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Evaluation of fibre twisting angle and composite properties

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Evaluation of fibre twisting angle and composite properties

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Composite materials

Fibres:

- Glass fibres
- Carbon fibres
- Cellulose fibres
- and more ….

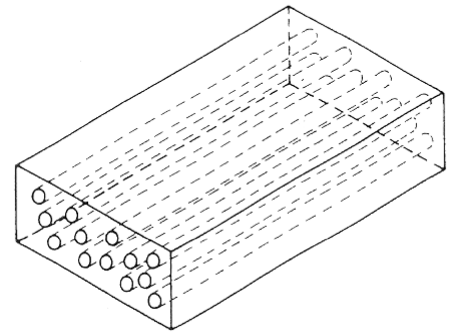
\+

Matrix:

- Polymers
- Metals
- Ceramics

=

Composite material



Glass fibres

Polyester matrix

Wind turbine blades made of glass/polyester composites

Composite parameters

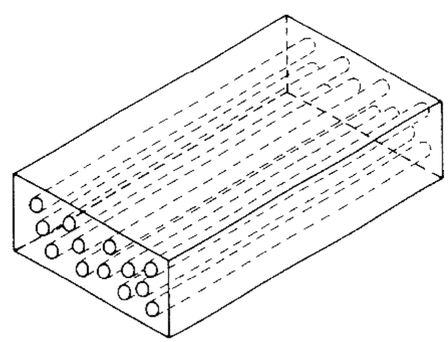
Mechanical properties of fibres

Fibre orientation

Mechanical performance of composites

Mechanical properties of matrix

Porosity



Fibre aspect ratio

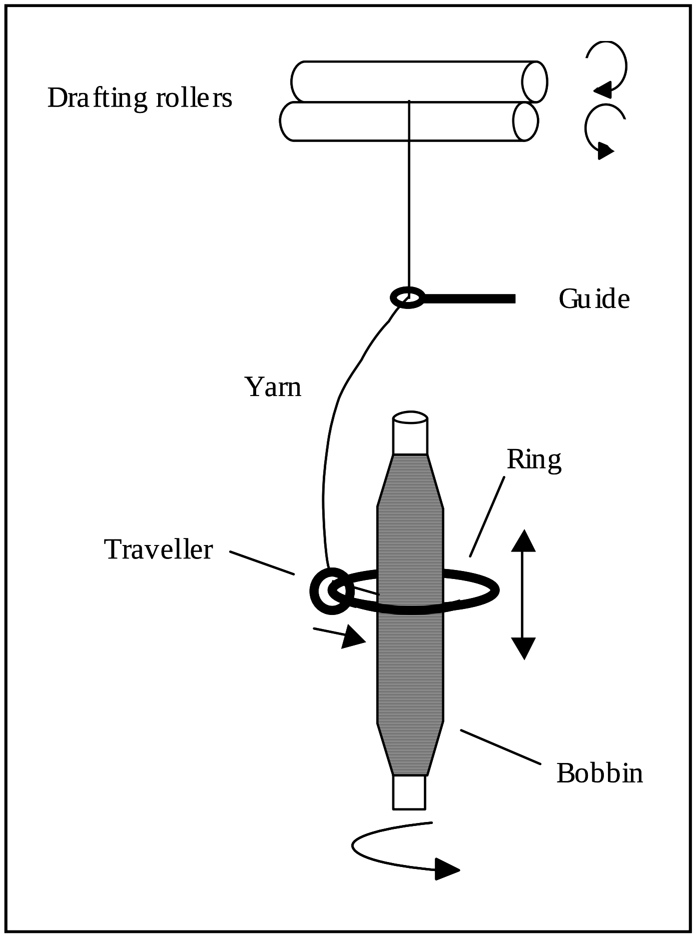
Fibre content

Fibre packing pattern

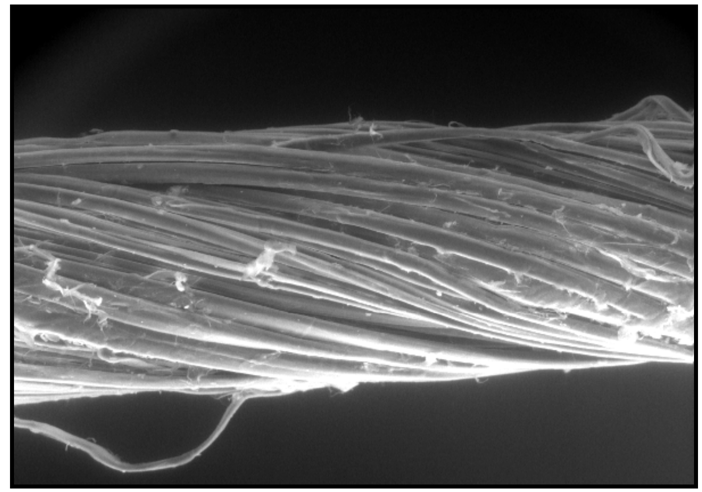
Fibre/matrix interface properties

Fibre twisting in natural fibre yarns

Ring spinning



Twisted fibres in yarn (SEM image)



Bobbin of yarn

Fibre twisting in natural fibre yarns

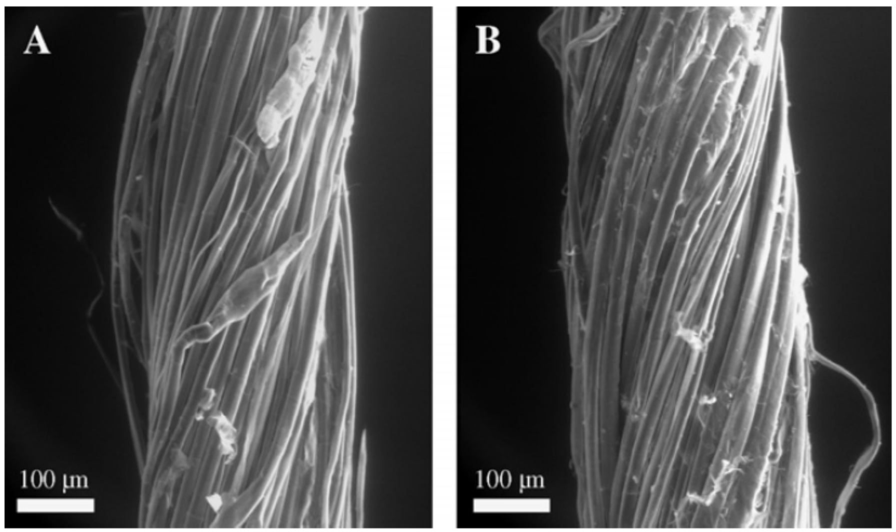


Fig. 2. Environmental scanning electron microscope images of hemp yarn: (A) is He47 and (B) is He53.

