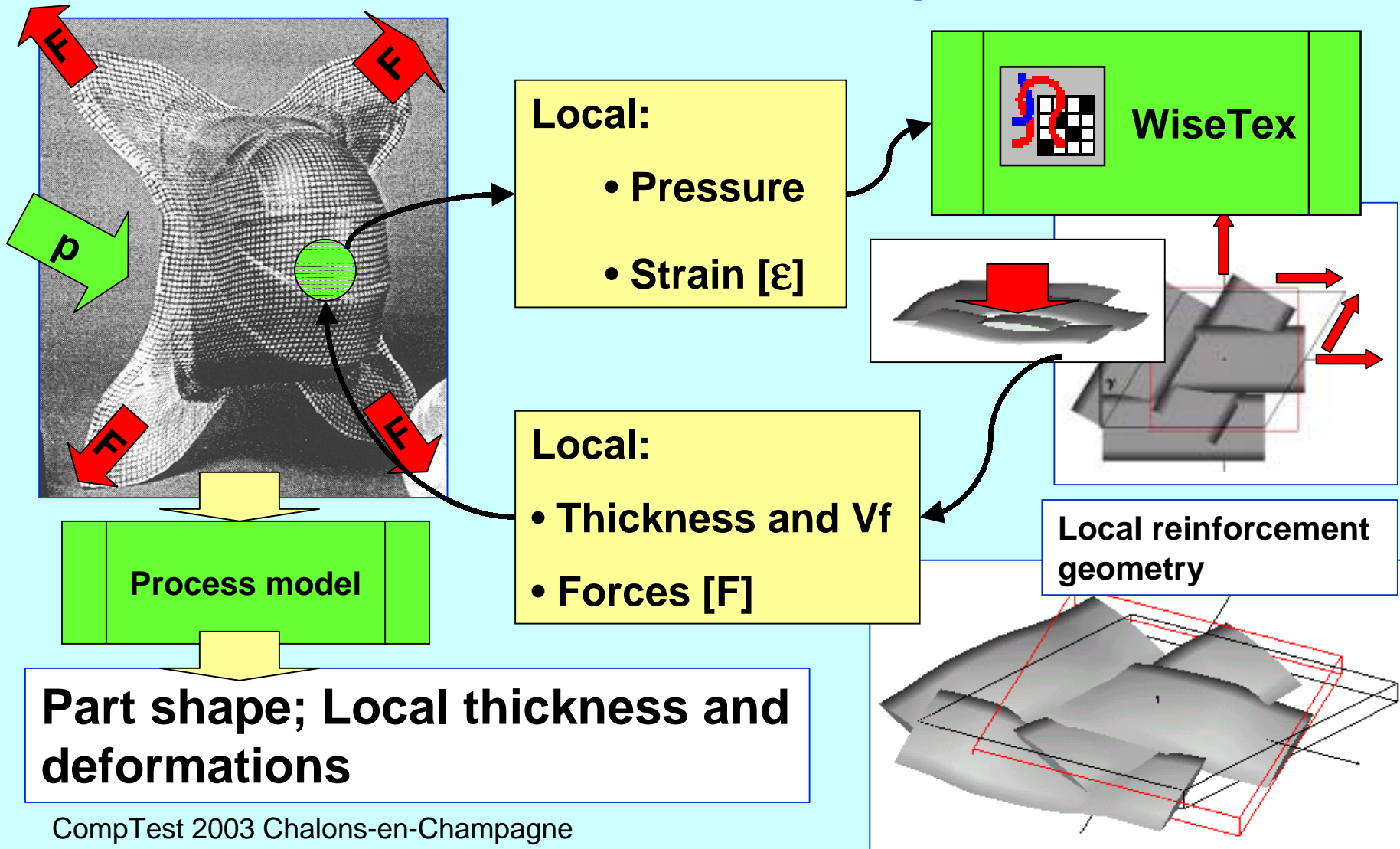
- **Compression**
- **Biaxial tension**
- **Shear**

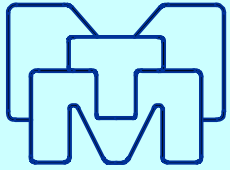
3. Availability of experimental data

- **Internal geometry**
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- **In-plane deformation of fabrics**

