MANCHESTER 1824

The University of Manchester

CompTest 2008, Dayton, OH

Meso-scale strain mapping in Plain and UD woven composites

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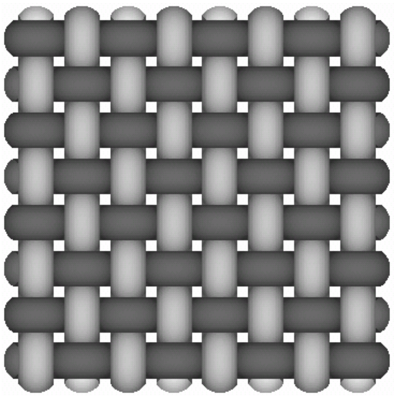
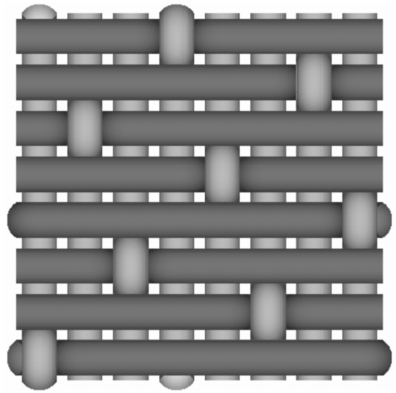
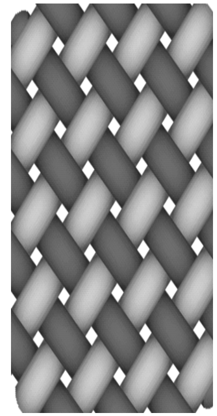
Textile Composites



Plain weave

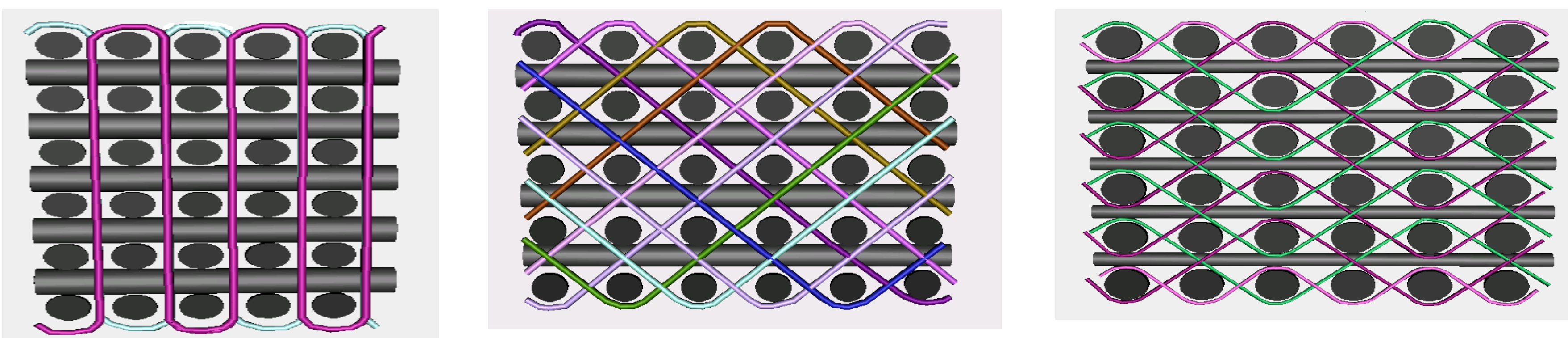


5-end sateen weave



braided structure

Non-crimp fabric (NCF)



3D weaves

Motivation

- **In dry textiles, interaction between reinforcing and binding tows results in local perturbations.**
- **Processing (compaction, drape etc) leads to further tow geometry changes in Textile Composites**
- **Limited experimental data is available on local strain distribution**

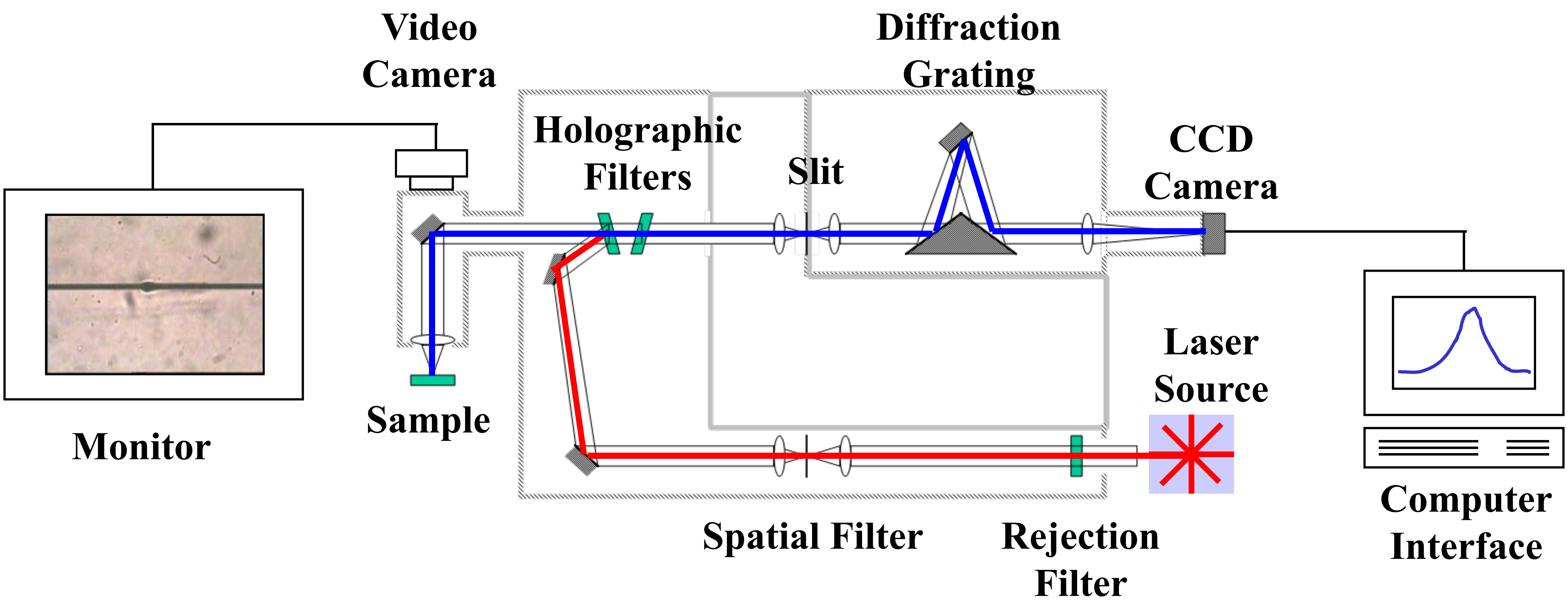
Strain Measurement

- Strain Gauges
- Bragg grating sensors (>100μm dia)
- DIC
- **Reinforcing fibers as strain gauges**

Outline

- Reinforcing fibers as strain gauges (gauge length =2 µm)
- Geometry of balanced Plain Weaves
- Strain gradients in ‘plain weave’ textile composites
- Prediction of limit strengths
- Geometry of UD weaves influenced by compaction
- Strain gradients in UD composites
- Discussion