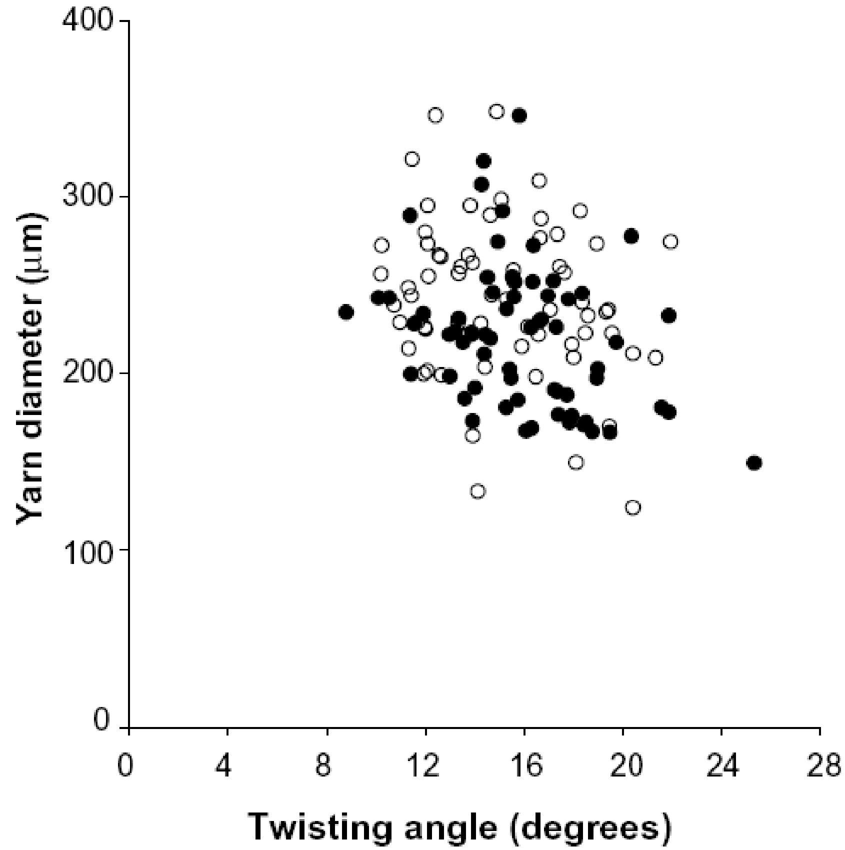
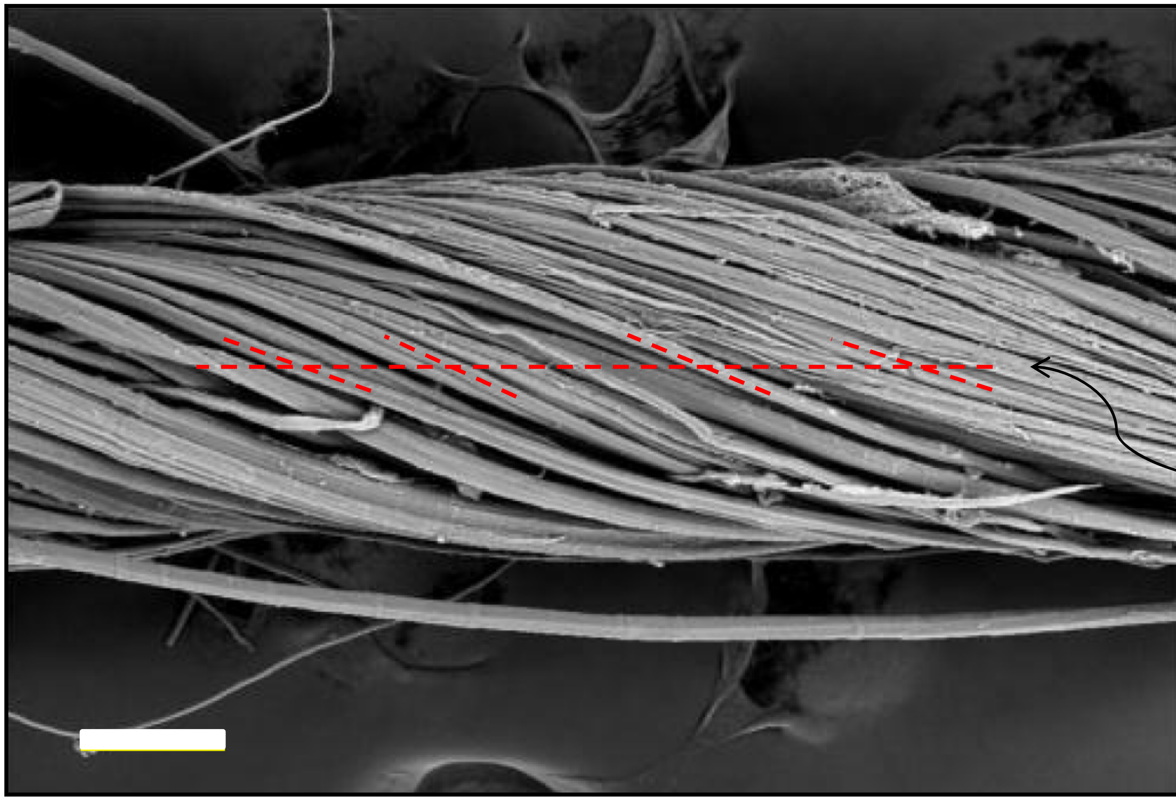


Fig. 3. Yarn diameter as a function of fibre twisting angle at the yarn surface for He47 (o) and He53 (•). Sample size is 65 for each yarn type.

Source: Madsen et al. (2007)

Fibre twisting in natural fibre yarns



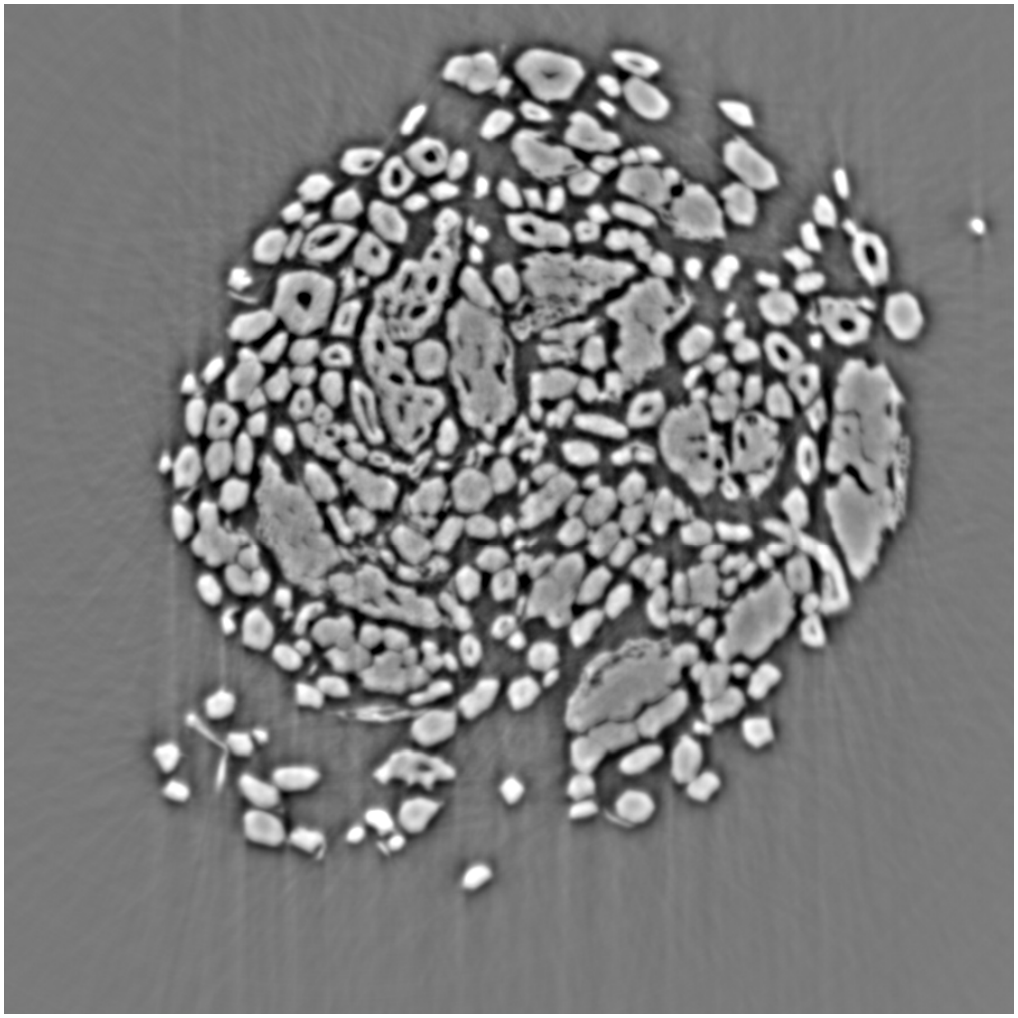
Yarn diameter: 390 ± 90 μm

Fibre twisting angle: 16 ± 3 °

Fig. 6.2. ESEM image of neat flax yarn. Scale bar is 100 μm.