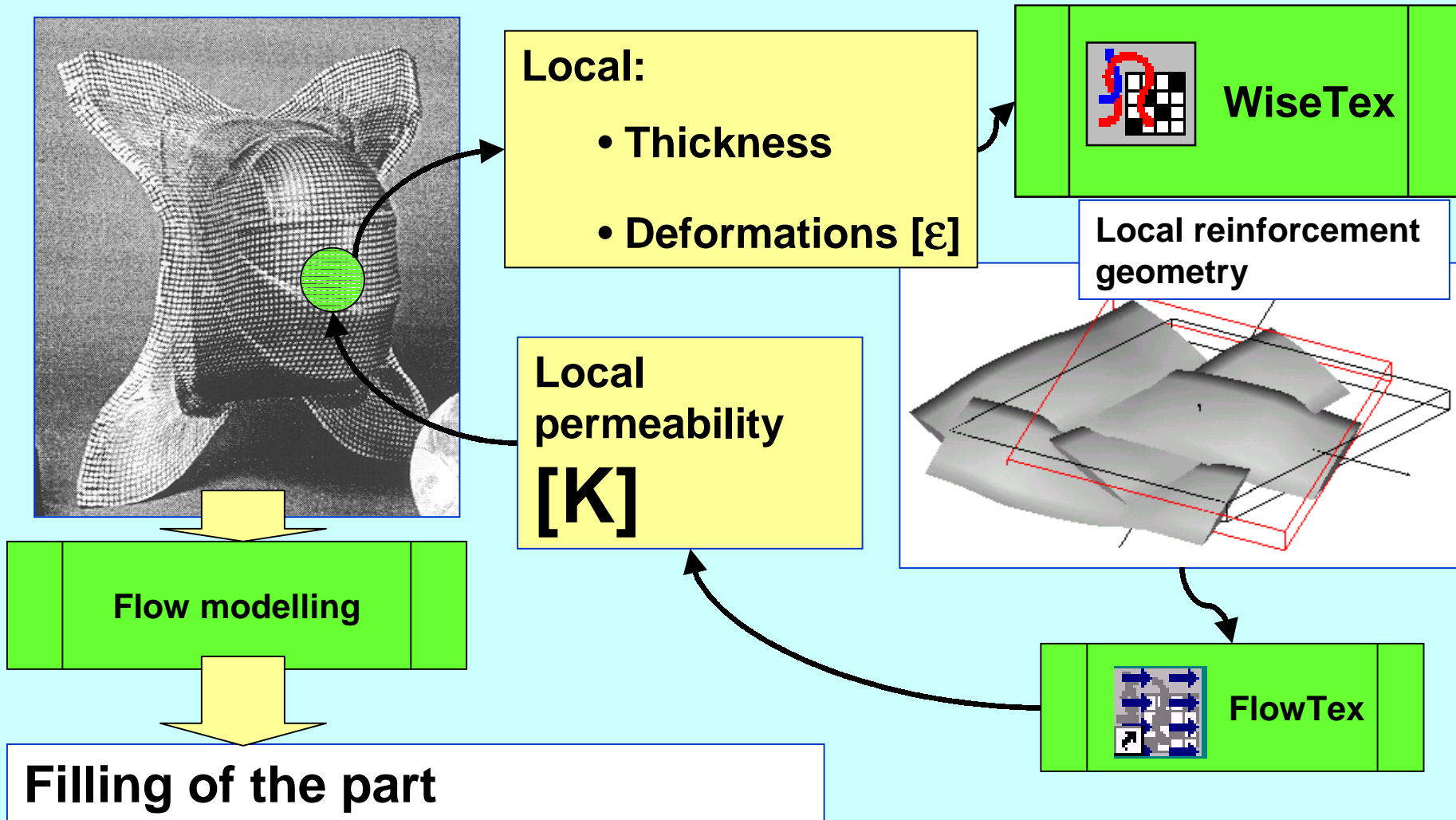


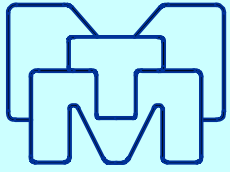
"Micro-macro": 3D shaping



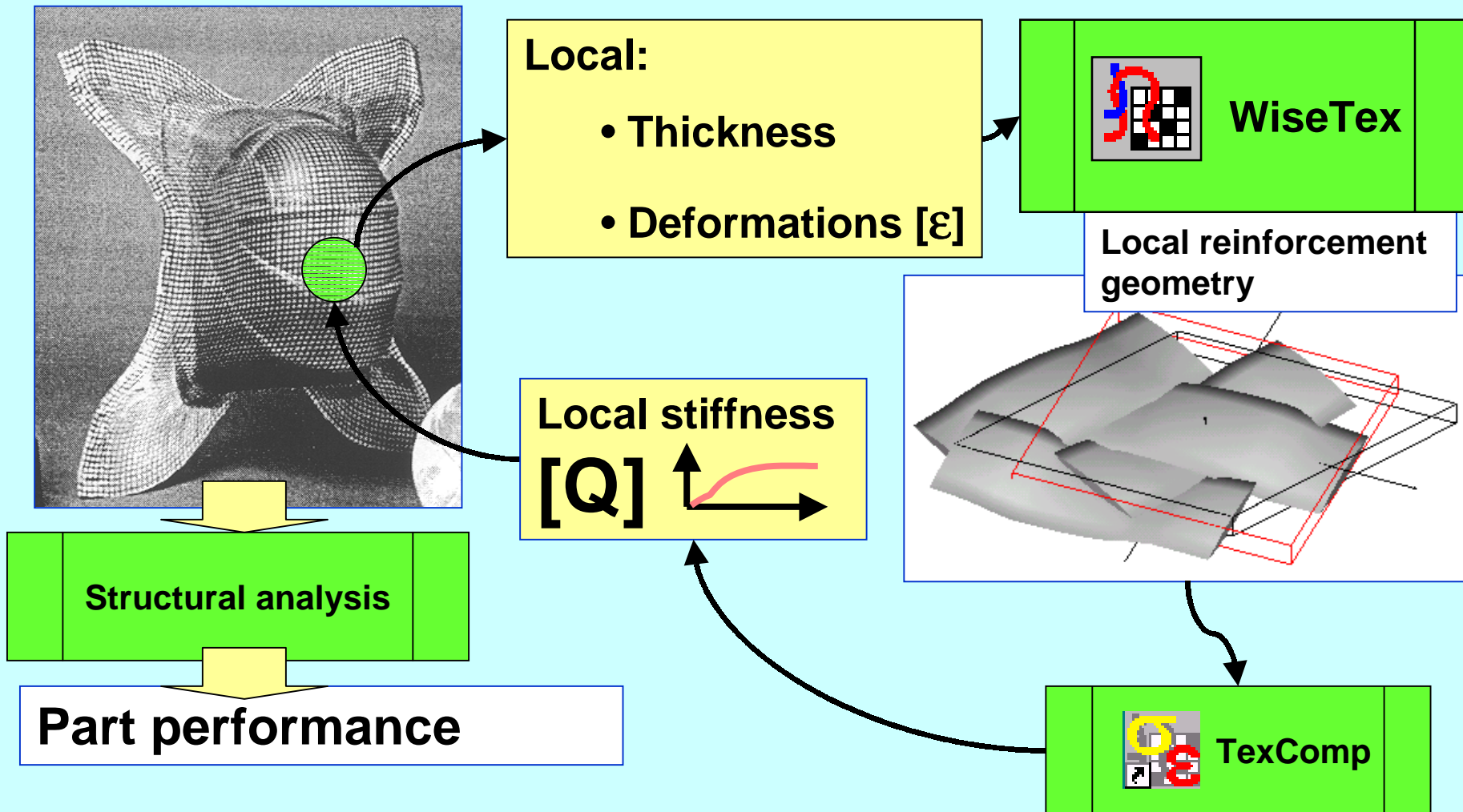


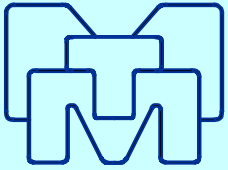
"Micro-macro": Impregnation





"Micro-macro": Part performance

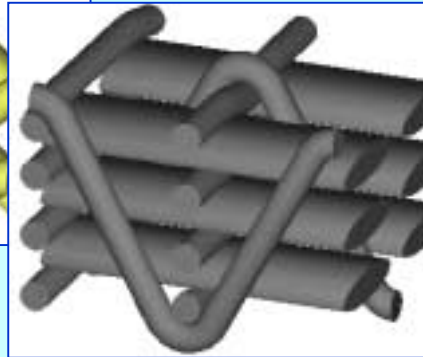
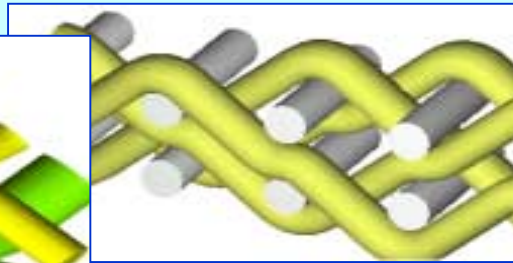
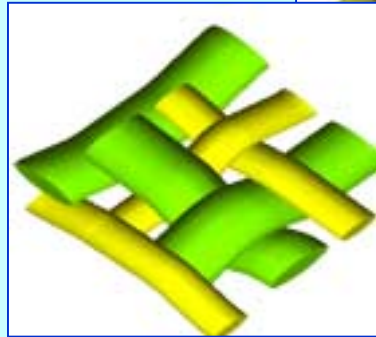




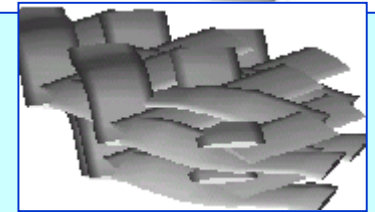
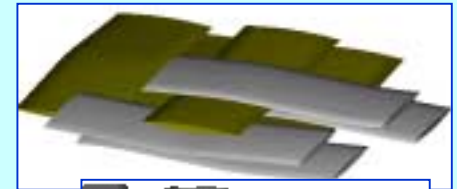
WiseTex textiles



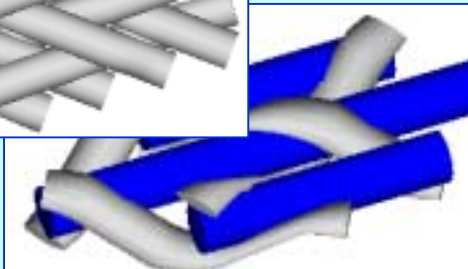
Woven



Laminates



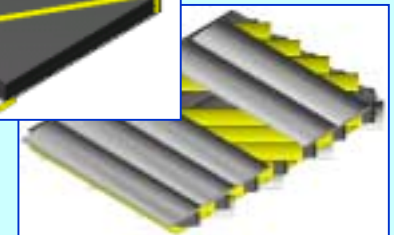
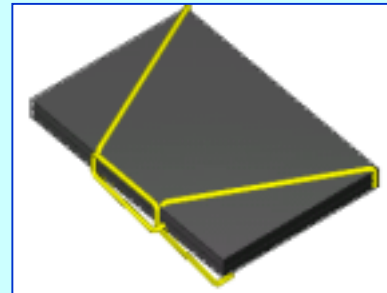
Braided

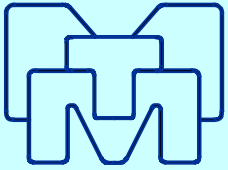


Knitted



Non crimp





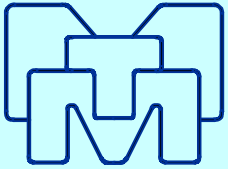
1. “Micro-macro” modelling chain

2. **WiseTex textile deformability models**

- Compression
- Biaxial tension
- Shear

3. Availability of experimental data

- Internal geometry
- Mechanical properties of yarns
- Compressibility of fabrics
- In-plane deformation of fabrics



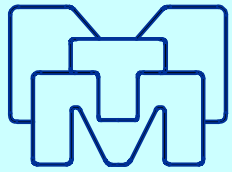
Compression: Model



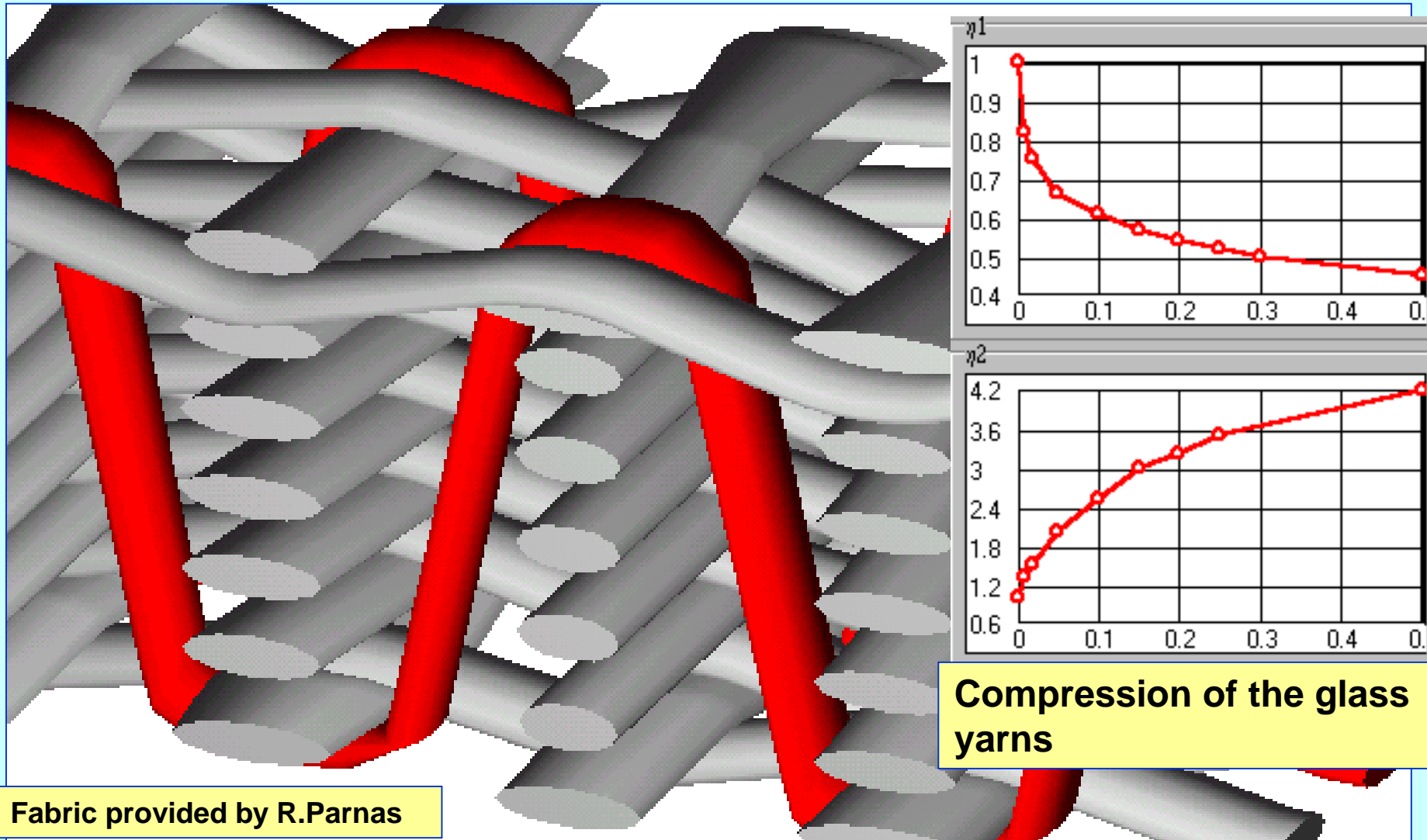
Compression: **(un)bending + compression** of yarns

*work of compressive force Q on change of thickness $db =$
= change of bending energy of yarns dW*

- The **spacing** of the yarns is **not** affected by compression.
- The **shape** of the compressed yarn cross-sections can be modelled as an **ellipse or lenticular** shape.
- The compression **force is evenly distributed**:
 - over the fabric surface
 - between regions of warp-weft contacts.
 - over the region of contact between yarns.