Optical/Raman microscope

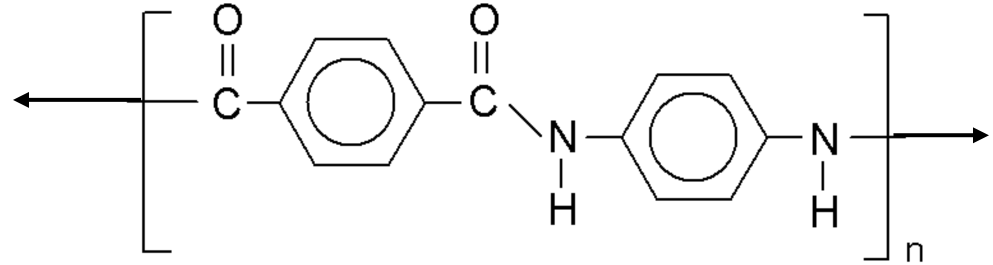


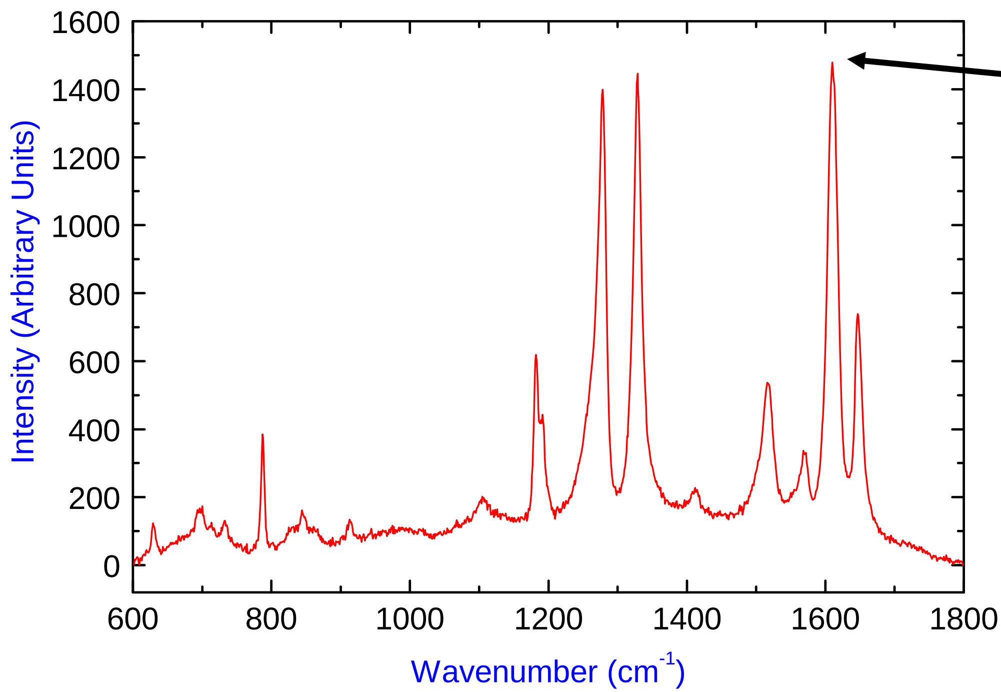
Laser spot size - 2 μm

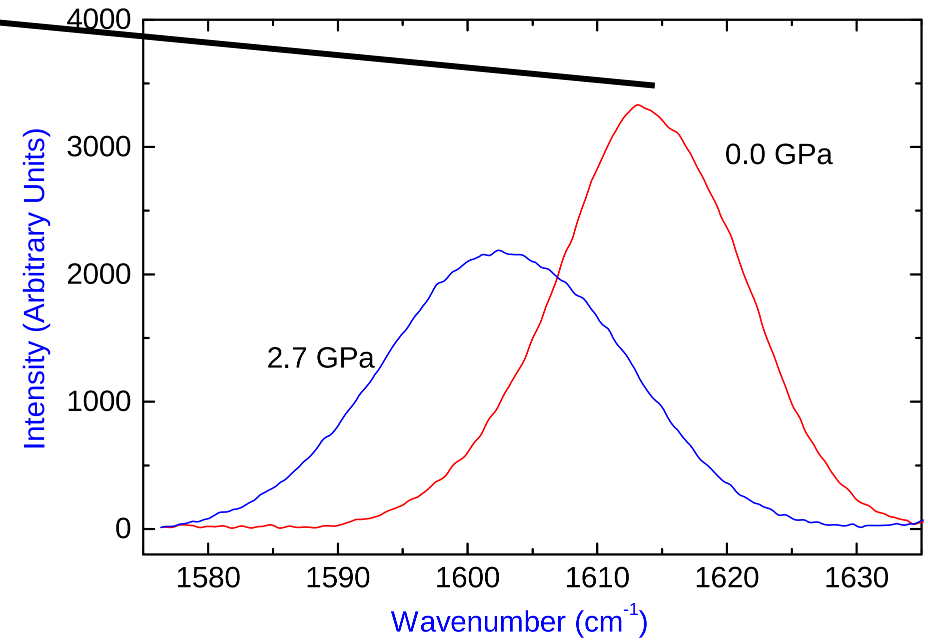
Raman Spectrum

Kevlar 49

1610 cm^{-1} Band
Aromatic Ring Stretching Mode





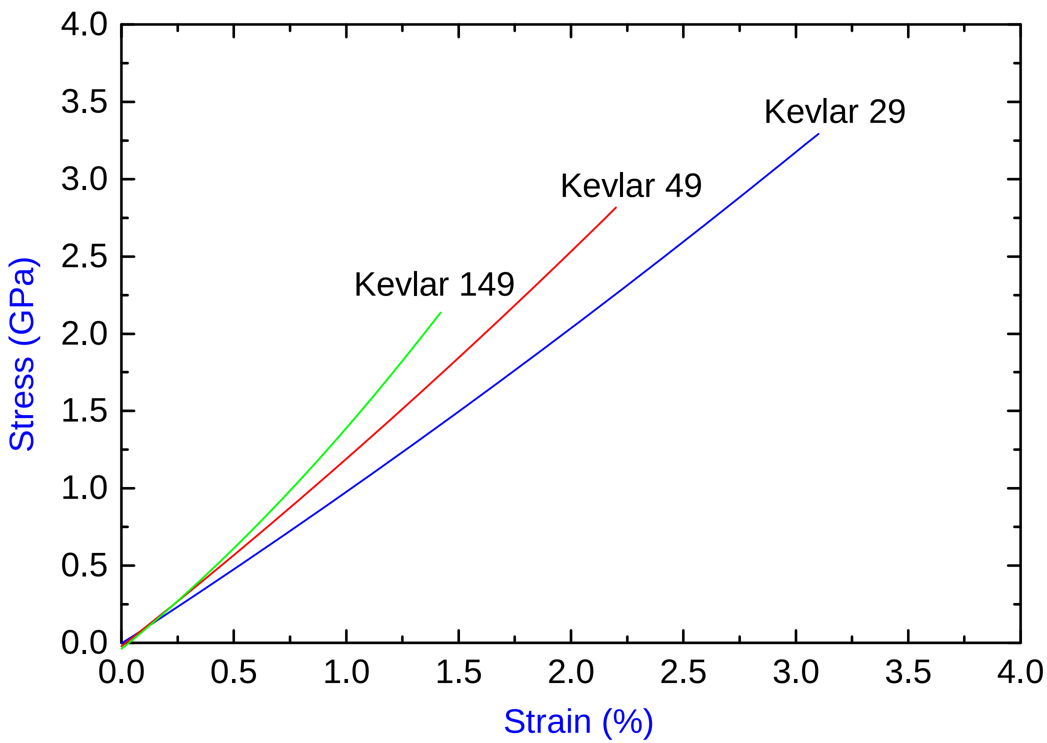


Full Raman Spectrum

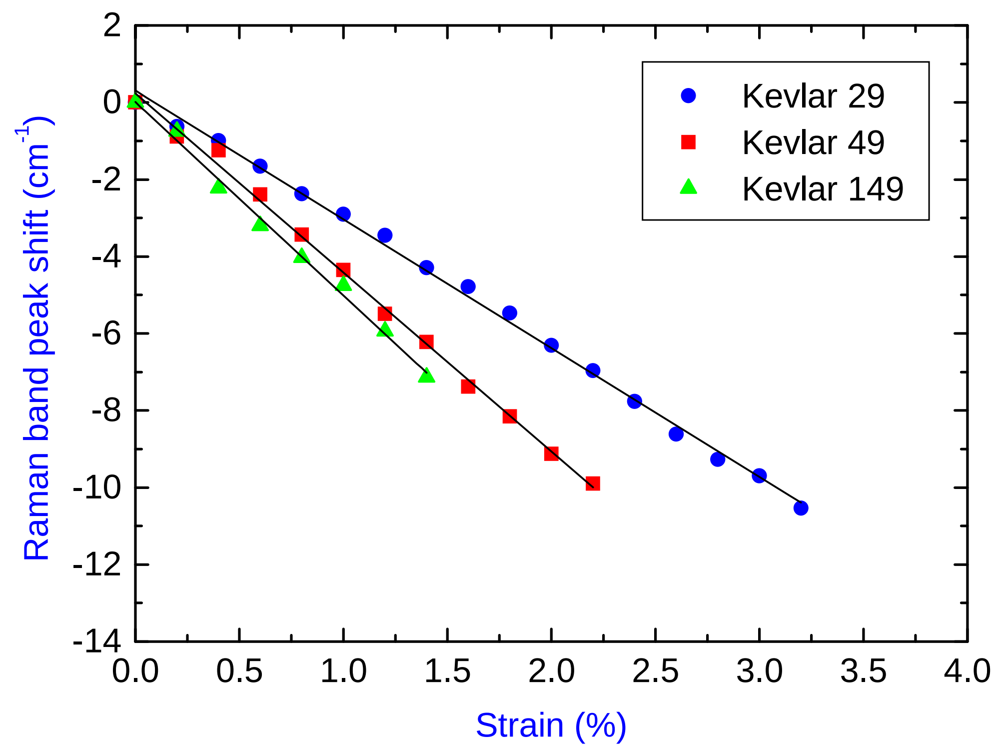
Stress-induced Band Shift

Strain-Induced Band Shifts

SINGLE FIBER DEFORMATION

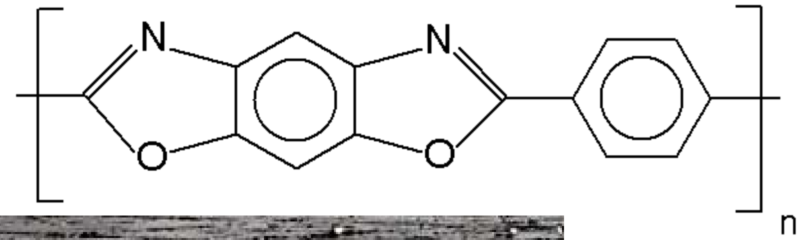


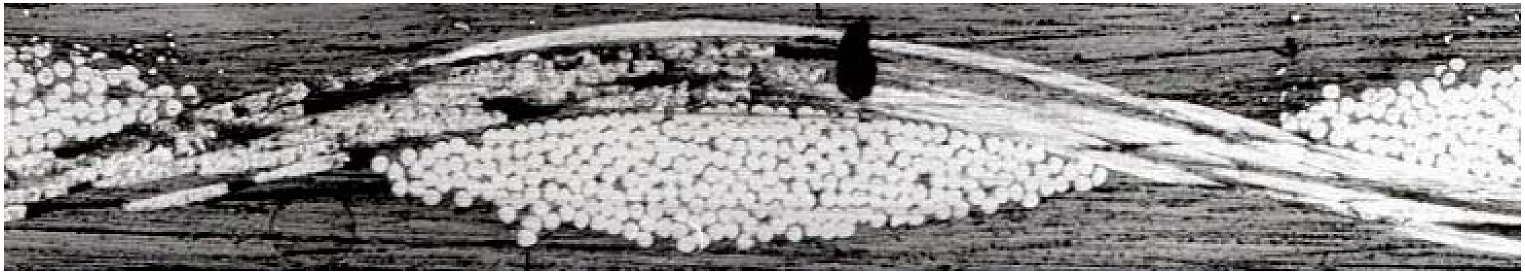
Stress-strain curves



Raman band shifts

Plain Woven PBO Composites

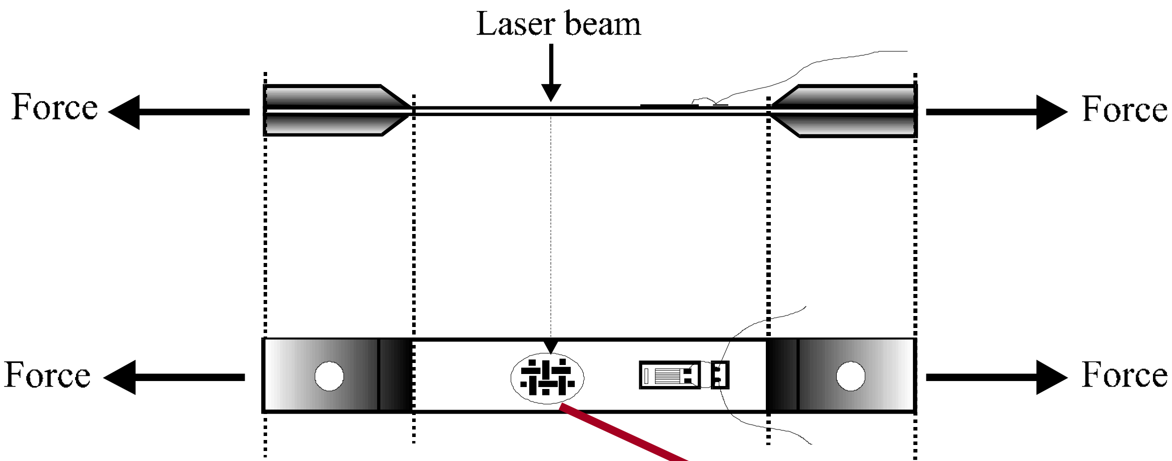




Sample	Fiber treatment	Resin system	Ends/cm	Picks/cm
PBO 1	corona treated	A	9.2	9.2
PBO 2	corona treated	B	9.2	9.2
PBO 3	as spun	B	10	10

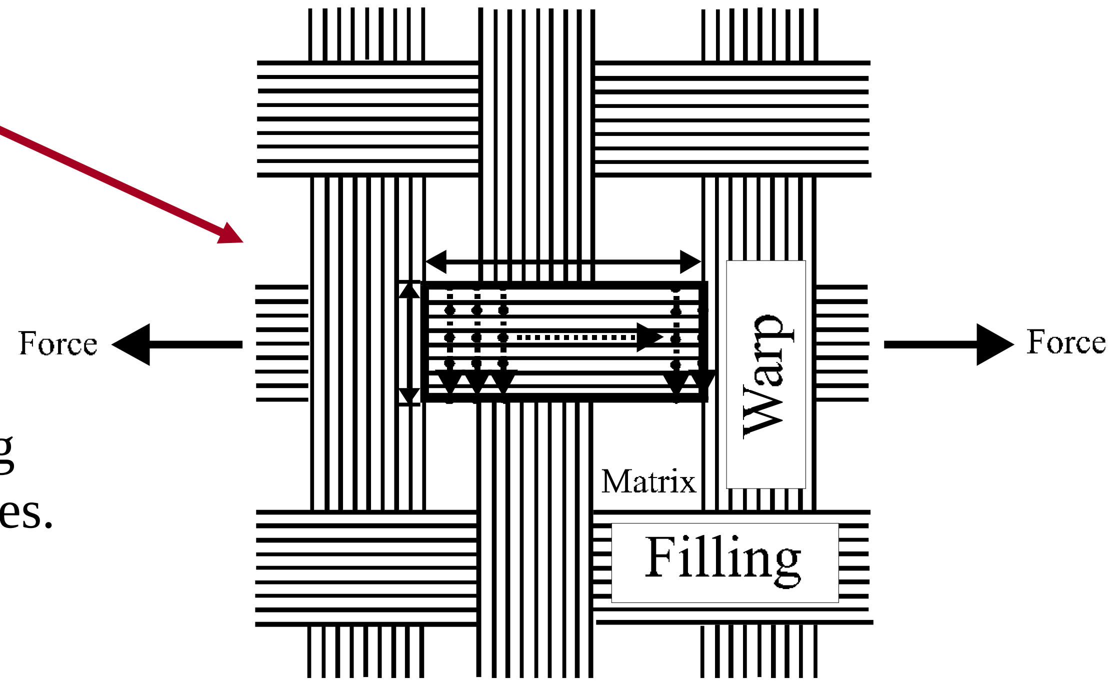
Linear density (Tex)	Number of filaments	Fiber diameter	Density g/cc	E_{11} GPa	E_{22} GPa	G_{12} GPa	γ_{12}
55.5	250	12 μm	1.54	180	0.91	1.02	0.35

Raman Deformation Mapping



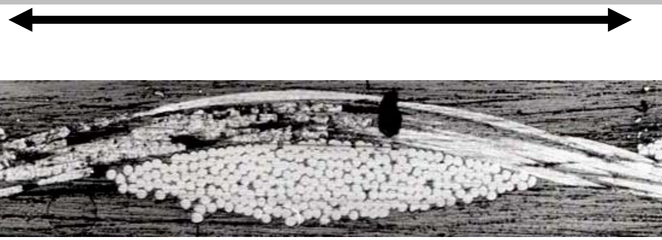
The laser beam was always polarised parallel to the axis of both the fibres and the applied force