Source: Pegoraro (2011), NATEX project

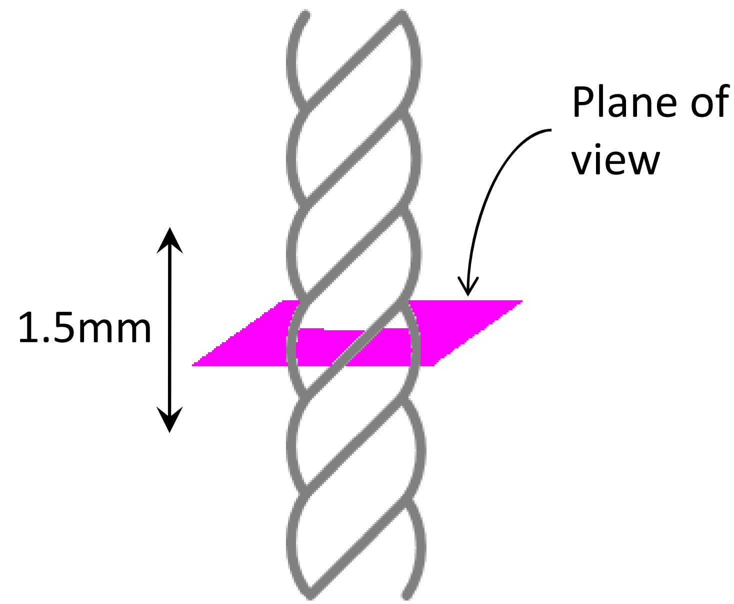
Fibre twisting in natural fibre yarns



X-ray tomography:

•Limited twisting angle in center of yarn

•High twisting angle at outer boundary of yarn



Source: Rask (2011), NATEX project

Fibre twisting in natural fibre yarns

Estimation of the mean fibre twisting angle in a ring spun yarn

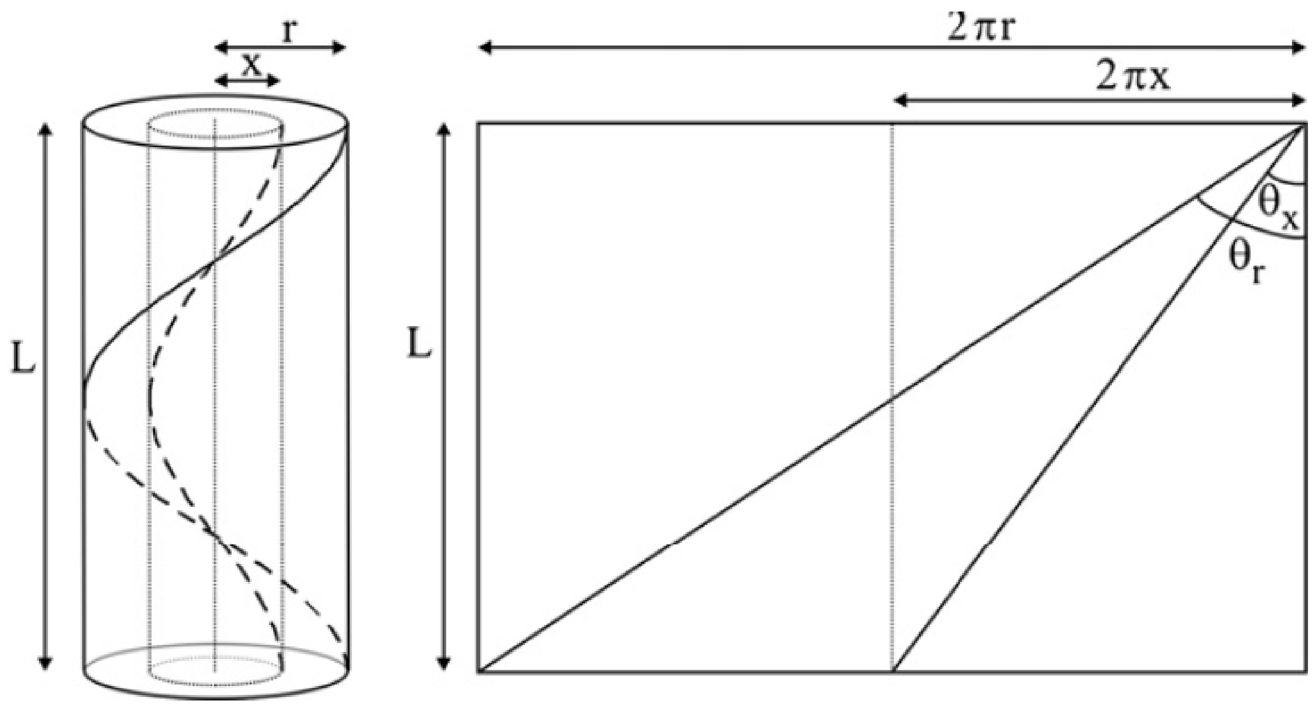


Fig. 7. Model of the twisted fibre structure in a ring spun yarn.

Source: Madsen et al. (2007)

Fibre twisting in natural fibre yarns

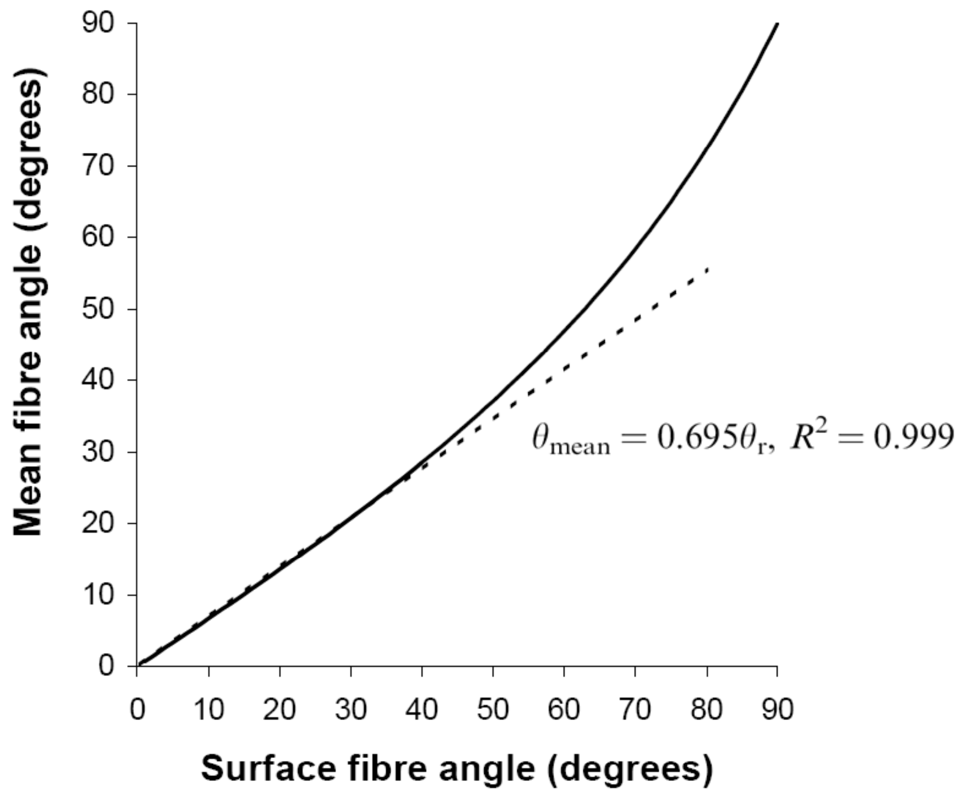
Estimation of the mean fibre twisting angle in a ring spun yarn

$$\theta_{mean} = \int_0^r \frac{2\pi x}{\pi r^2} \tan^{-1}\frac{2\pi x}{L}\, dx$$

$$\theta_{mean} = \theta_r + \frac{\theta_r}{\tan^2\theta_r} - \frac{1}{\tan\theta_r}$$

for $\theta_r < 40°$

$$\theta_{mean} \approx 0.7\,\theta_r$$



Fibre twisting in natural fibre yarns

Tool for calculating the fibre twisting angle

Correlating fibre twisting angles and production twisting number for a ring-spun yarn