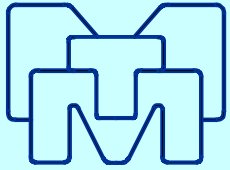


Compression: 3D woven - data



Fabric provided by R.Parnas

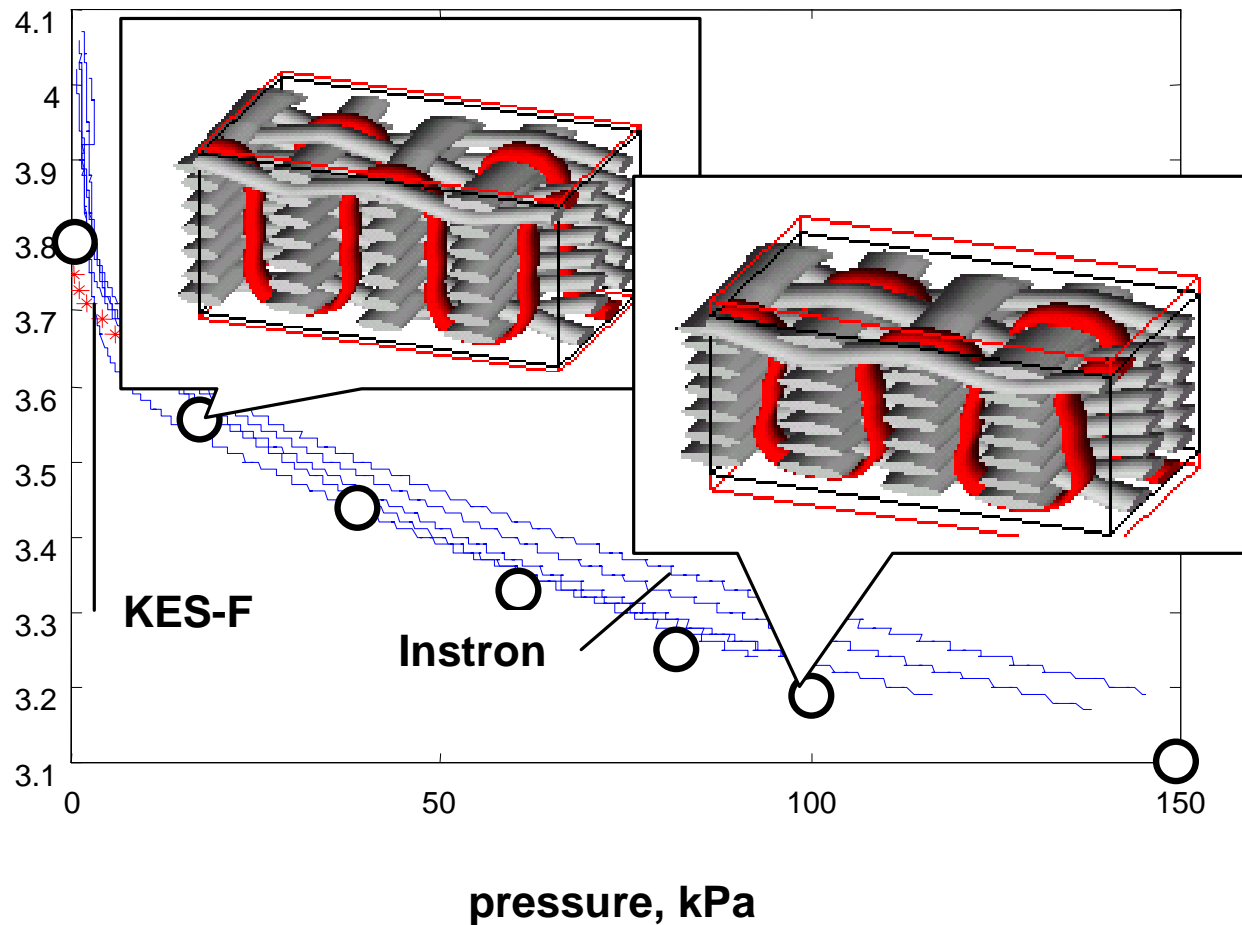
Compression of the glass yarns

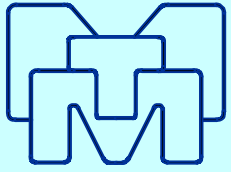


Compression: 3D woven – results (1)



Fabric thickness, mm

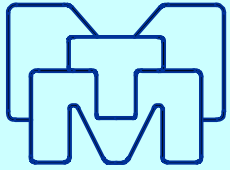




Compression: 3D woven – results (2)



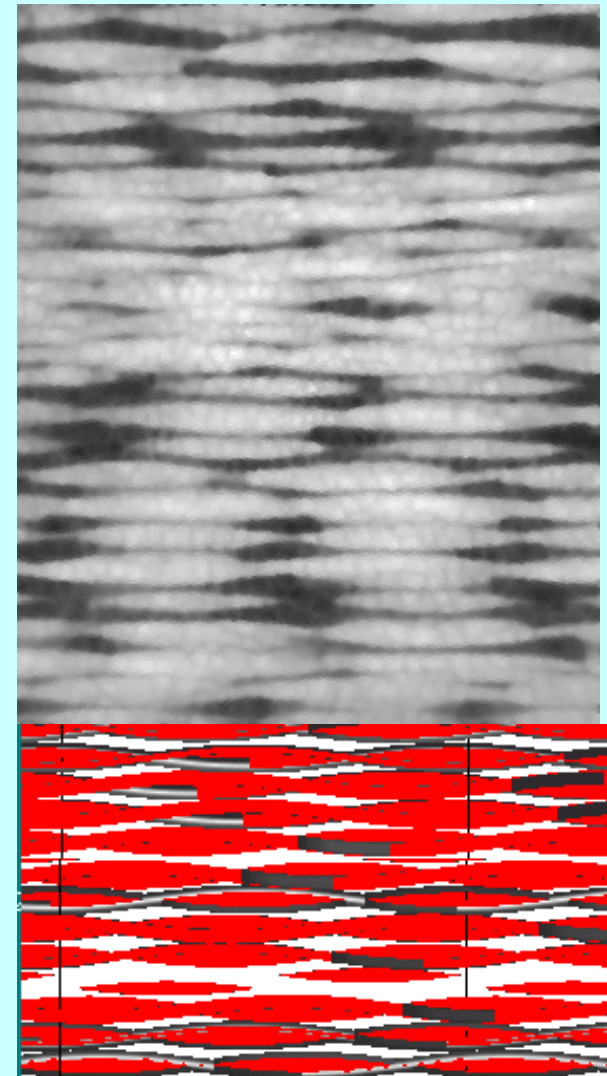
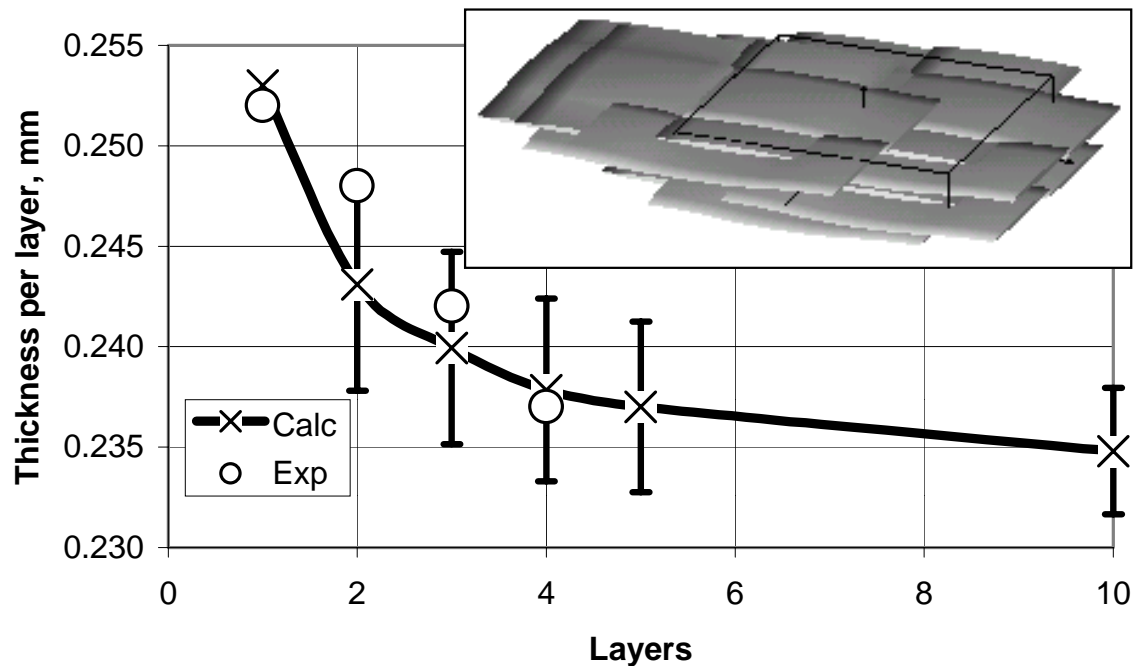
300 kPa

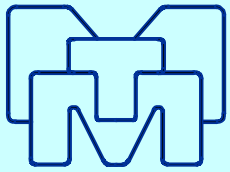


Compression: Multiple layers



Plain woven glass fabric





Biaxial tension: Model



Step 1. Compute $p_{Wa} = p_{Wa0}(1 + \varepsilon_y)$; $p_{We} = p_{We0}(1 + \varepsilon_x)$

Step 2. Set changes of weft crimp heights $\Delta h_{ij} = 0$

Step 3. Compute fabric **internal structure** for $h_{ij} = h_{ij0} + \Delta h_{ij}$

Step 4. Compute average **yarns strains** $\varepsilon = l/l_0 - 1$

Step 5. Compute **yarns tensions** $T = T(\varepsilon)$

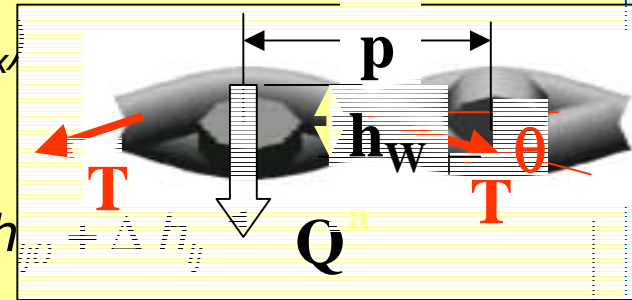
Step 6. Compute **transversal forces** Q (due to bending and tension)

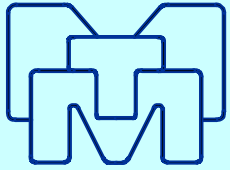
Step 7. Compute **compression** of the yarns under the forces Q

Step 7. Compute Δh_{ij} using the condition of **minimum of total (bending plus tension) energy** of the yarns in the repeat.