The woven composites were deformed in the axial direction

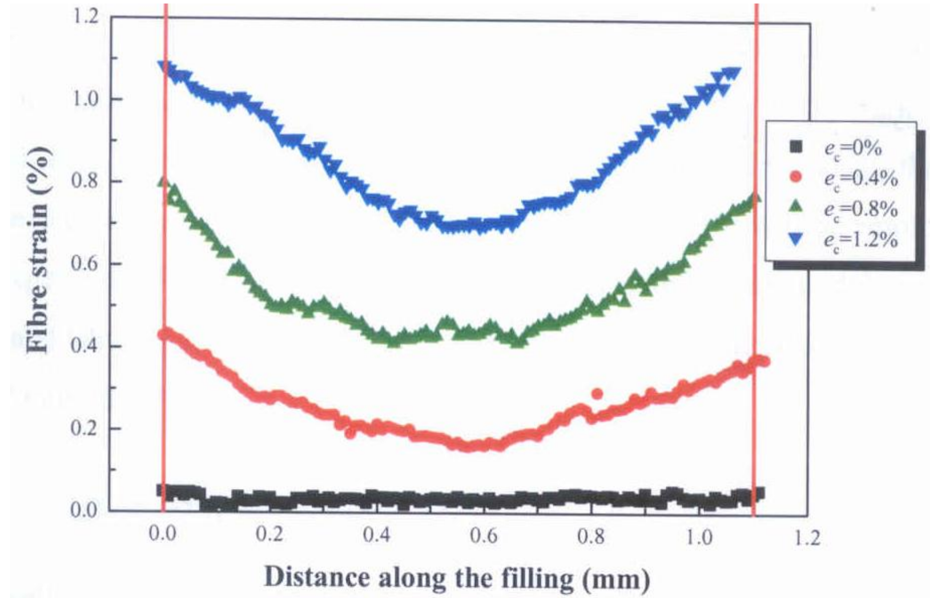


Fibre deformation was mapped during the deformation of the woven composites. The overall composite strain was determined from the strain gauge

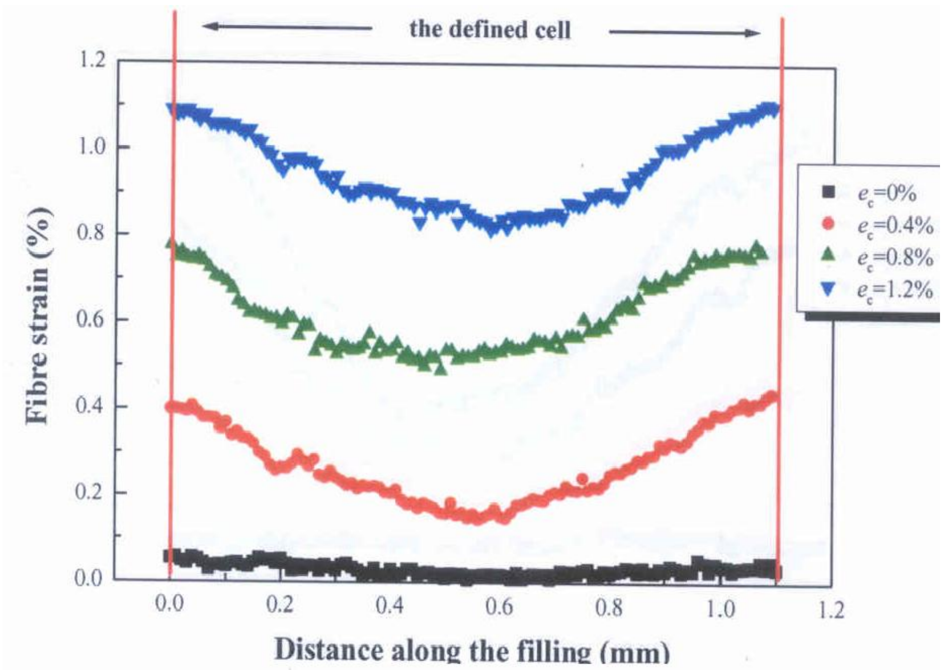
1D Strain Distributions along tow centre line