November 2010

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θ_s, Surface fibre twisting		θ_m, Mean fibre twisting*		L, length of single twist	Twisting number (turns/meter)
degrees	radians	degrees	radians	meter	1/meter
1	0.017	0.67	0.012	0.2160	4.6
2	0.035	1.33	0.023	0.1080	9.3
3	0.052	2.00	0.035	0.0719	13.9
4	0.070	2.67	0.047	0.0539	18.5
5	0.087	3.34	0.058	0.0431	23.2
6	0.105	4.01	0.070	0.0359	27.9
7	0.122	4.68	0.082	0.0307	32.6
8	0.140	5.35	0.093	0.0268	37.3
9	0.157	6.02	0.105	0.0238	42.0
10	0.175	6.69	0.117	0.0214	46.8
11	0.192	7.37	0.129	0.0194	51.6
12	0.209	8.05	0.140	0.0177	56.4
13	0.227	8.73	0.152	0.0163	61.2
14	0.244	9.41	0.164	0.0151	66.1
15	0.262	10.09	0.176	0.0141	71.1
16	0.279	10.78	0.188	0.0131	76.1
17	0.297	11.47	0.200	0.0123	81.1
18	0.314	12.16	0.212	0.0116	86.2
19	0.332	12.86	0.224	0.0109	91.3
20	0.349	13.55	0.237	0.0104	96.5
21	0.367	14.26	0.249	0.0098	101.8

Input parameters here:

tex value (g/1000m)
100

ρ_f, fibre density (g/cm3)
1.55

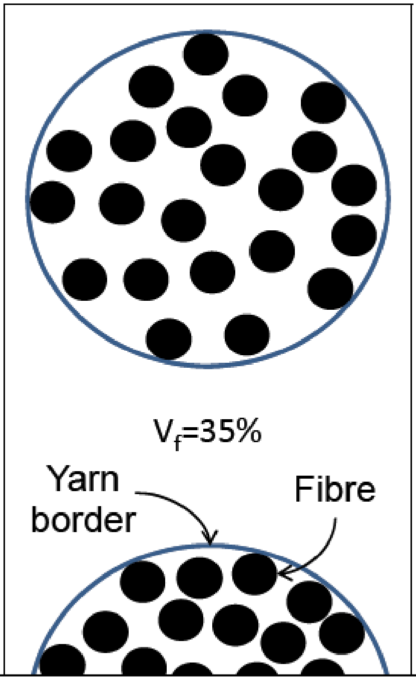
V_f, volume percentage of fibres in yarn (%)
57.04

See sketches to the right for illustration of V_f

If the volume percentage of fibres in the yarn is unknown, it can be found from the yarn radius:

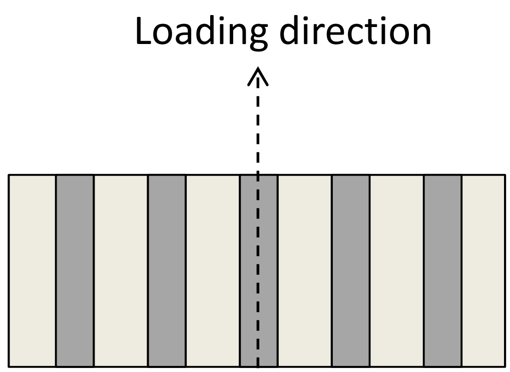
r, yarn radius (mm)
0.6

measured volume percentage of fibres in yarn (%):
57.04



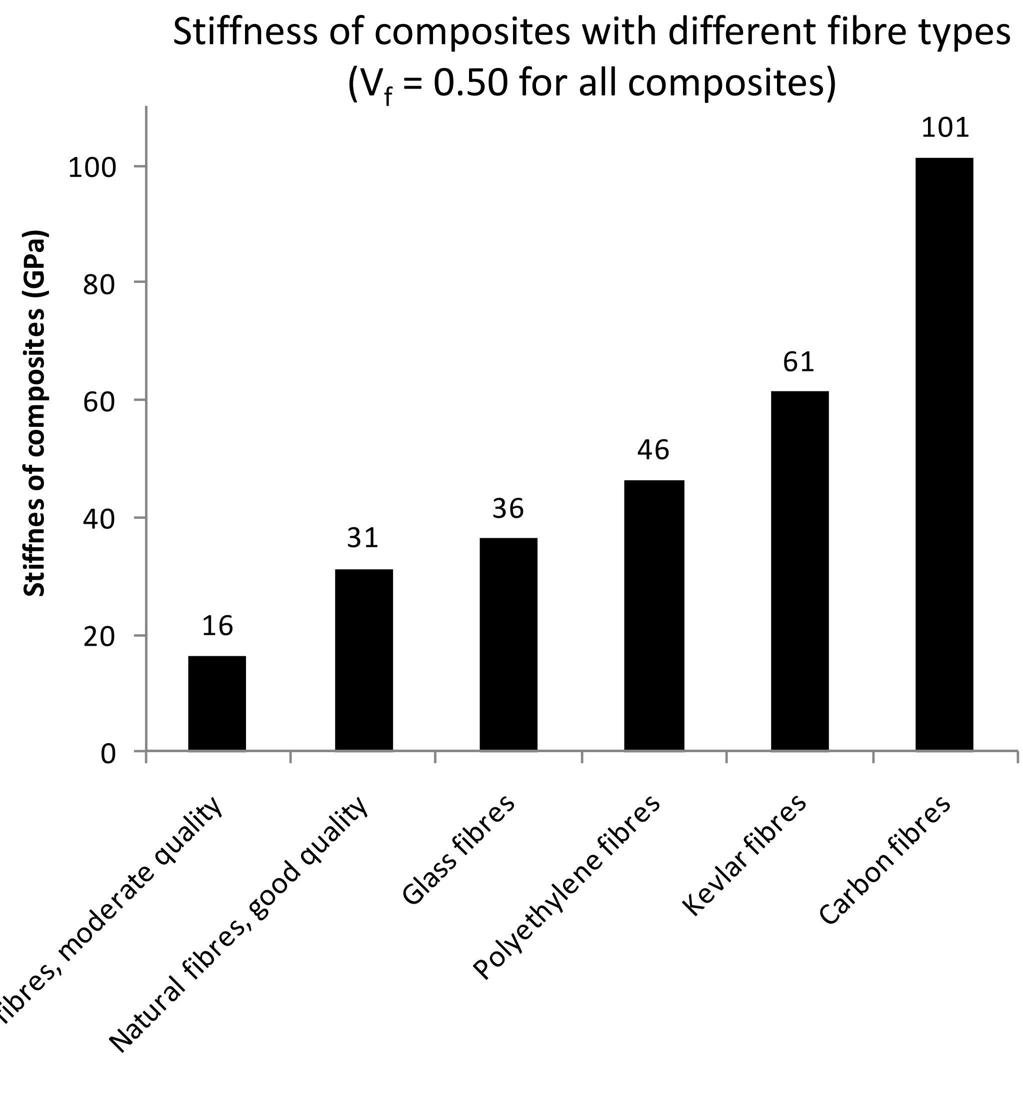
Fibre orientation in composites

Unidirectional fibres



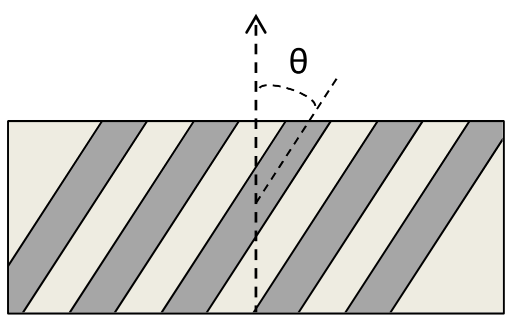
Rule-of-mixtures model

$$E_{c0} = V_f E_f + (1 - V_f) E_m$$



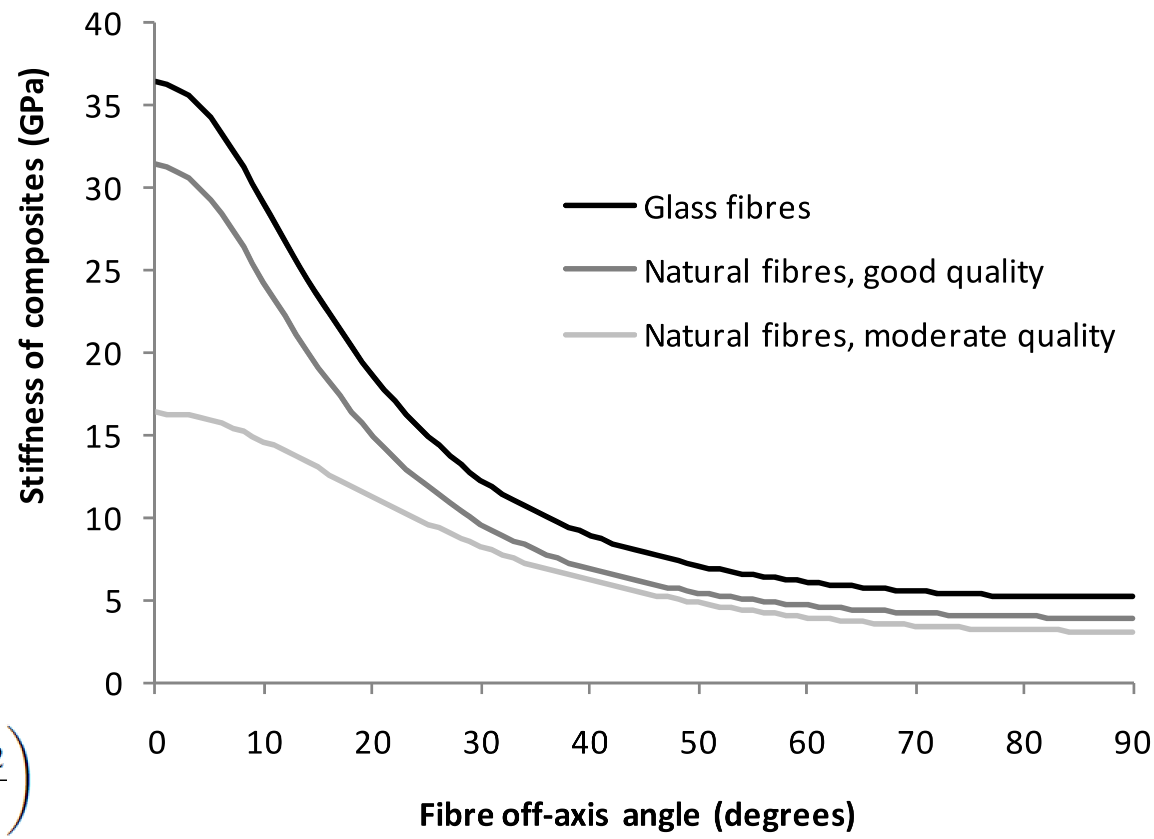
Fibre orientation in composites

Unidirectional fibres: off-axis angle



Plane stress model

$$\frac{1}{E_{c\theta}} = \frac{\cos^4\theta}{E_{c1}} + \frac{\sin^4\theta}{E_{c2}} + \sin^2\theta\cos^2\theta\left(\frac{1}{G_{c12}} - \frac{2v_{c12}}{E_{c1}}\right)$$



Unidirectional natural fibre yarn composites – Effect of yarn off-axis angle

Hemp yarn/PET composites

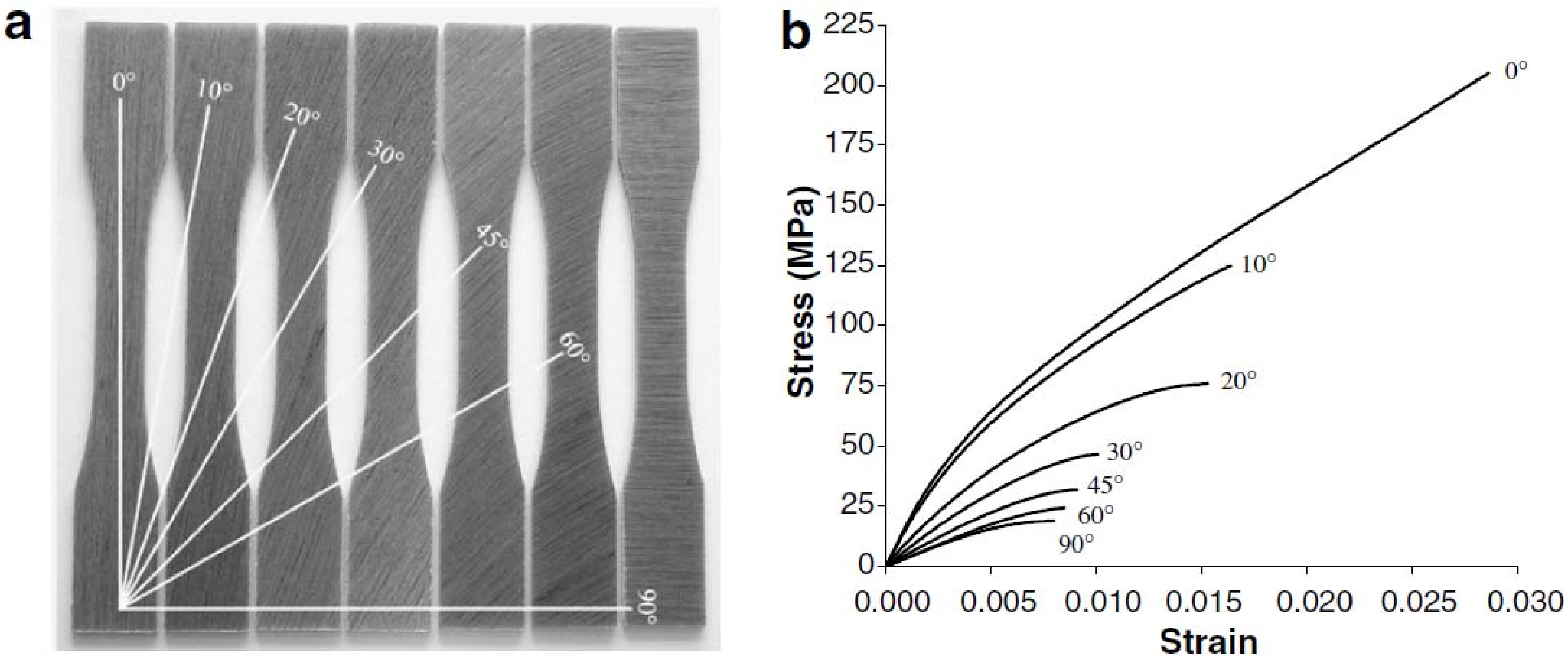
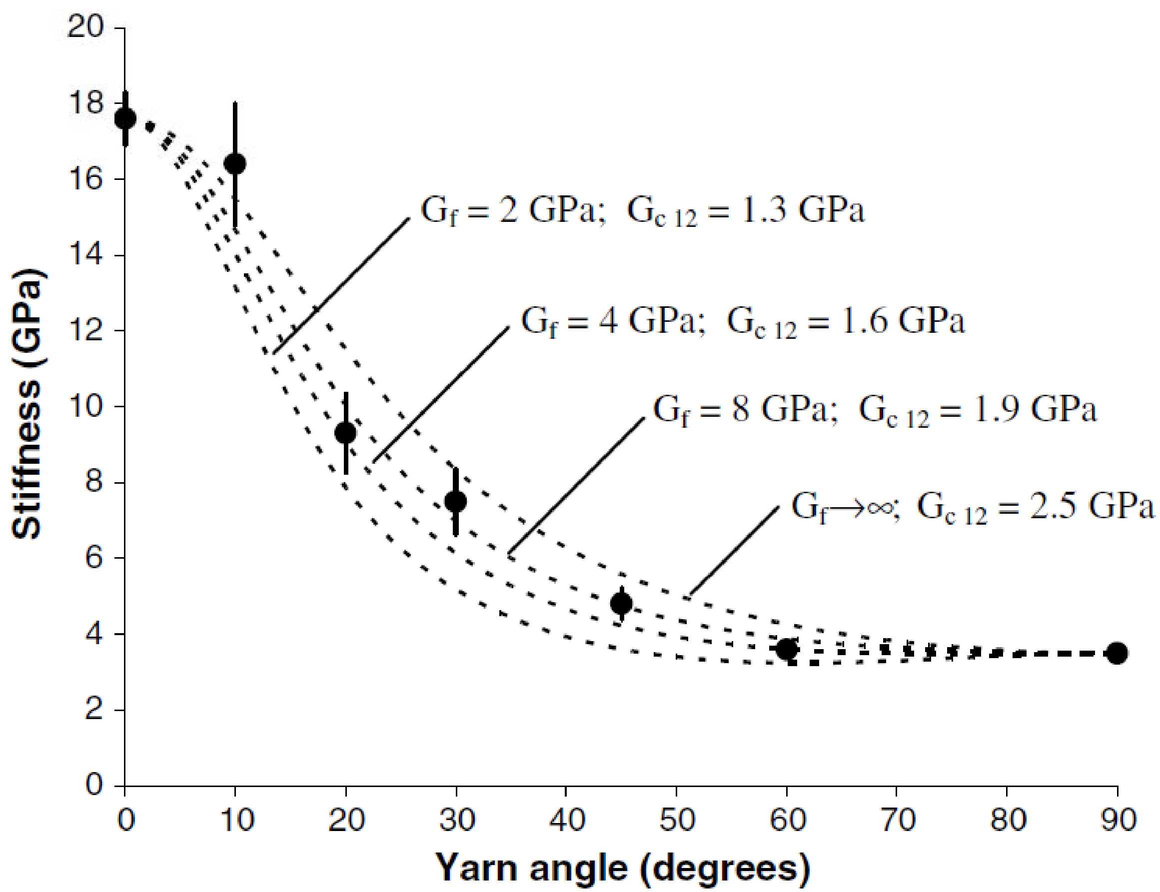


Fig. 8. (a) Shows examples of tensile specimens of He53/PET composites with the yarn axis inclined at various angles to the loading direction. (b) Shows the corresponding stress-strain curves.