Step 8. Check convergence of Δh_{ij} ; if not, go to Step 3.

Step 9. Compute applied forces summing up the yarns tension

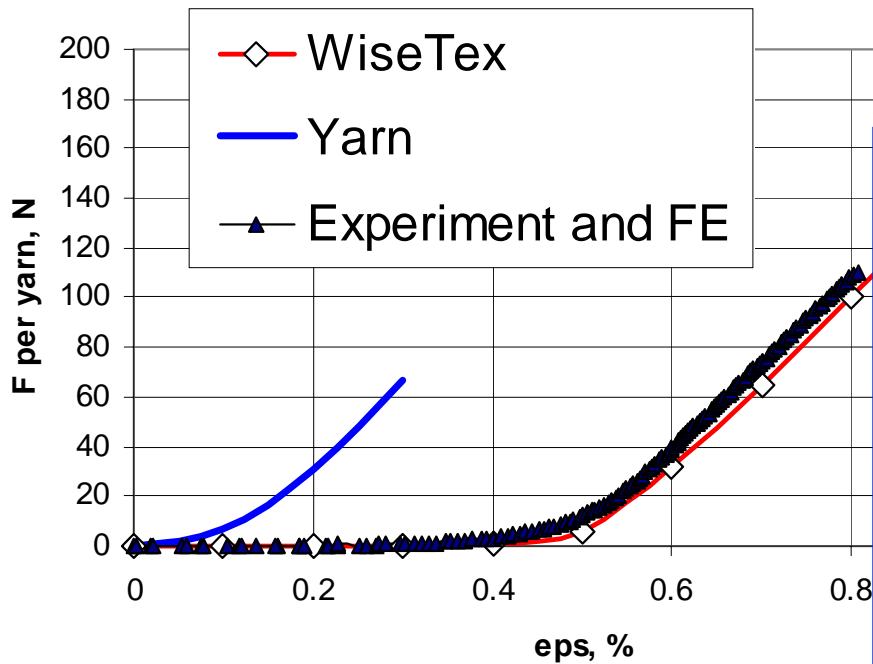




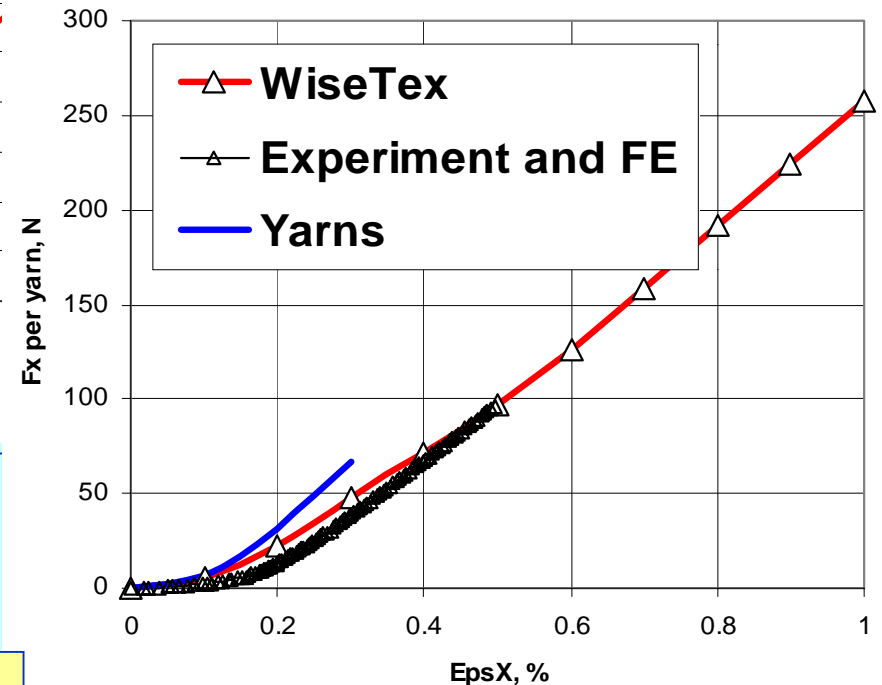
Biaxial tension: Results



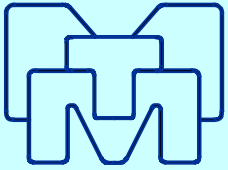
Free Y



EpsX = EpsY



Experimentants and FE: Ph.Boisse



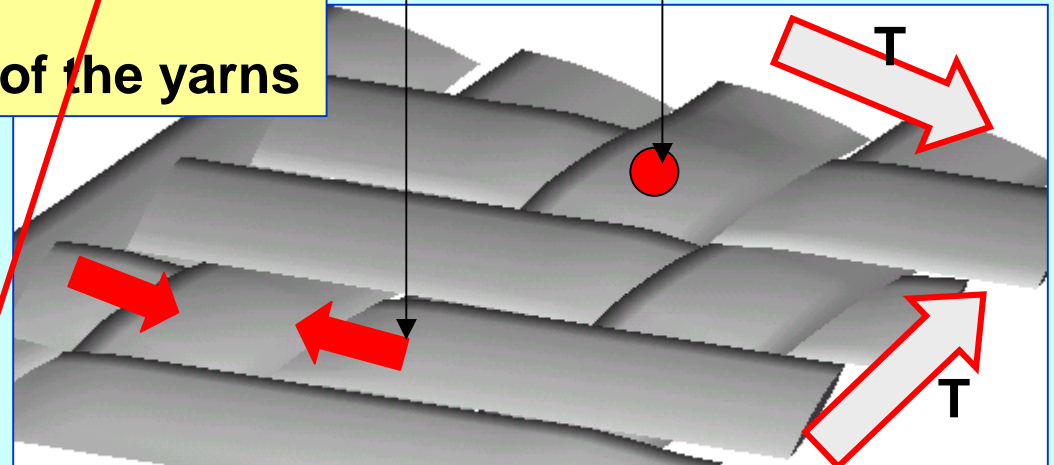
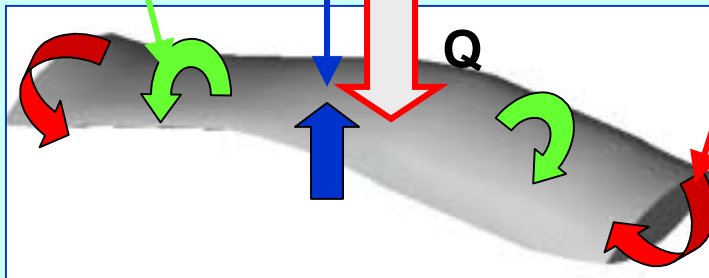
Shear: Model



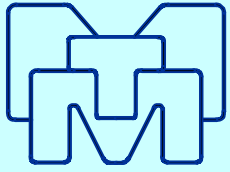
Components of shear resistance:

- **Friction** between the yarns
- **Lateral compression** of the yarns
- **(Un) bending** of the yarns
- **Torsion** of the yarns
- **Vertical displacement** of the yarns

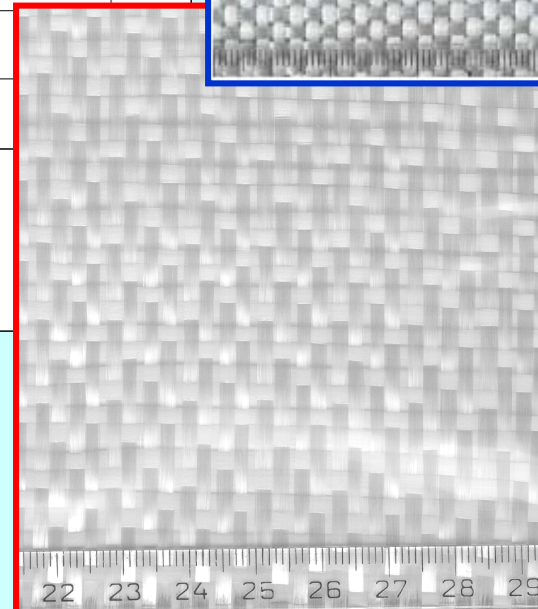
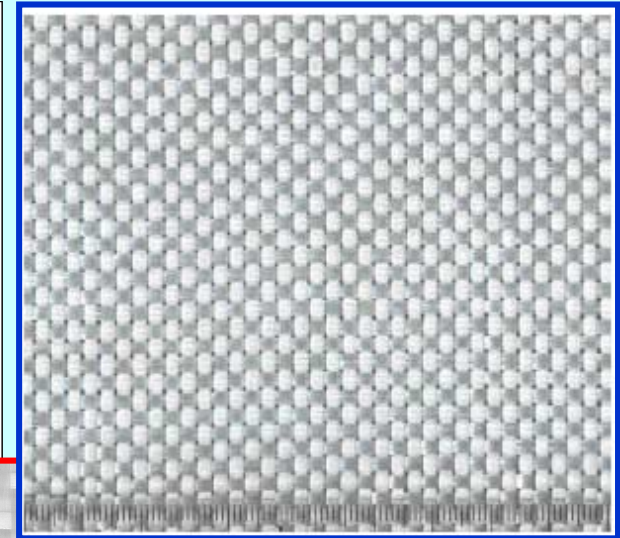
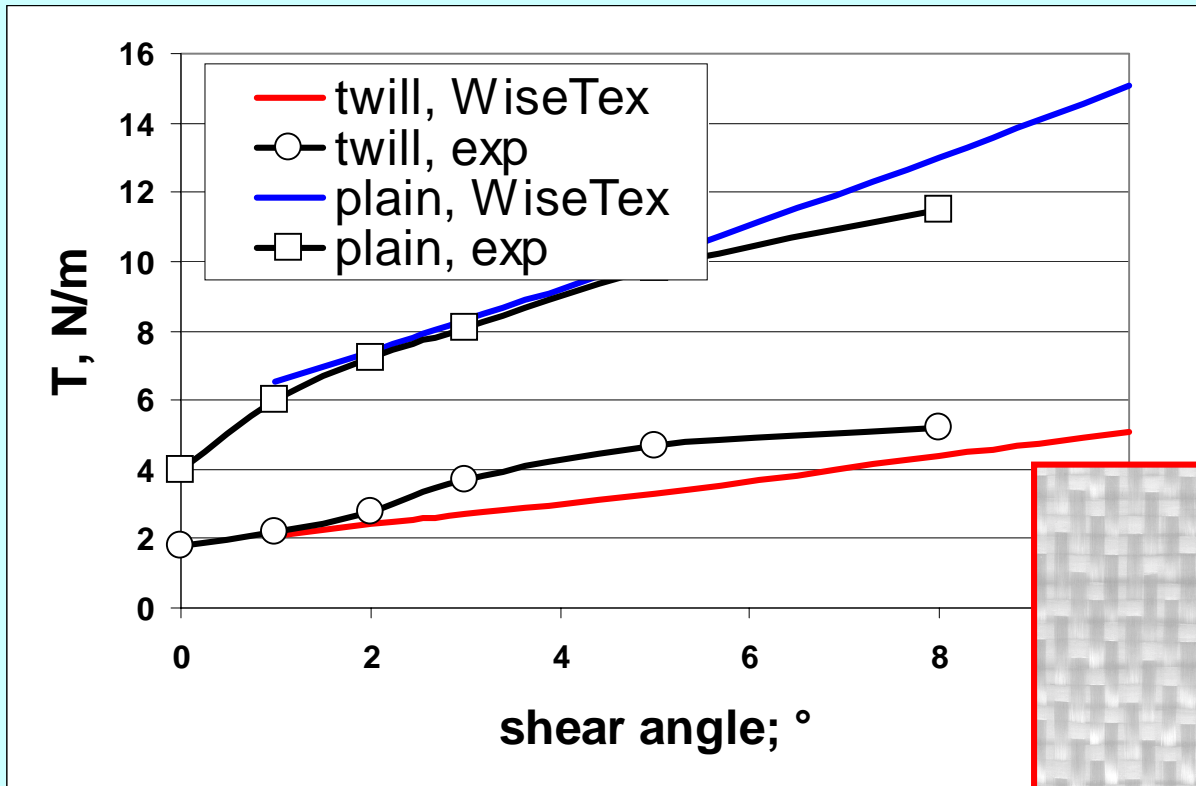
$$A(\gamma) = \sum A_i(\gamma) \\ = TXY\gamma \cos \gamma$$