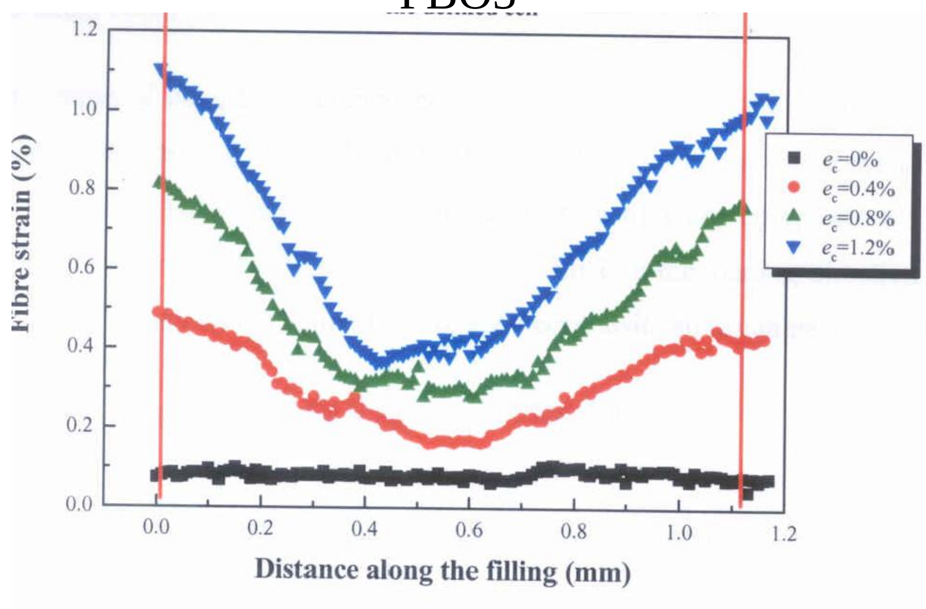
PBO2



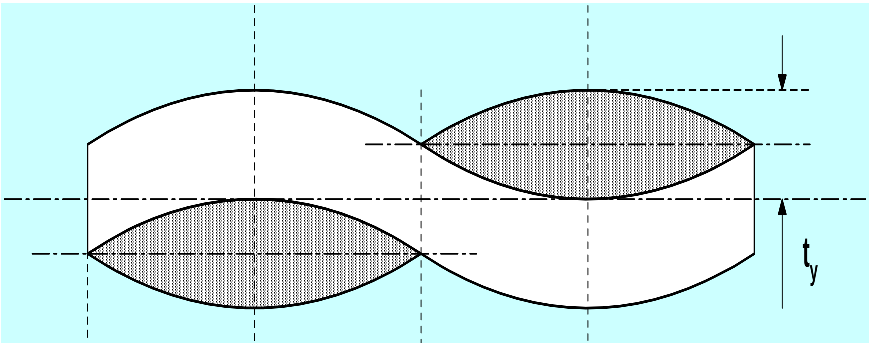
PBO1

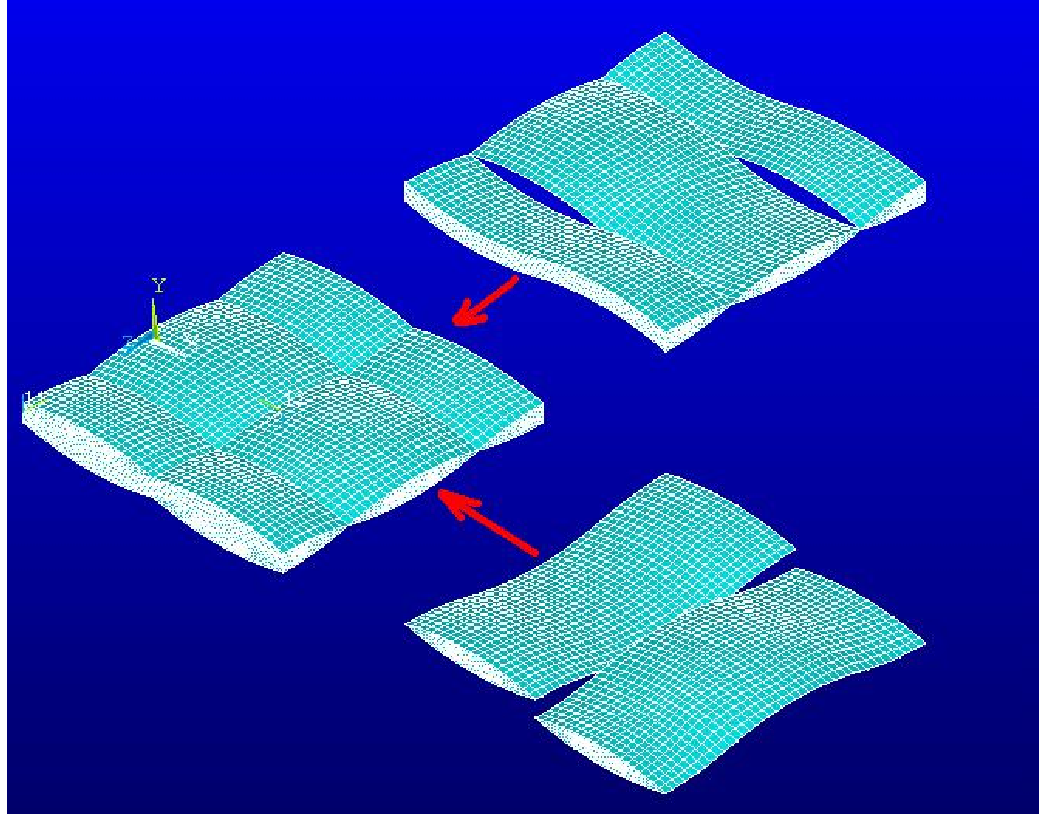


PBO3



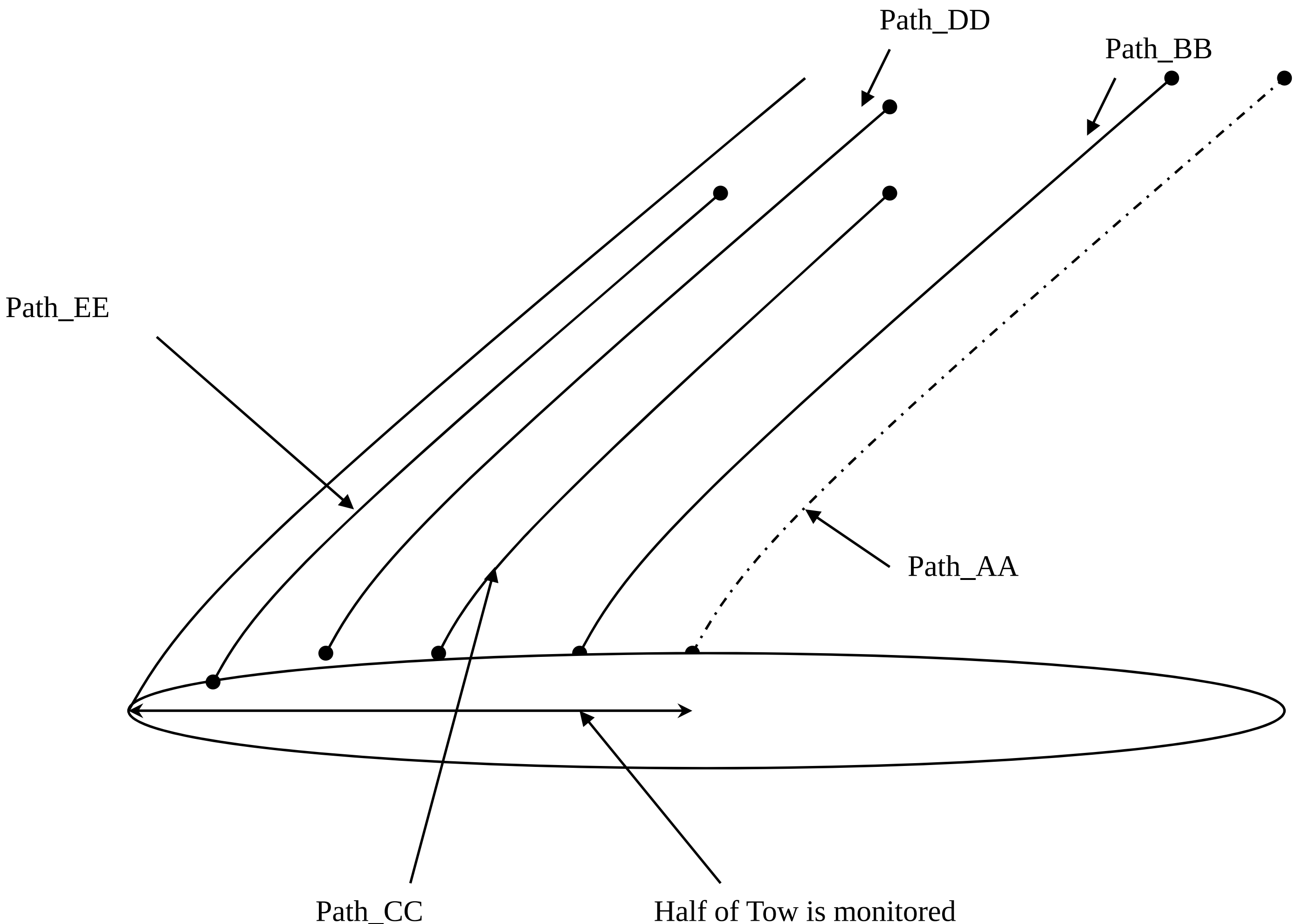
Lenticular Geometry



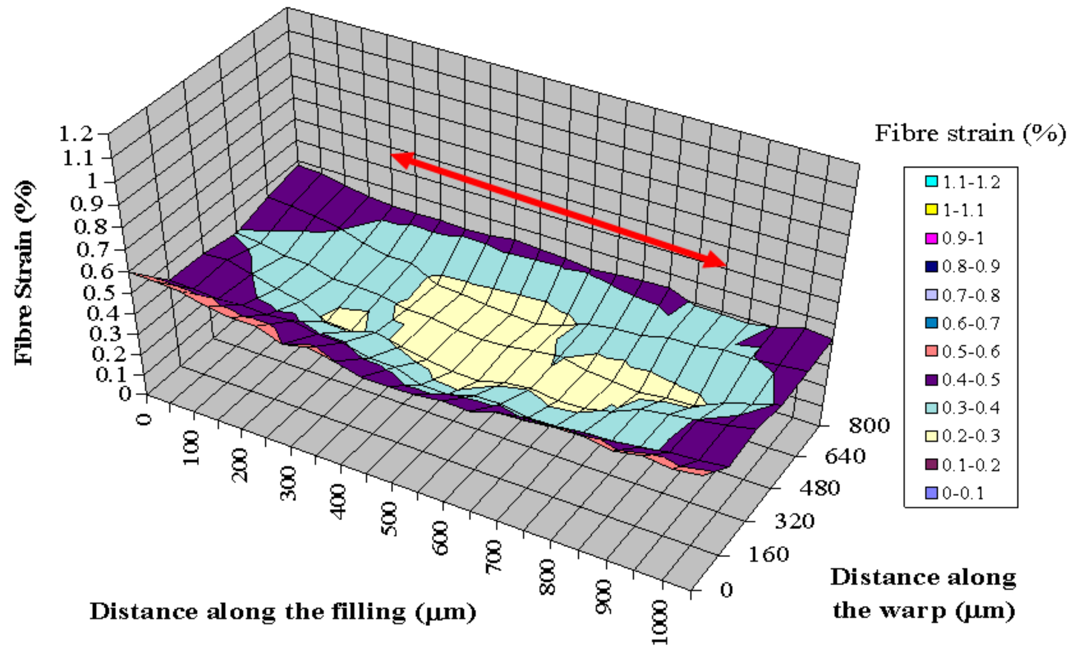


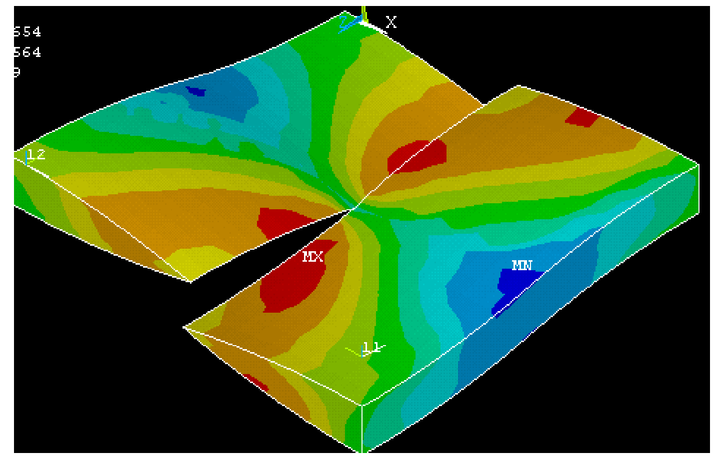
Sample	Yarn width mm	Yarn (t) thickness mm	(R) Radius of lenticule	ϕ (deg) Off-axis angle	(A) mm² Yarn cross-section area	(ρ_d) yarn packing factor
PBO1	1.1	0.074	4.11	7.7	0.0542	0.6655
PBO2	1.1	0.103	2.98	10.6	0.0753	0.478
PBO3	1.02	0.129	2.06	14.3	0.0885	0.4069