Source: Madsen et al. (2007)

Unidirectional natural fibre yarn composites – Effect of yarn off-axis angle

Hemp yarn/PET composites



Source: Madsen et al. (2007)

Unidirectional natural fibre yarn composites – Effect of yarn off-axis angle

Flax yarn/PET composites

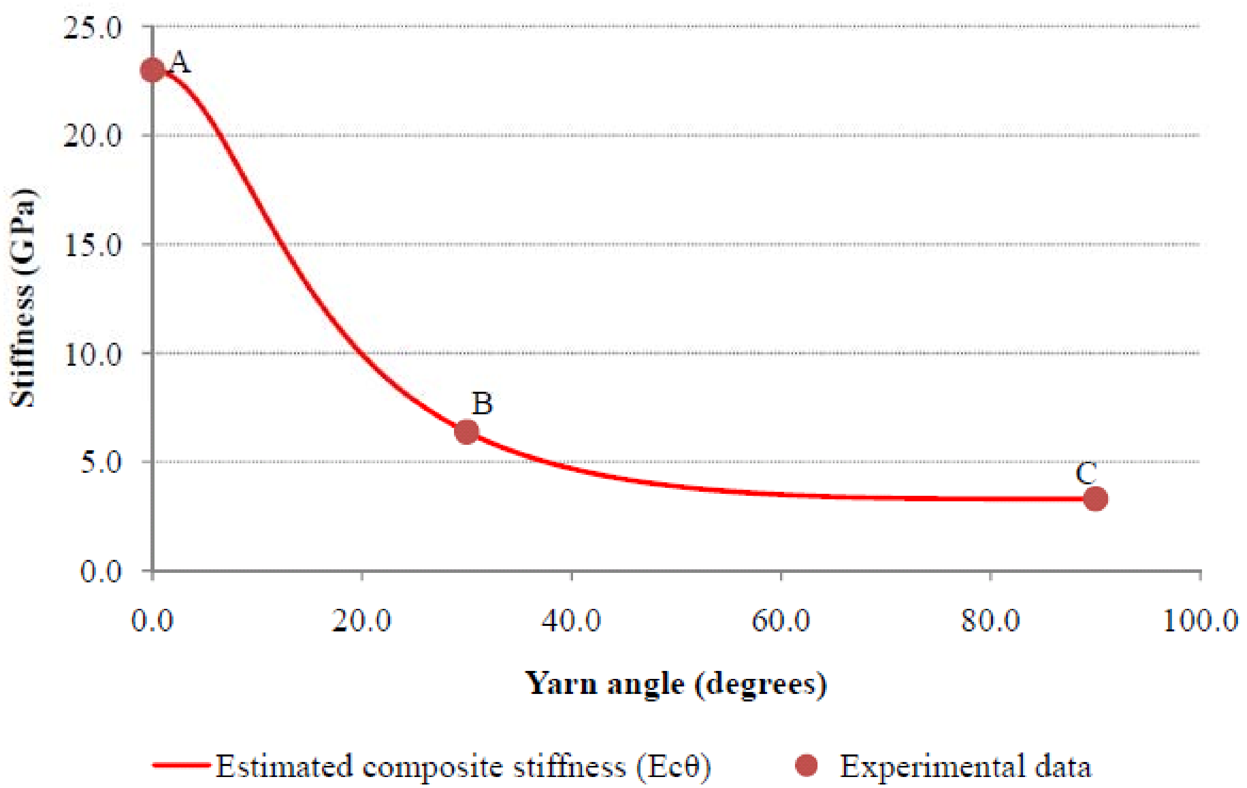
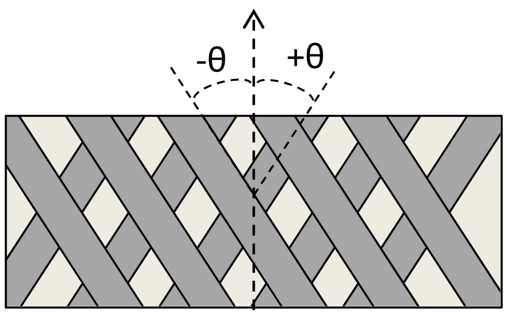


Figure 6.31 Stiffness as a function of yarn angle.