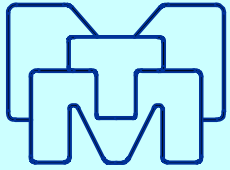


$$Q = Q_{bending} + Q_{tension} + Q_{compression}$$



Shear: Results – KES-F range

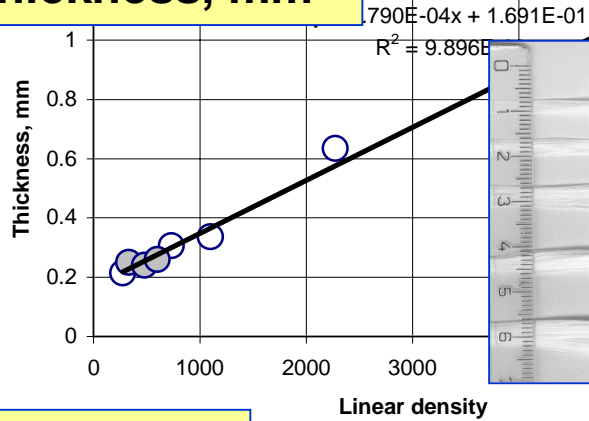




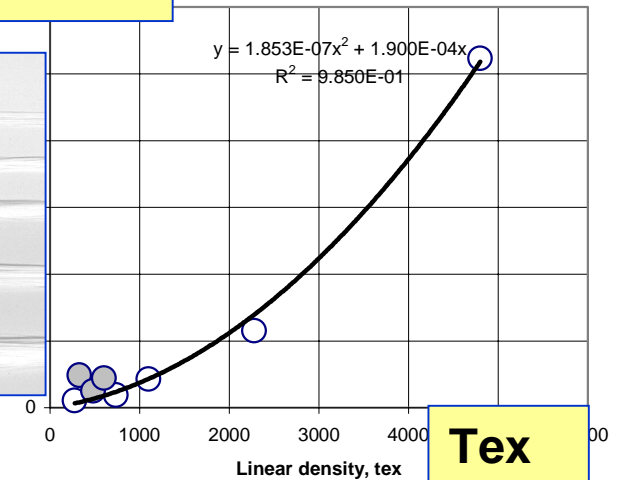
Master diagrams for glass rovings



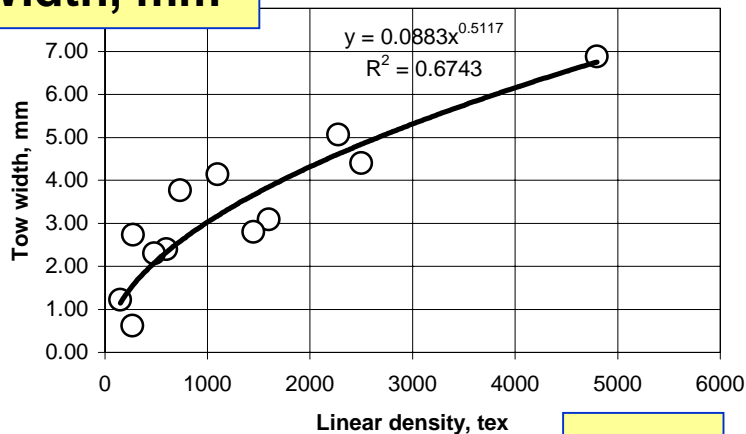
Thickness, mm



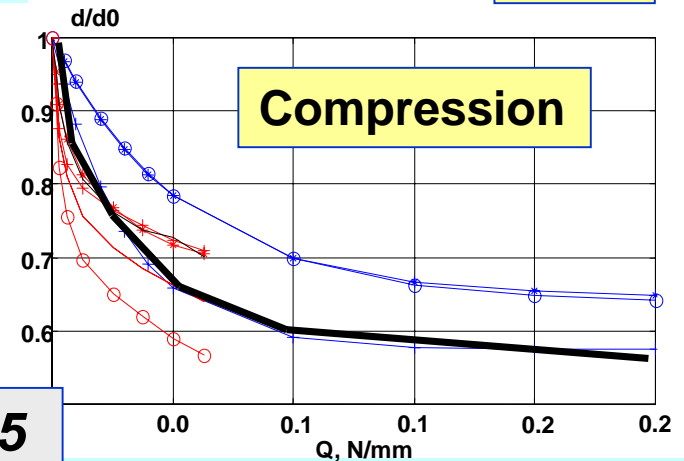
B, N mm²

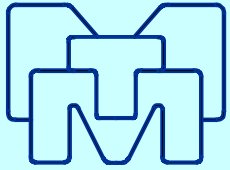


Width, mm

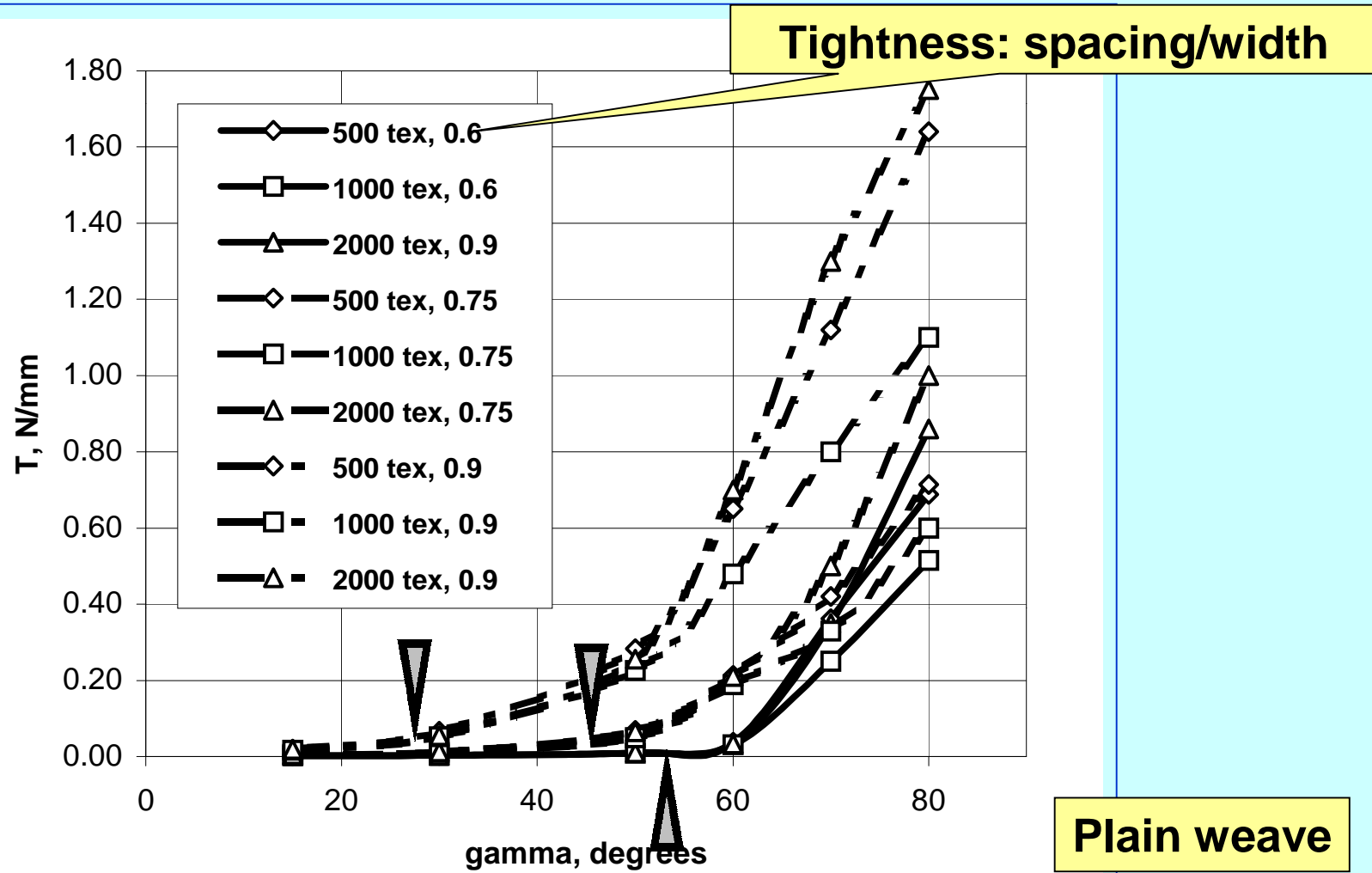


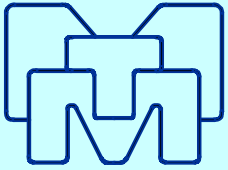
f = 0.25





Shear: Results – picture frame range



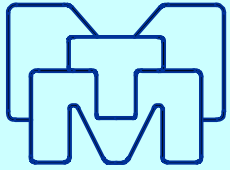


1. **“Micro-macro” modelling chain**
2. ***WiseTex* textile deformability models**