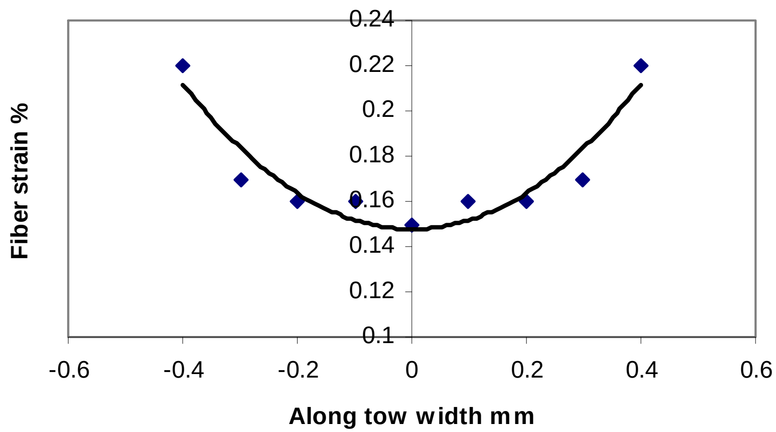
Computing 2D strains in a tow

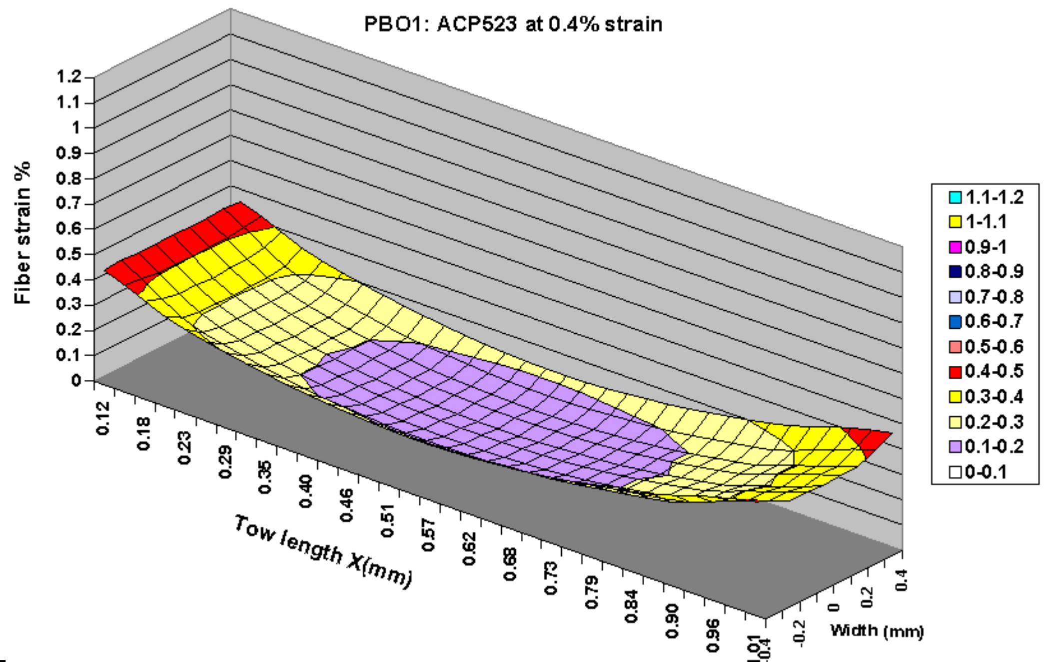


PBO1: ACP 523 0.4% strain

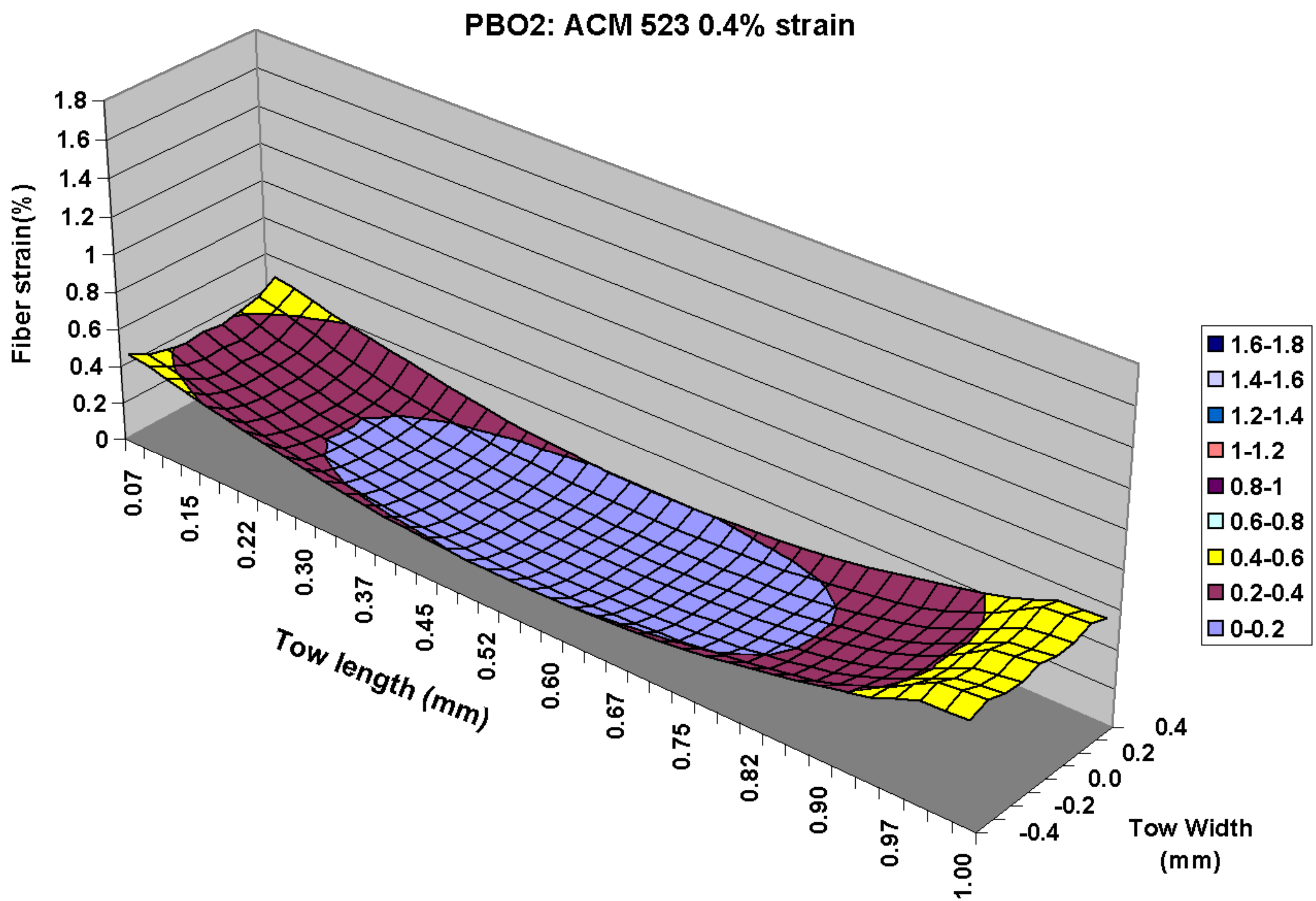




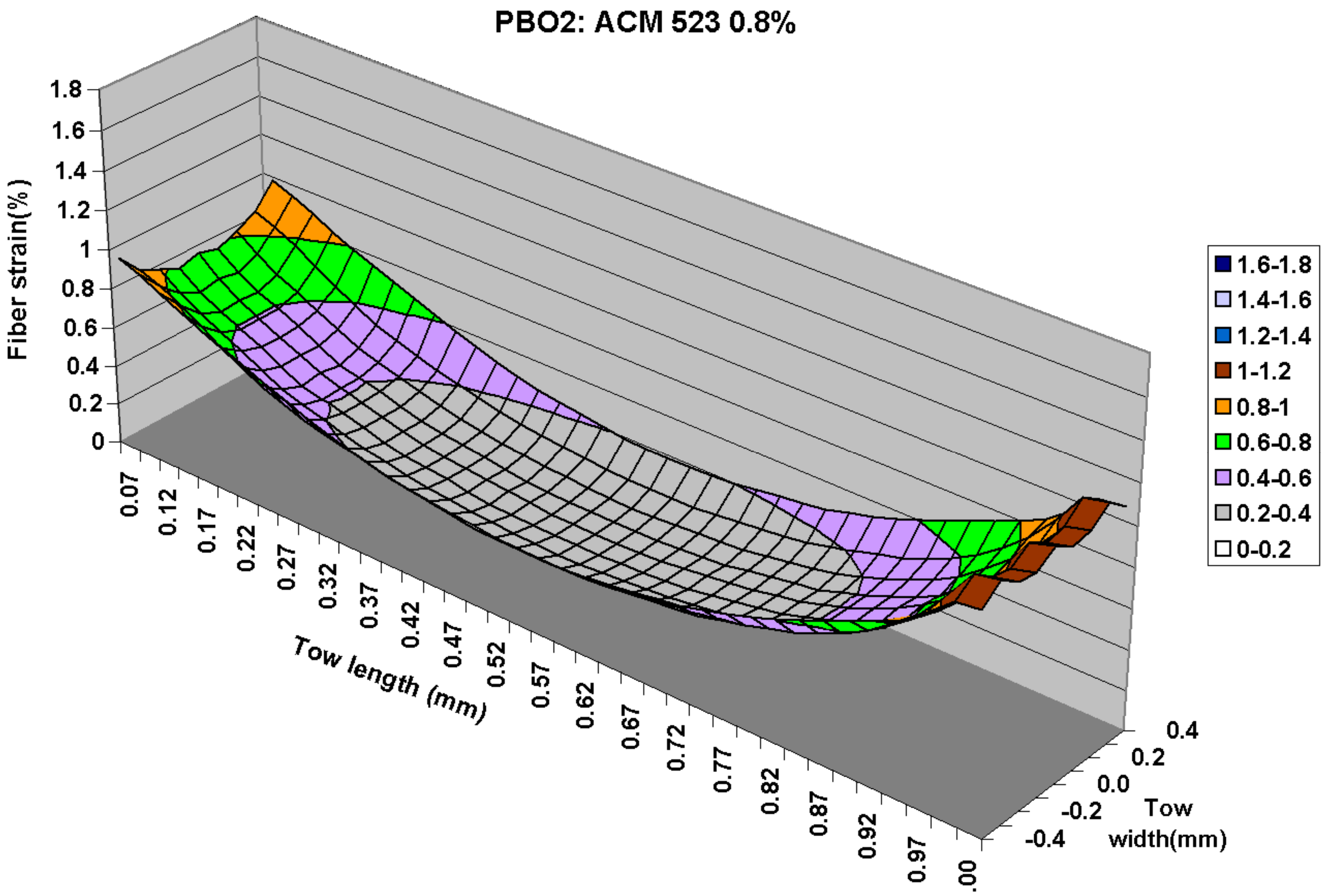




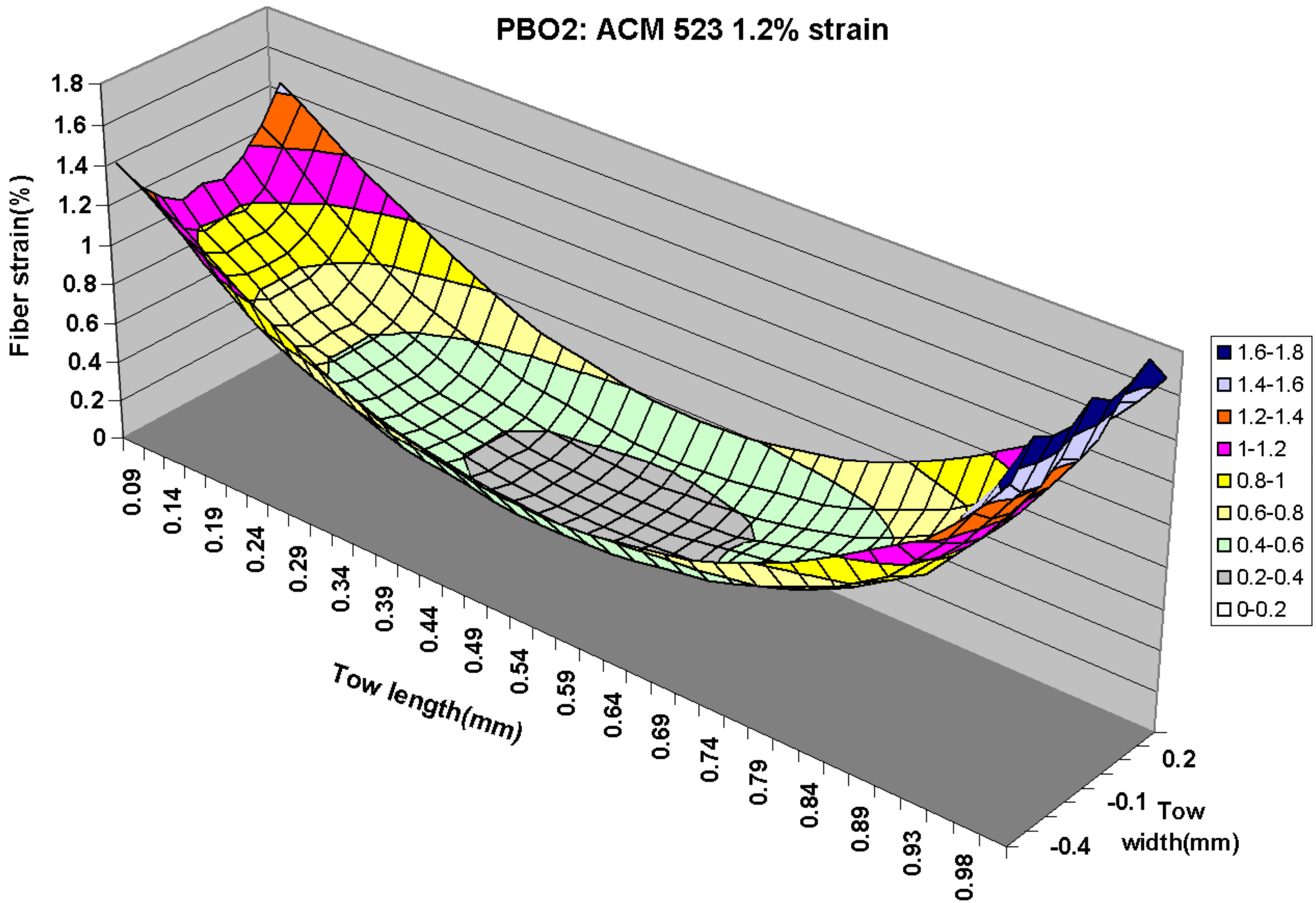
strain distribution across tow width



PBO2: ACM 523 0.4% strain
Fiber strain(%)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.07
0.15
0.22
0.30
0.37
0.45
0.52
0.60
0.67
0.75
0.82
0.90
0.97
1.00
Tow length (mm)
0.4
0.2
0.0
-0.2
-0.4
Tow Width (mm)
1.6-1.8
1.4-1.6
1.2-1.4
1-1.2
0.8-1
0.6-0.8
0.4-0.6
0.2-0.4
0-0.2

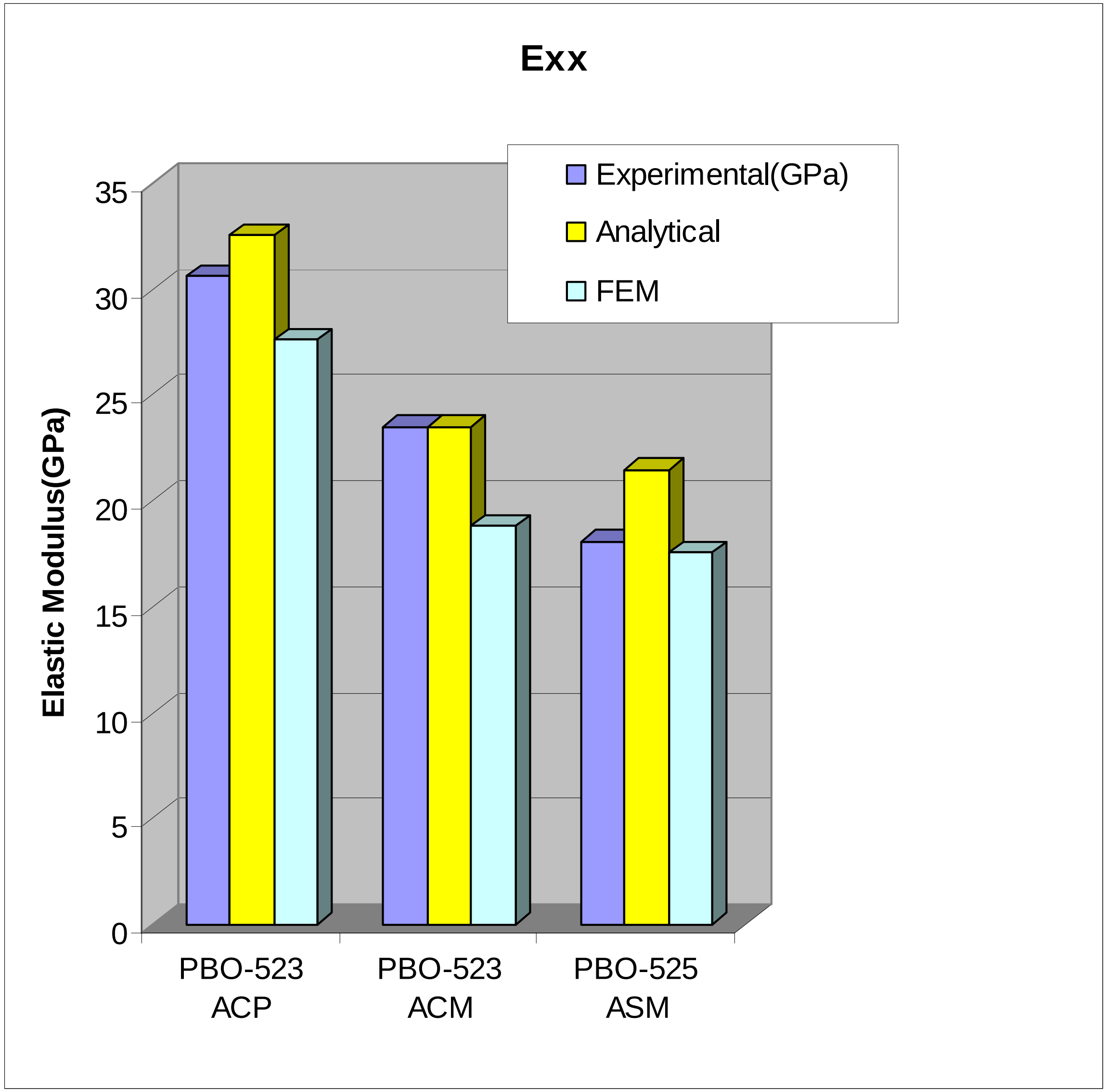


PBO2: ACM 523 0.8%
Fiber strain(%)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Tow length (mm)
0.07
0.12
0.17
0.22
0.27
0.32
0.37
0.42
0.47
0.52
0.57
0.62
0.67
0.72
0.77
0.82
0.87
0.92
0.97
1.00
Tow width(mm)
0.4
0.2
0.0
-0.2
-0.4
1.6-1.8
1.4-1.6
1.2-1.4
1-1.2
0.8-1
0.6-0.8
0.4-0.6
0.2-0.4
0-0.2



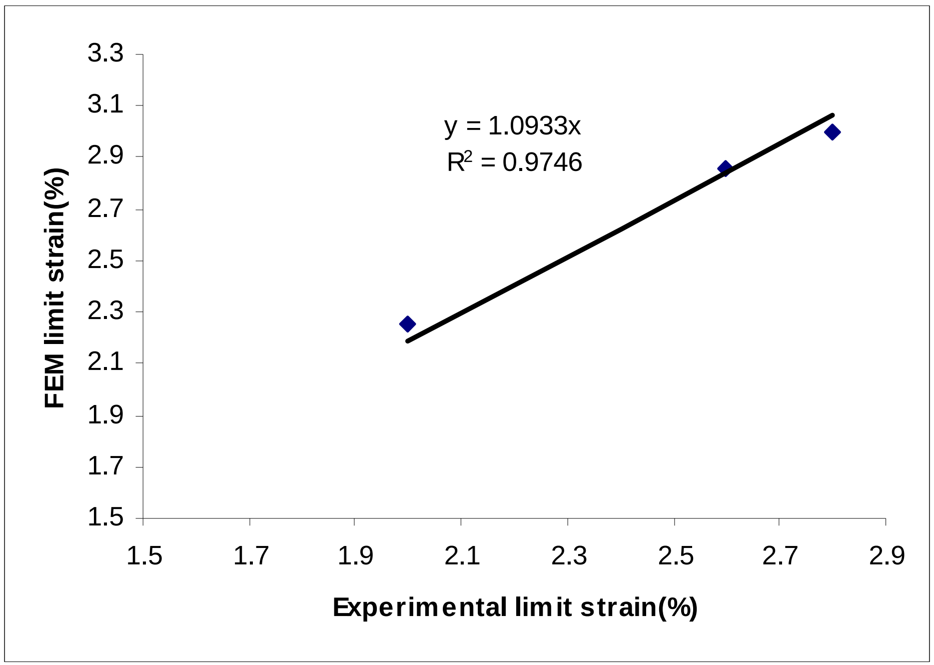
PBO2: ACM 523 1.2% strain
Fiber strain(%)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.09
0.14
0.19
0.24
0.29
0.34
0.39
0.44
0.49
0.54
0.59
0.64
0.69
0.74
0.79
0.84
0.89
0.93
0.98
Tow length(mm)
0.2
-0.1
-0.4
Tow width(mm)
1.6-1.8
1.4-1.6
1.2-1.4
1-1.2
0.8-1
0.6-0.8
0.4-0.6
0.2-0.4
0-0.2