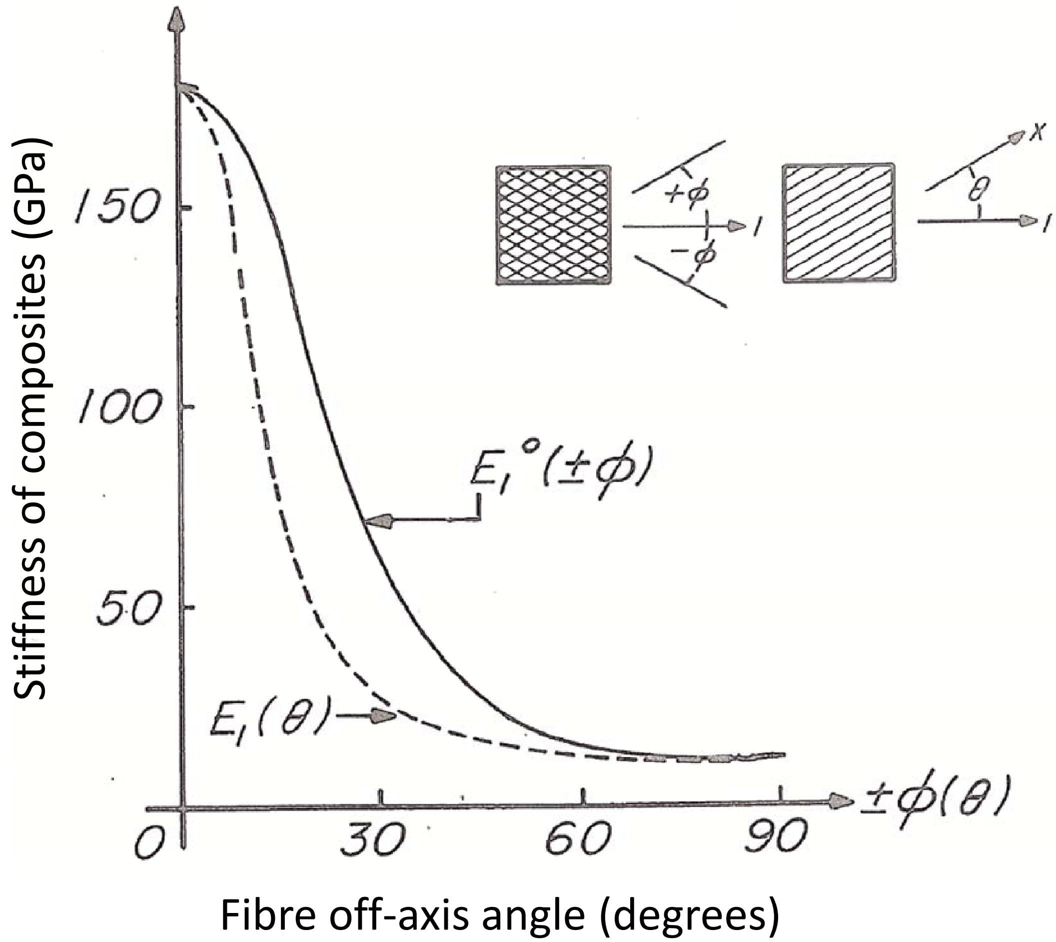
Source: Pegoraro (2011), NATEX project

Fibre orientation in composites

Unidirectional fibres: ± off-axis angle



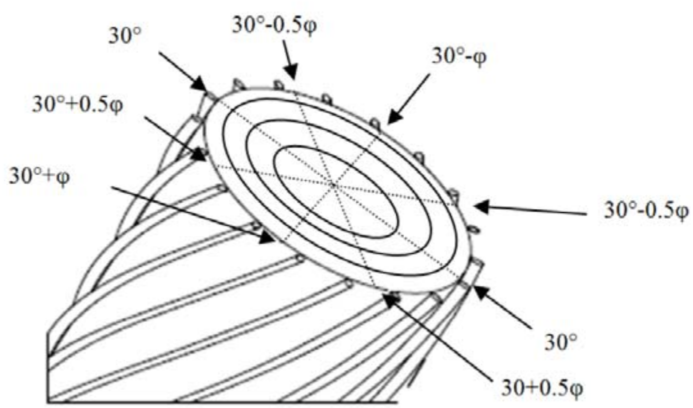
Composites laminate theory



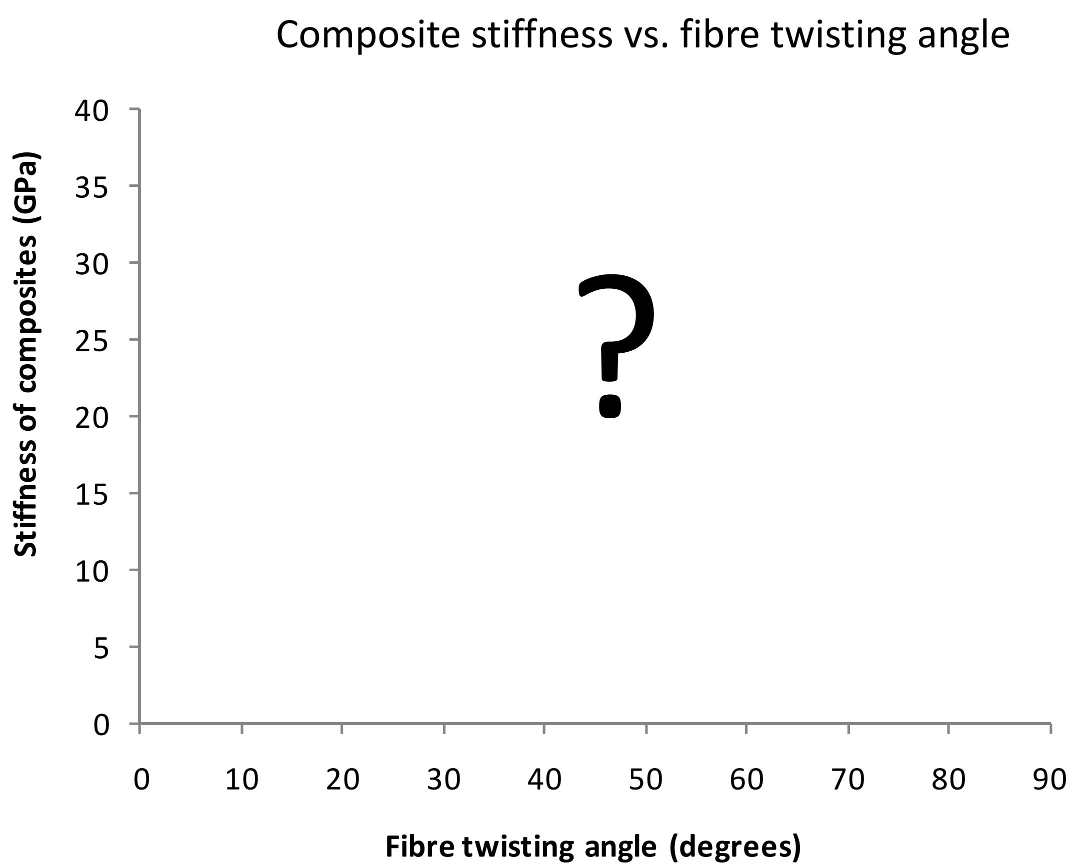
Source: Tsai and Hahn (1980)