- **Compression**
- **Biaxial tension**
- **Shear**

3. Availability of experimental data

- **Internal geometry**
- **Mechanical properties of yarns**
- **Compressibility of fabrics**
- **In-plane deformation of fabrics**



Data: Internal geometry

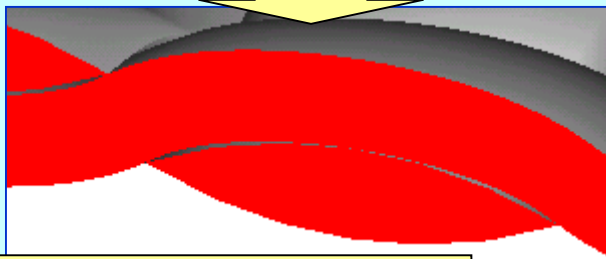


Data: dimensions of yarn cross-sections

Calculation using data on yarn compressibility and bending rigidity



Solid yarns



Compressible yarns

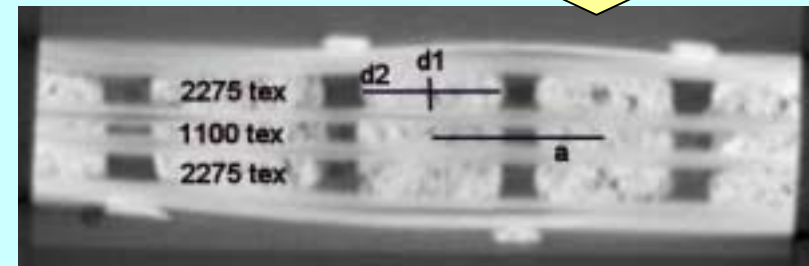
Direct measurements

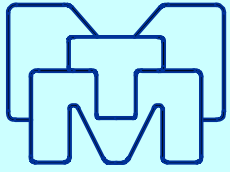
Optical microscopy:

- Make a cross-section
- Polish it
- Make an image
- ... and again

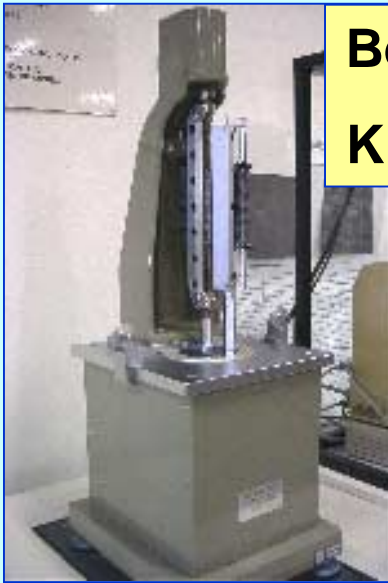
X-ray tomography:

- Resolution 20 μm
- Bad contrast: carbon
- Good contrast: glass

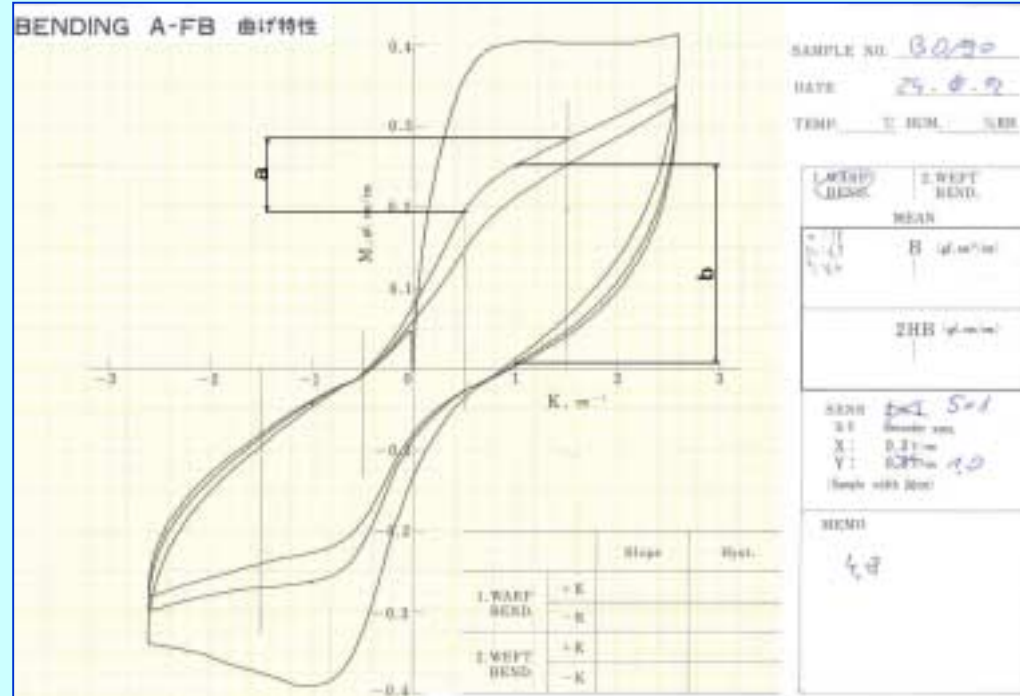




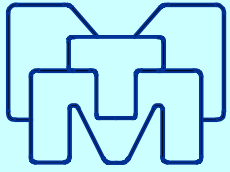
Data: Mechanical properties of yarns (1)



**Bending
KES-F**



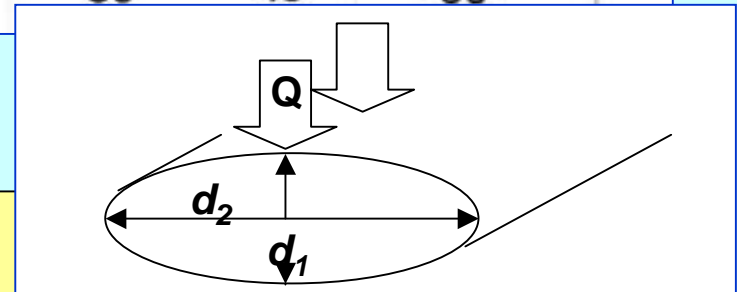
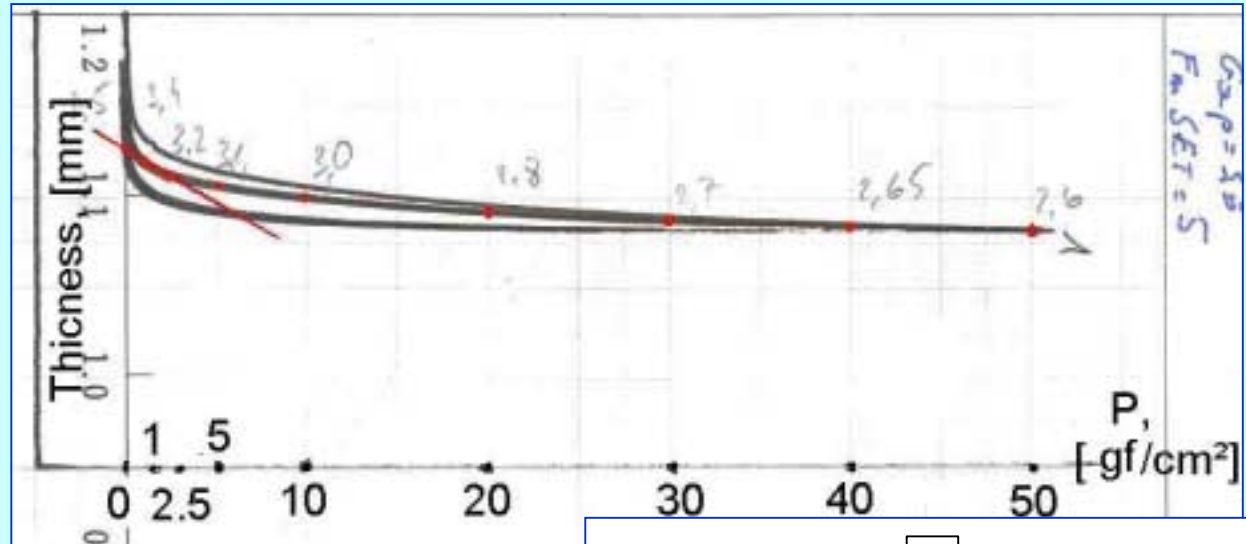
- High non-linearity
- Arbitrary chose of the curvature scope
- Possible parasite stiffness for sized and heavy tows – use 2nd cycle
- Reasonably reliable measurement



Data: Mechanical properties of yarns (2)

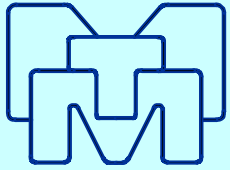


Compression:
KES-F



- Large scatter
- Unreliable initial thickness – use interpolation
- Reasonably reliable measurement for d_1
- No standardised technique for d_2 – use empirical relations