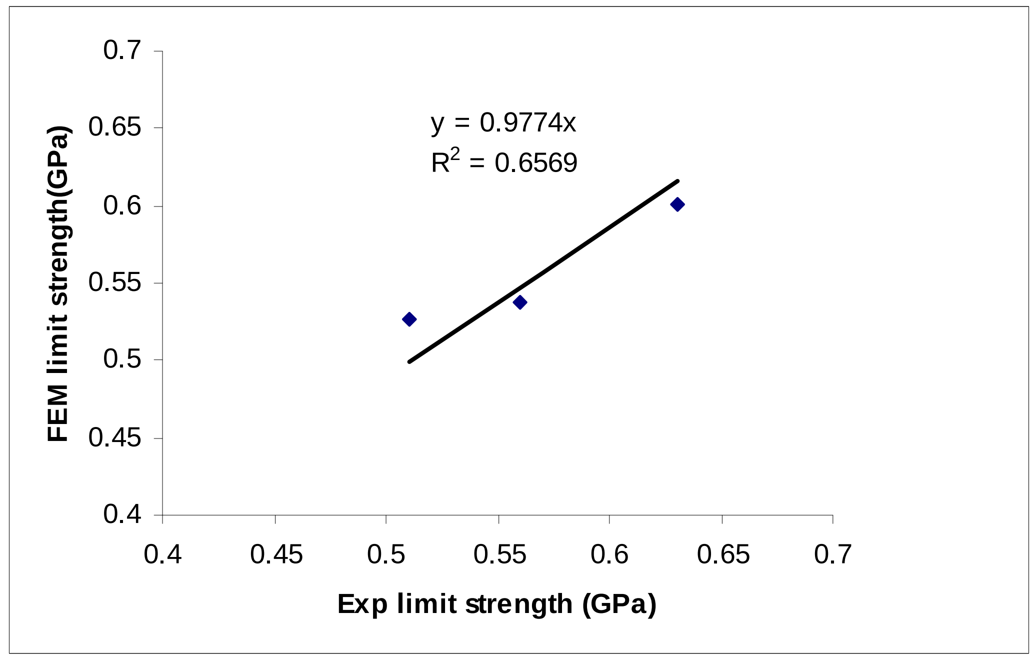
Elastic Properties



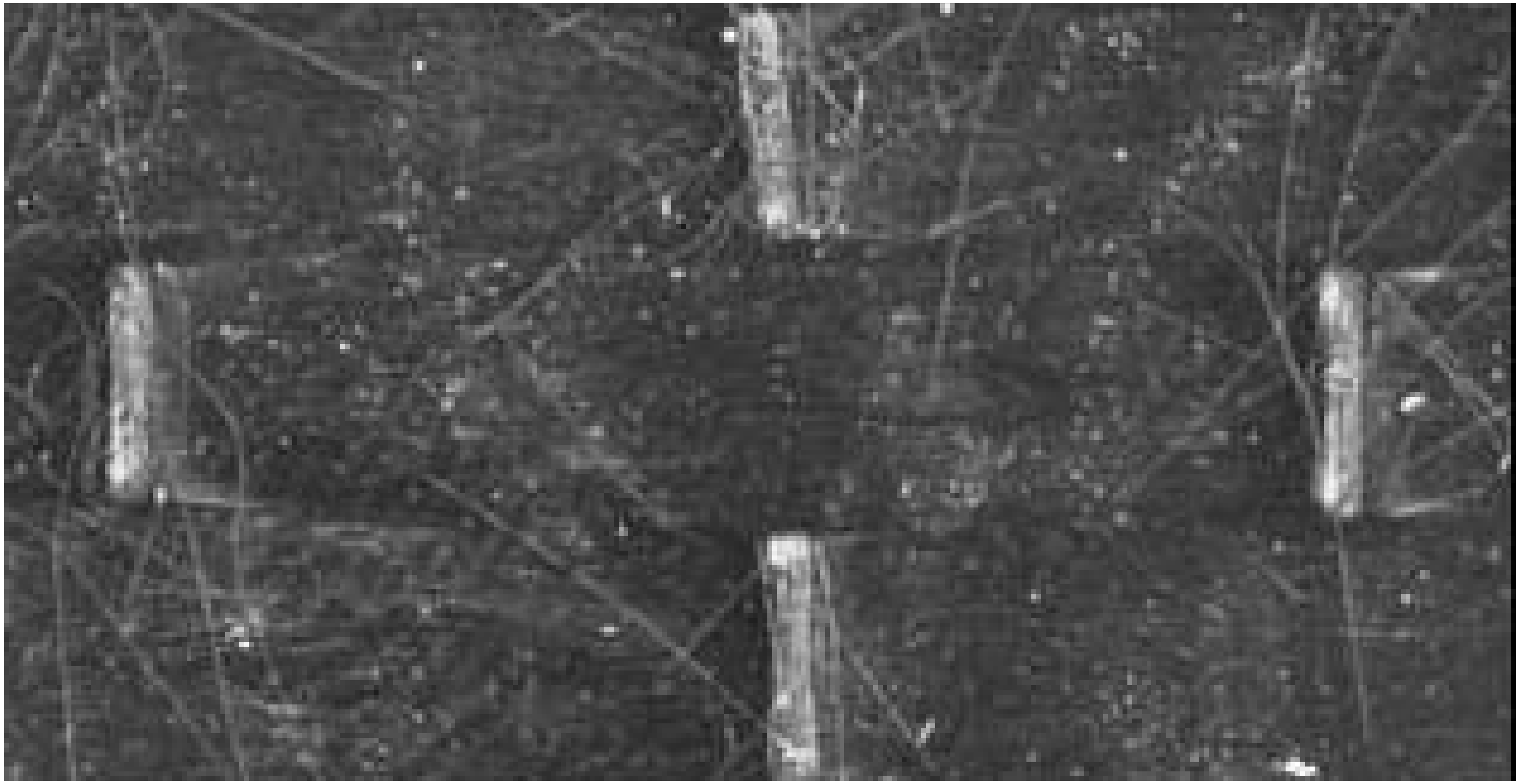
Strength & Failure Strains

composite	Exp, strain %	Exp, strength GPa	FEM, strain %	FEM, strength GPa
PBO-523 ACP	2	0.63	2.25	0.601
PBO-523 ACM	2.6	0.56	2.86	0.5383
PBO-525 ASM	2.8	0.51	3	0.5267



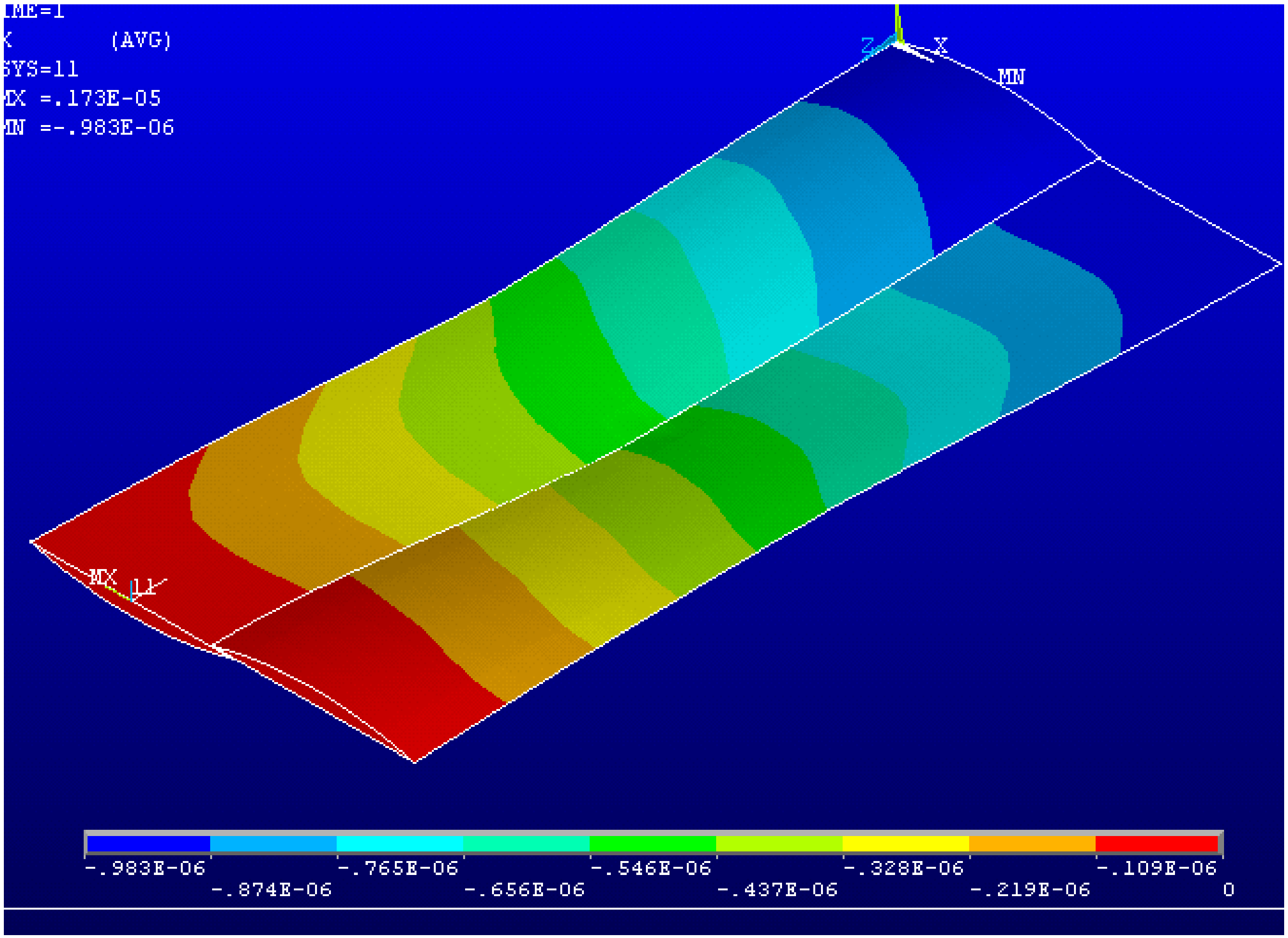


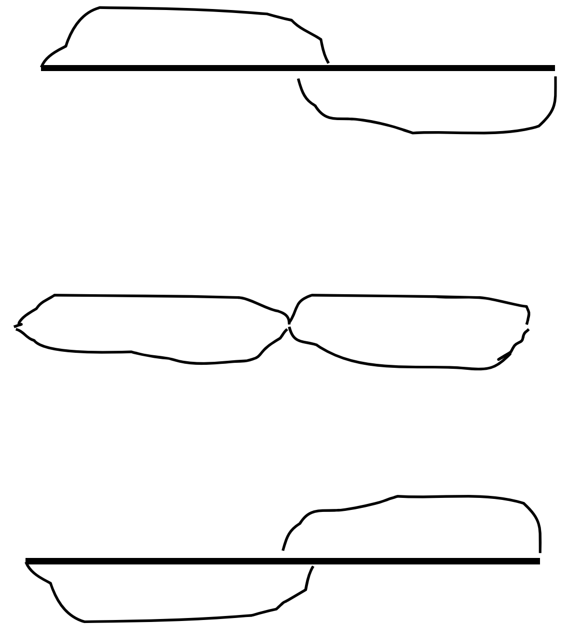
UD weave or uni-weave



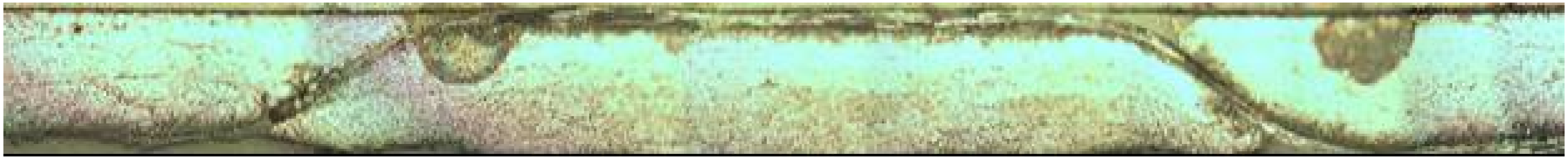
Unbalanced plain weave with majority of fibers(98%) in warp direction)