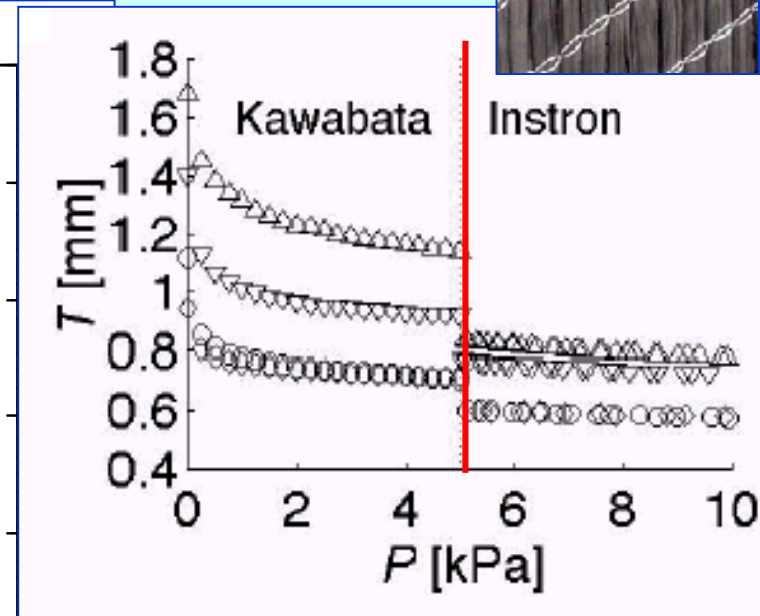
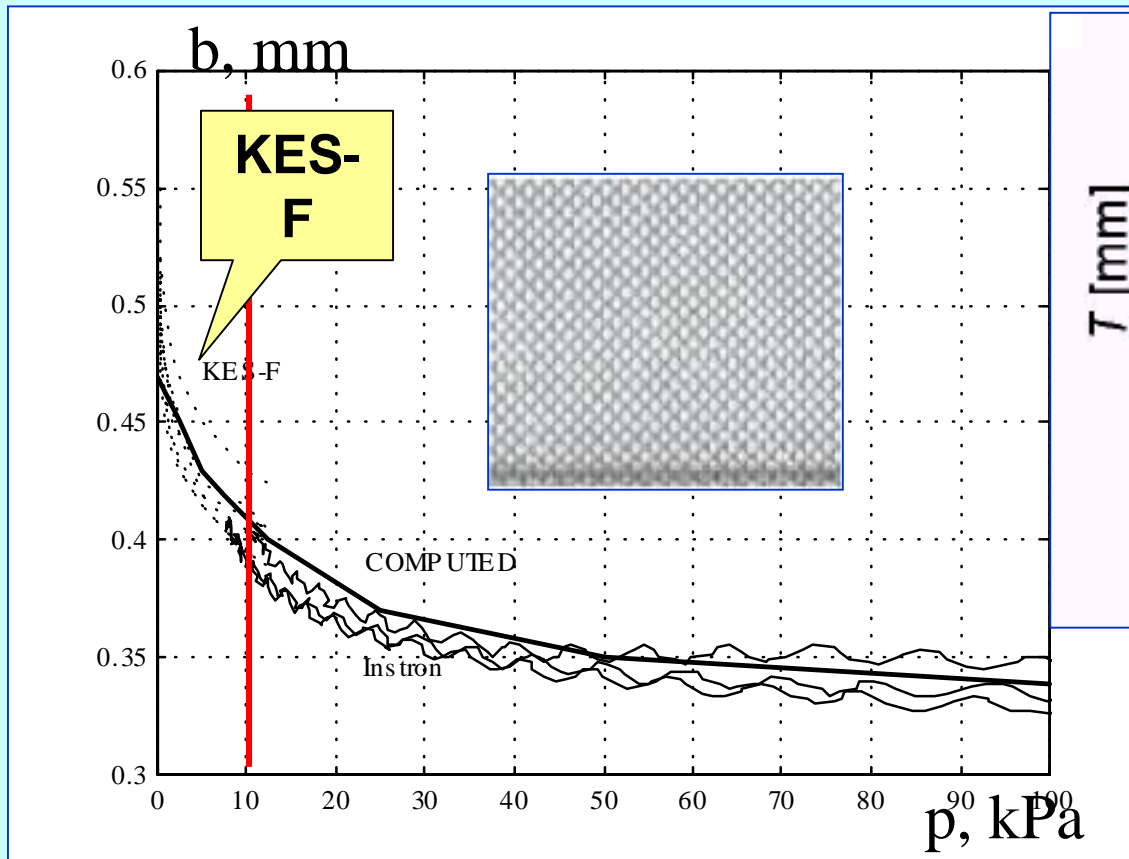
$$\eta_2 = \eta_1^{-1/3 \dots -1/2}$$



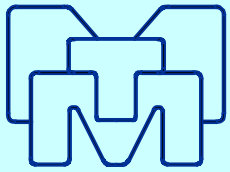
Data: Compressibility of fabrics



Problem: Measurement at lower/higher pressure range



Relaxed thickness found by interpolation



Data: Fabric tension

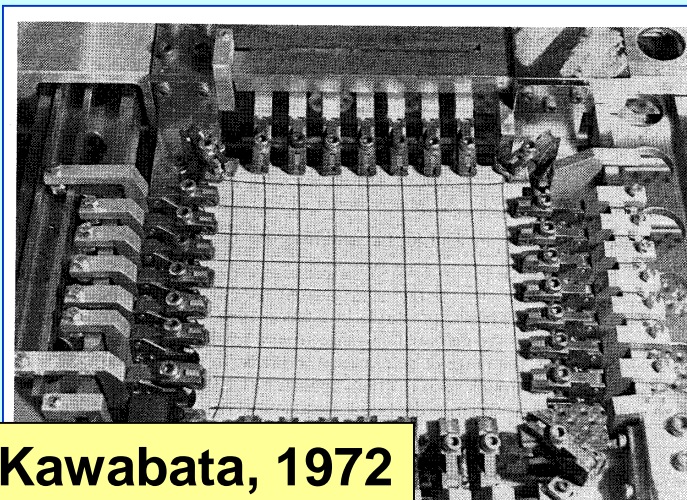


ENSAM Paris

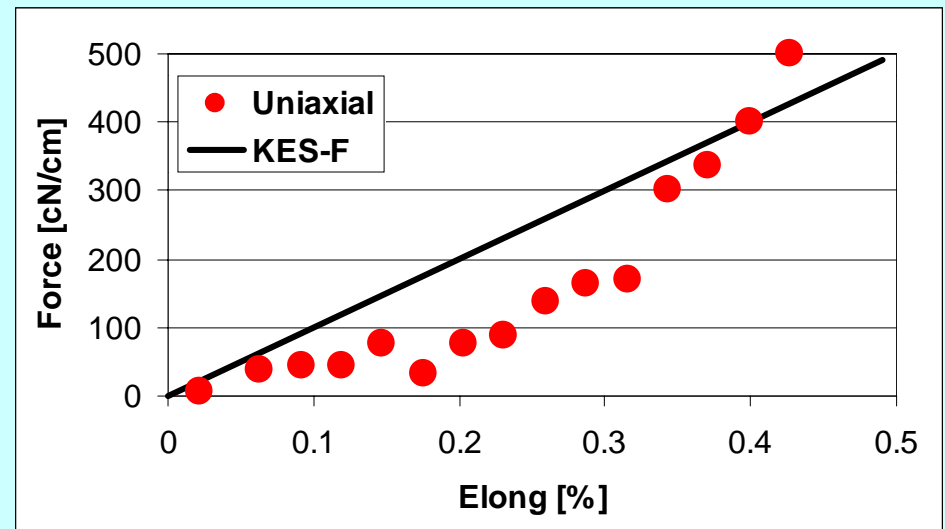
Biaxial machines

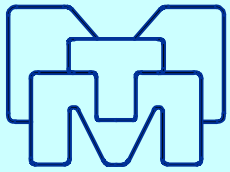


KU Leuven

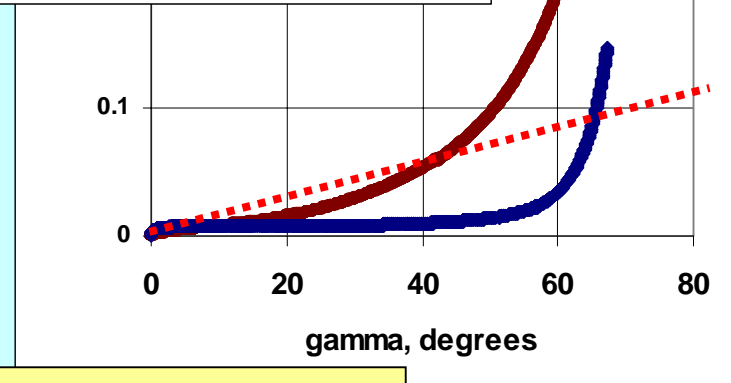
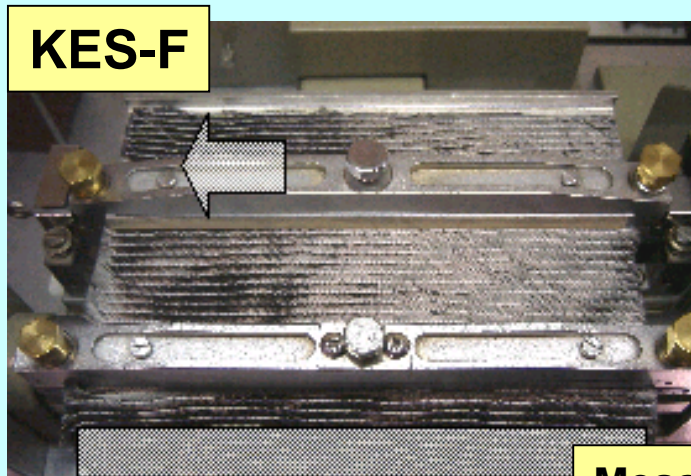
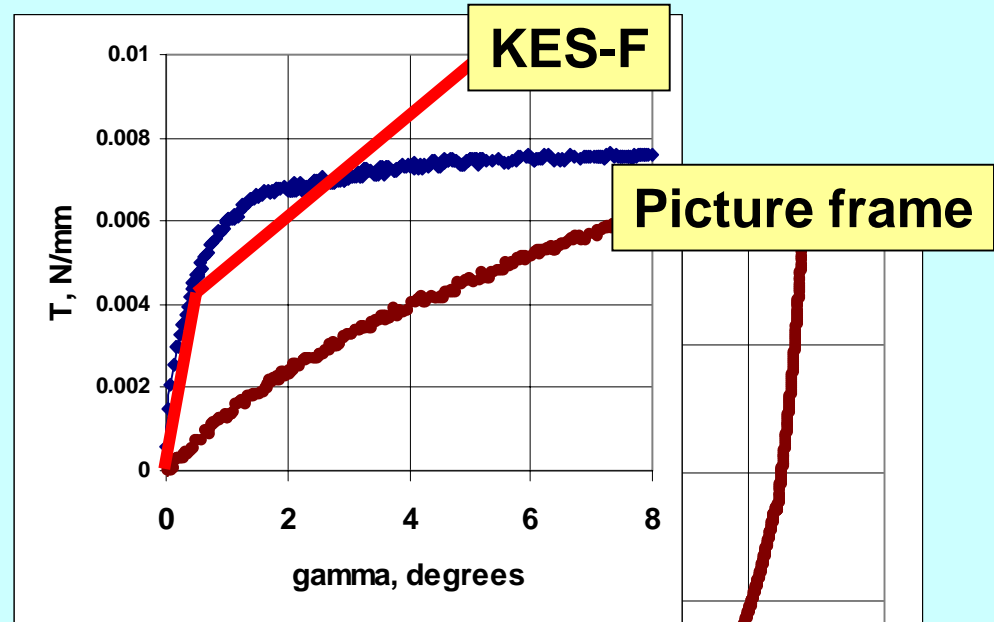
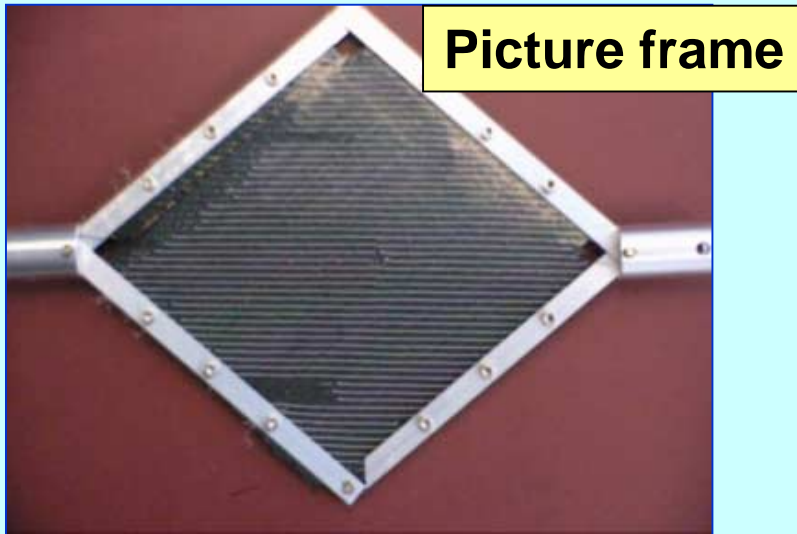