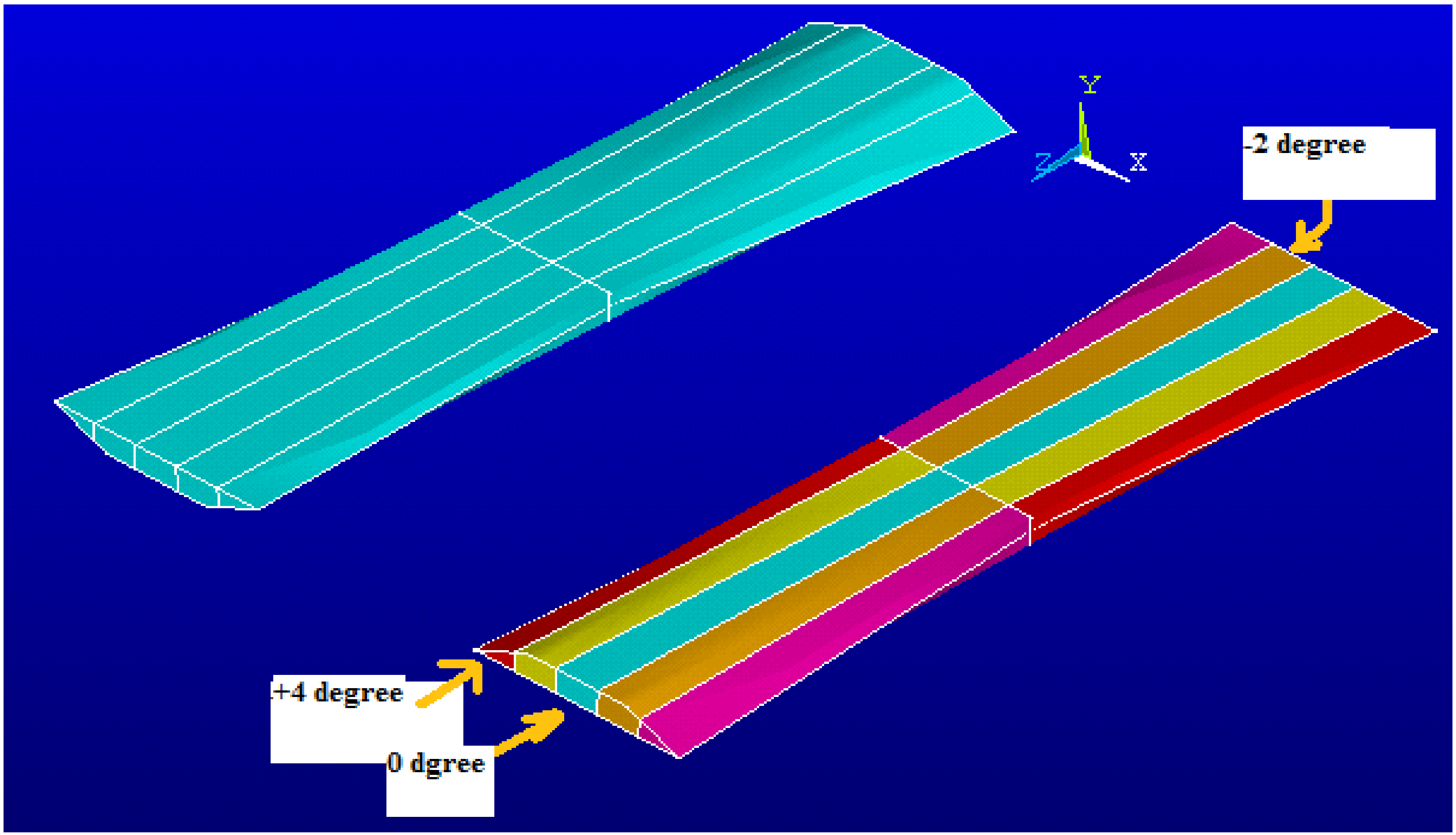
Geometry of UD woven fabric



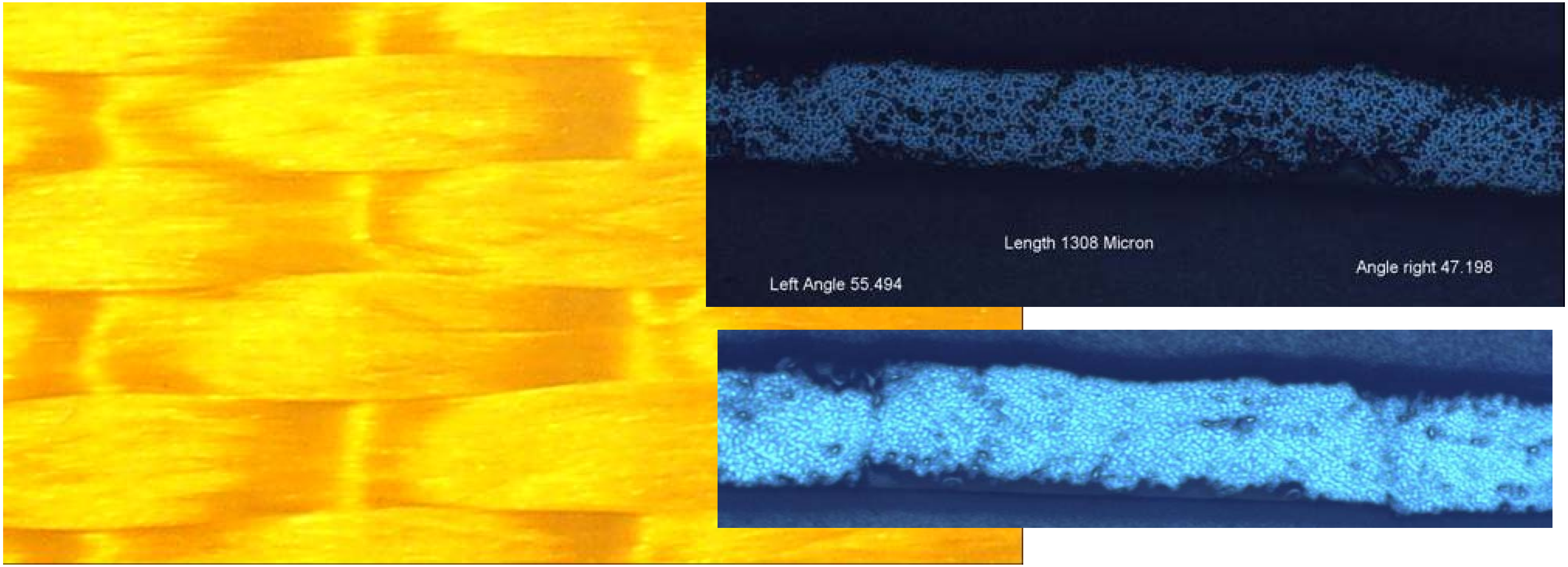


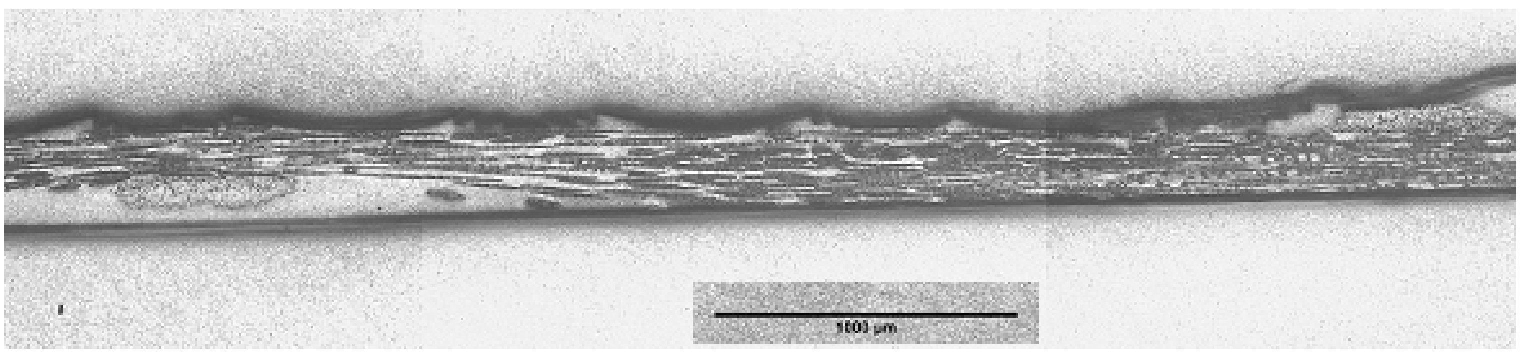
Tow geometry after compaction



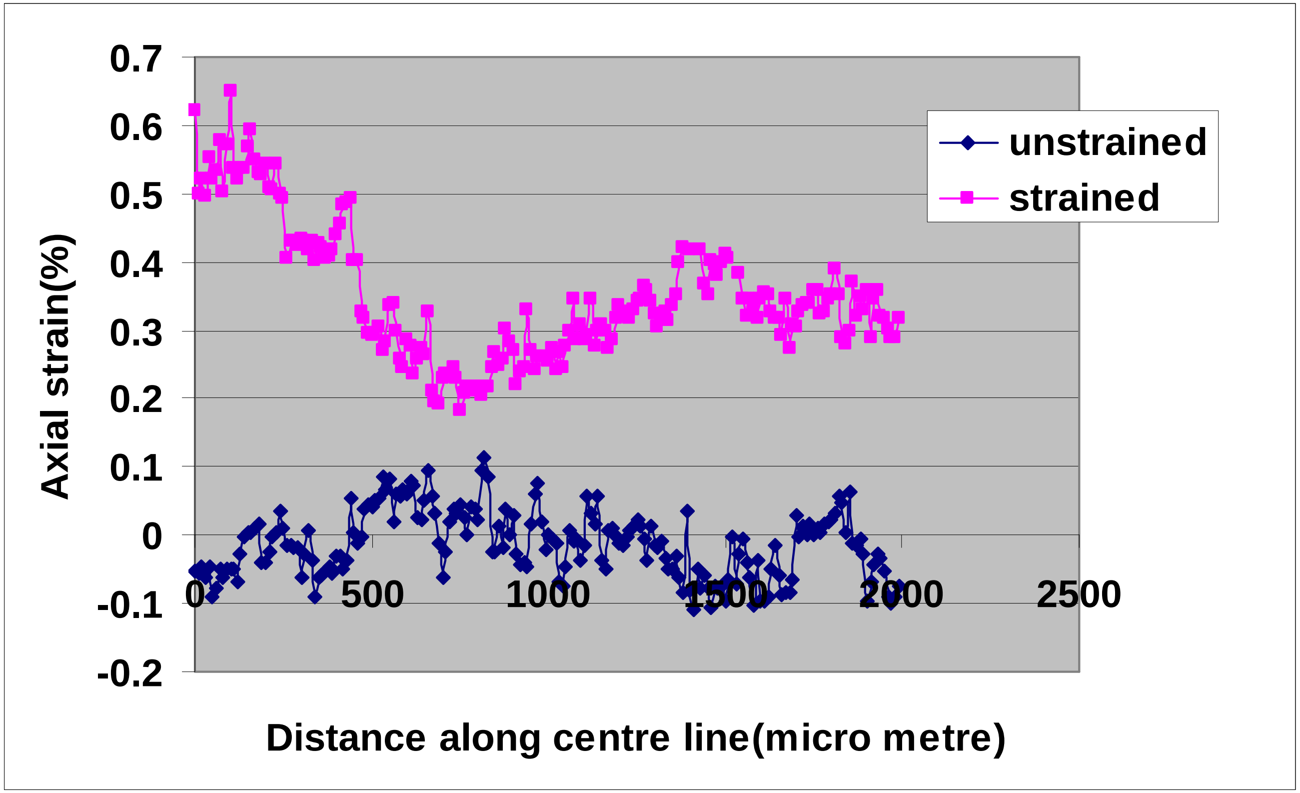


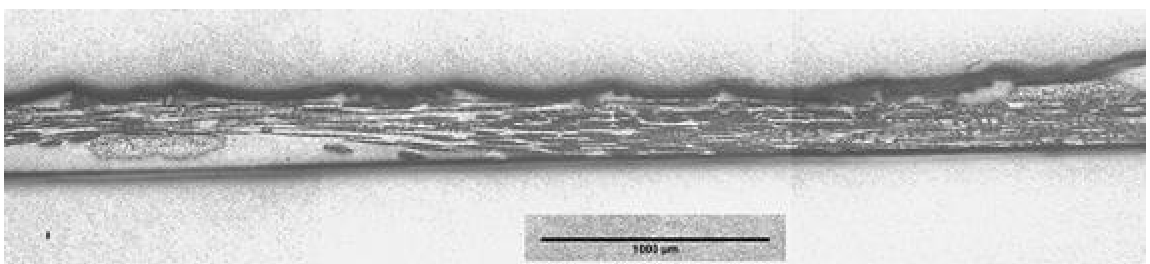
Model Kevlar UD composite



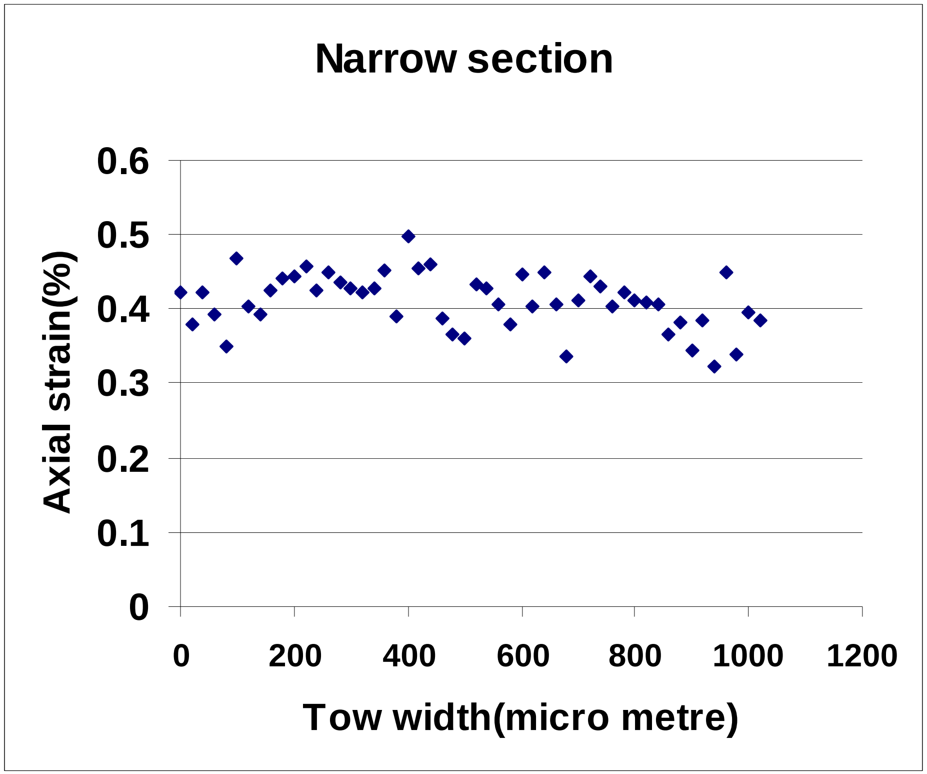


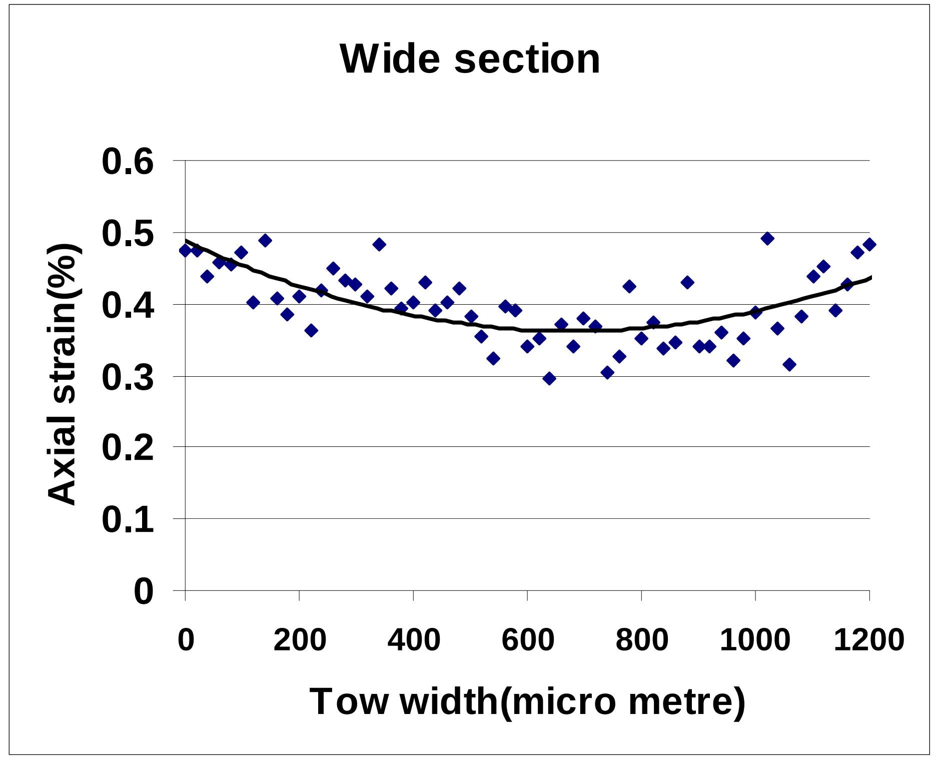
Axial strains plot along tow centreline





Axial Strains across tow width

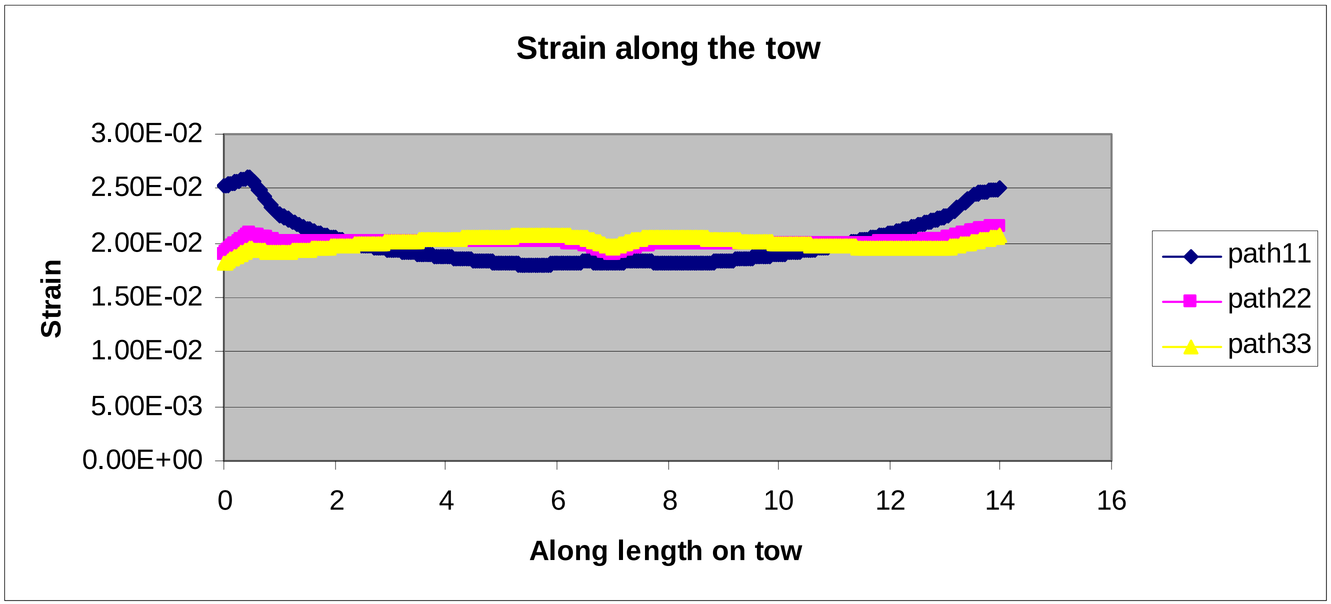




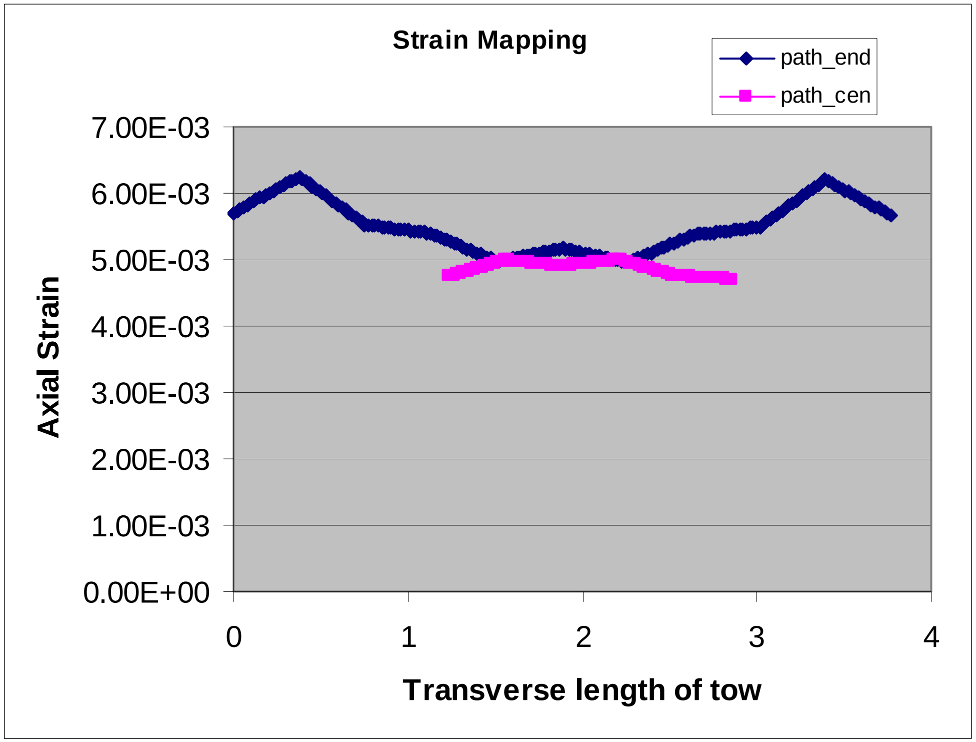
FE Predictions on carbon UD laminate