Kawabata, 1972

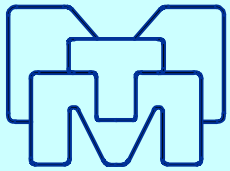




Data: Fabric shear (1)



Measurements: J. Verrey, M. Barburski

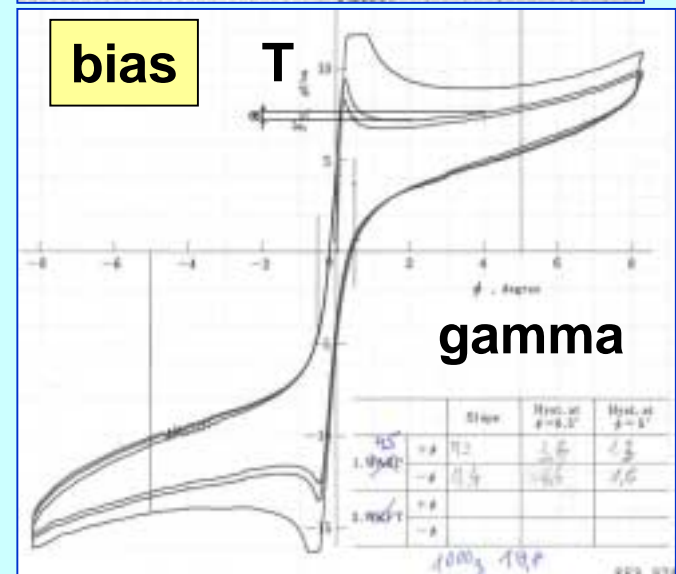
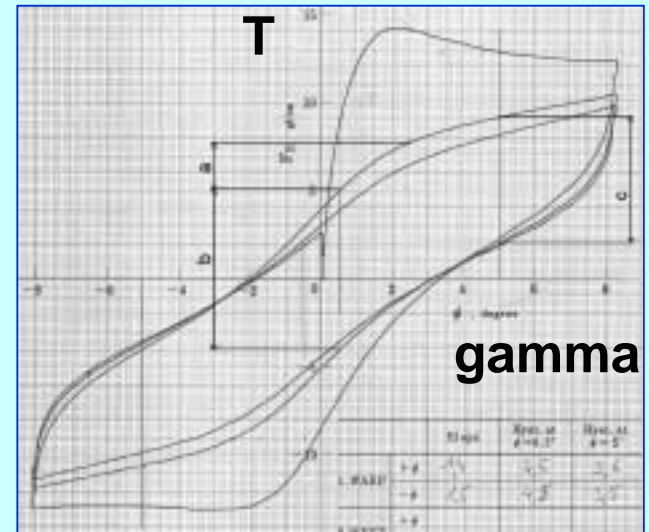


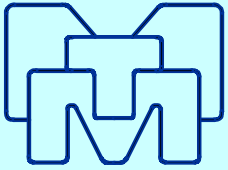
Data: Fabric shear (2)



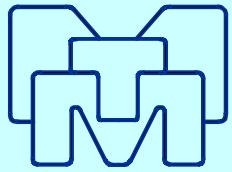
Problems:

- Parasite stiffness – use 2nd cycle
- Wrinkling
- Testing with fibres in bias direction

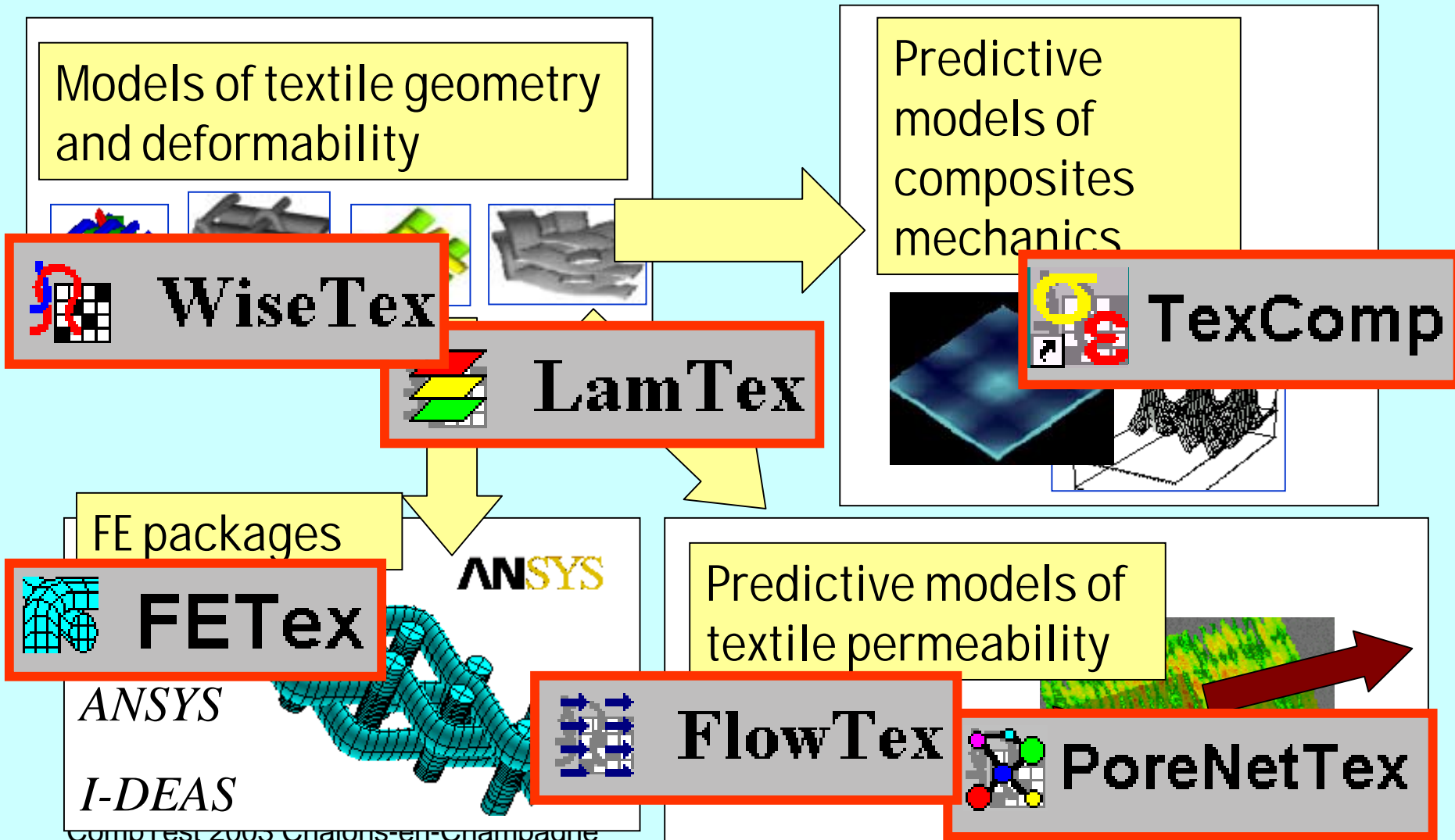


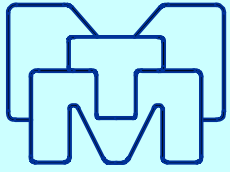


To conclude...



"WiseTex" software family...





... asks for established testing techniques



1. **Internal geometry:** Optical microscopy, X-ray 3D analysis, reliable models
2. **Compressibility of yarns:** KES-F, need for the “second direction” method
3. **Bending rigidity of yarns:** KES-F
4. **Compressibility of fabrics:** KES-F + standard machines, investigations needed in combining the two
5. **Tension:** Biaxial machines, needed: normalisation of the experimental procedure (gripping, sample size etc)
6. **Shear:** Uncertainty with shear frame measurements, difficulties with KES-F for stiff fabrics
7. **Full field strain registration:** Does not exist for textiles