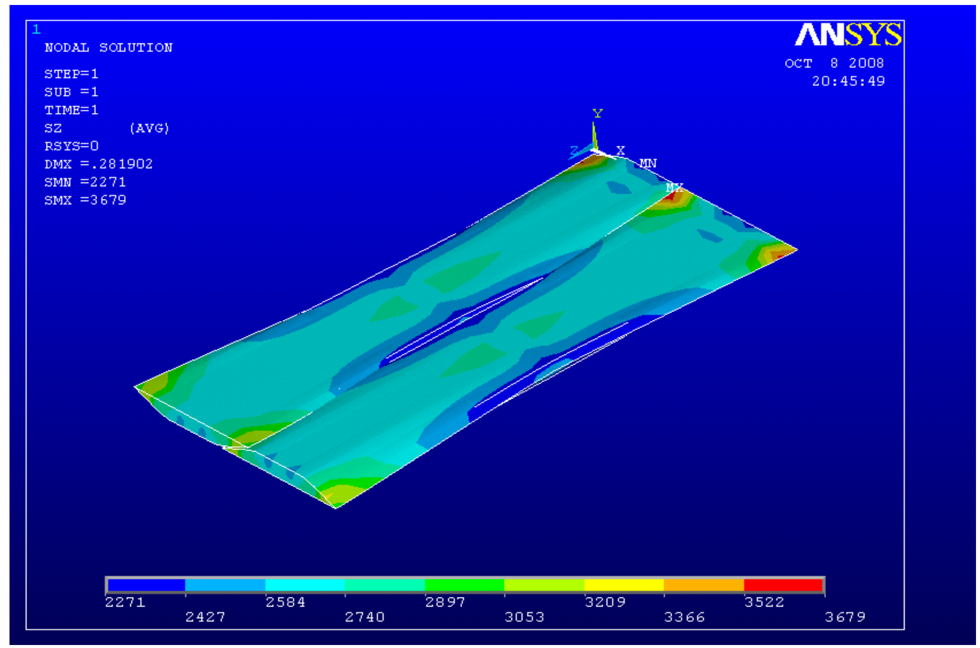
- Tow properties at 0.577 fiber volume fraction
- E_{11}=133.86GPa, E_{22}=7.251GPa G_{12}=8.78GPa, V_{12}=0.302

Results	FE prediction	Experimental
Longitudinal Modulus	129.1 GPa	128 GPa



FE prediction of axial strains across tow width





Discussion

- Meso-scale strain gradients in textile composites can be measured using reinforcing fibers as strain gauges, with a gauge length of 2μm.
- Kevlar, PBO have been used as strain sensors. Future plans to use high modulus carbon fibers.
- Influence of tow distortions due to stitching, 3D weaving can be assessed.