Fibre orientation in composites

Twisted fibres

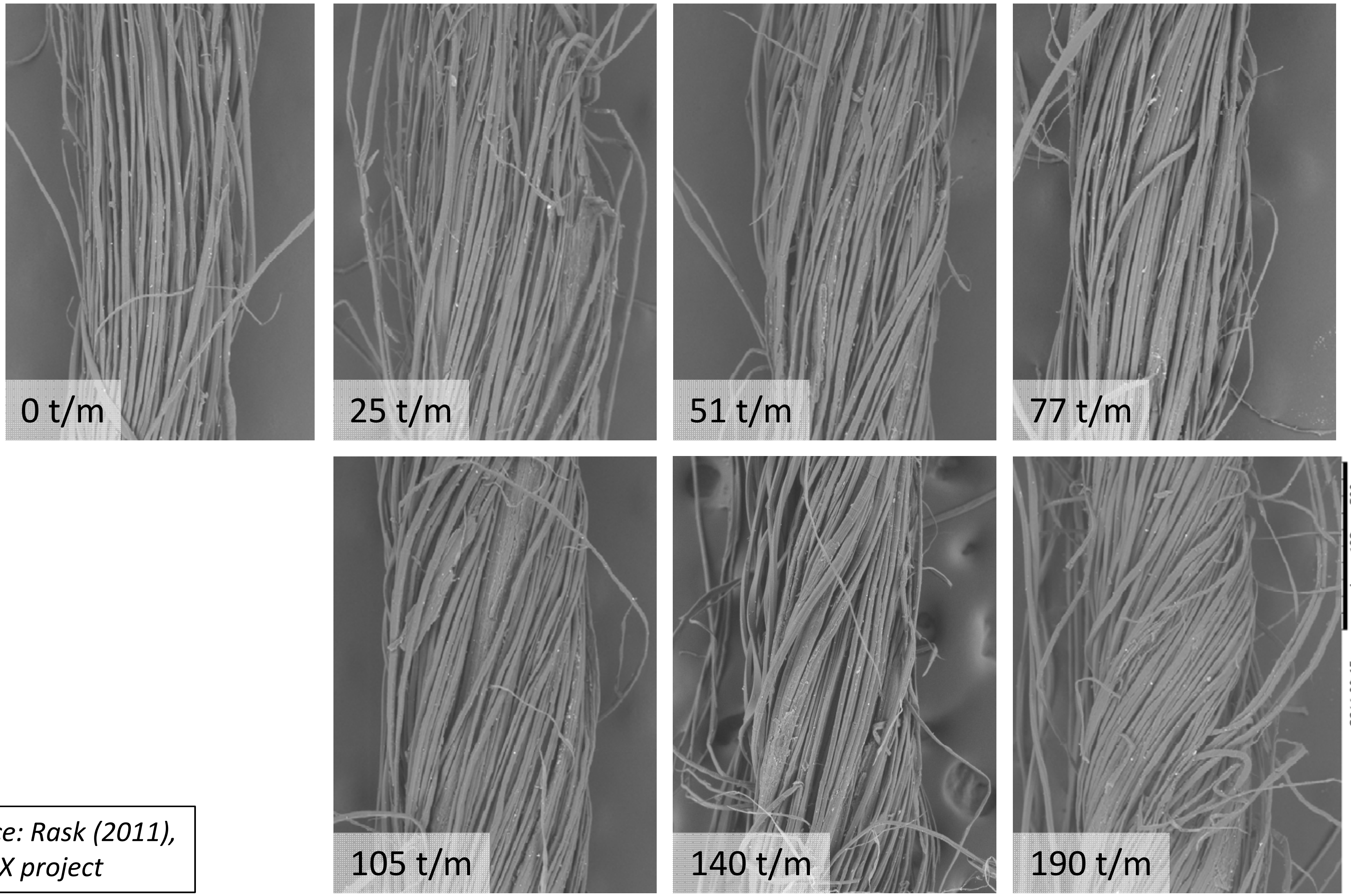


- Complex 3D fibre orientation
- No existing model available



Unidirectional natural fibre yarn composites

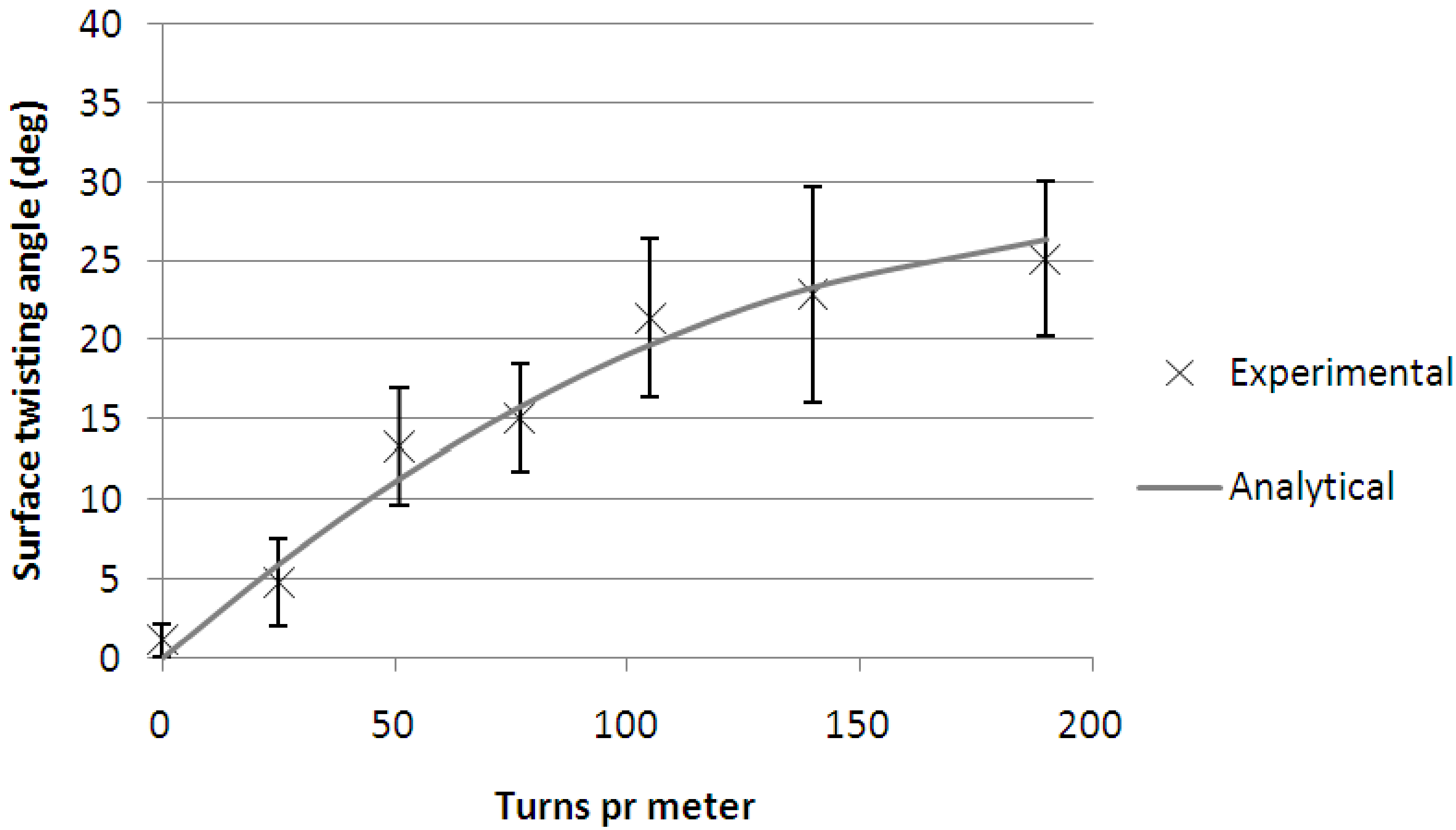
– Effect of fibre twisting angle



Source: Rask (2011), NATEX project

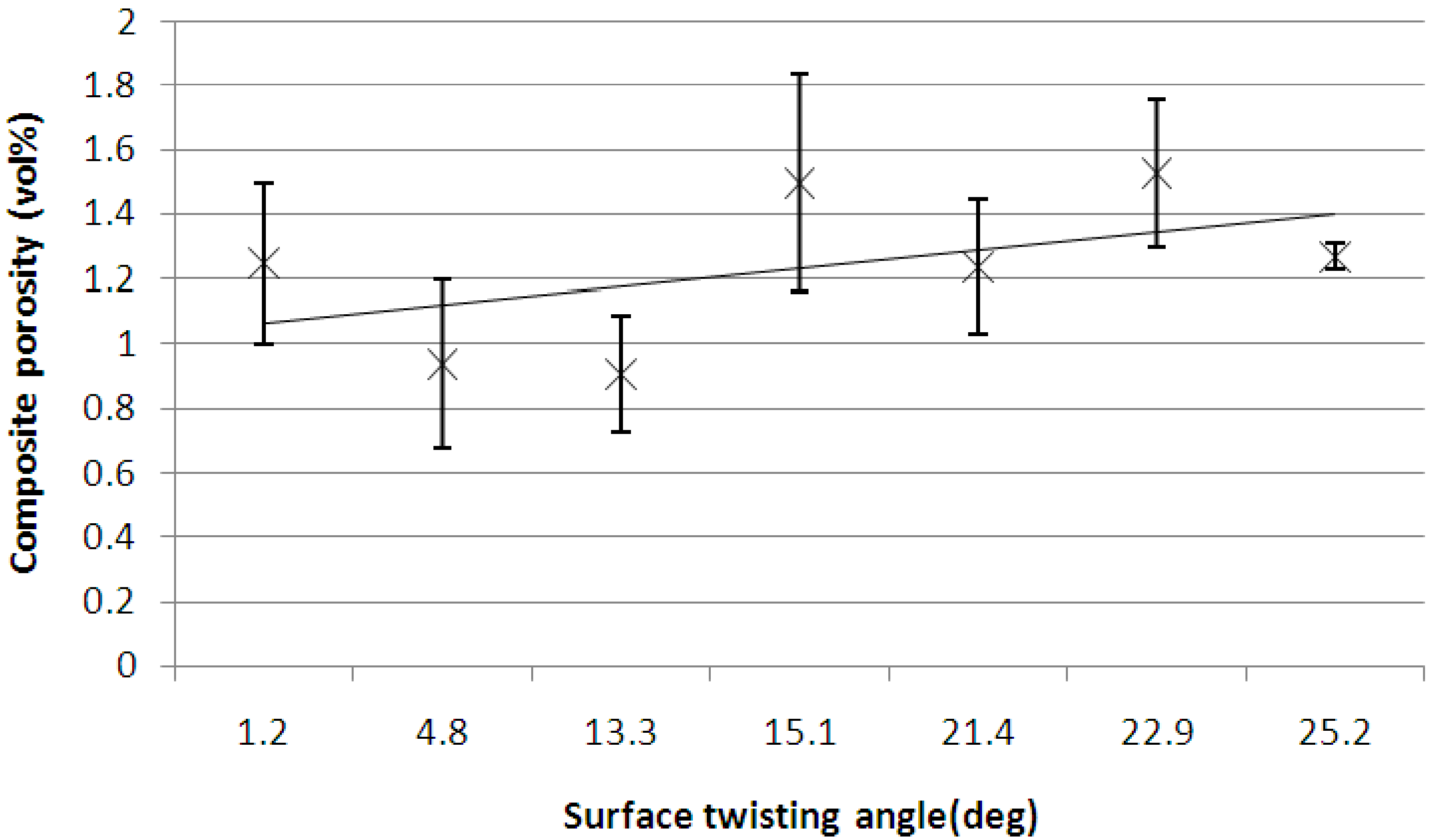
Unidirectional natural fibre yarn composites

– Effect of fibre twisting angle



Source: Rask (2011), NATEX project

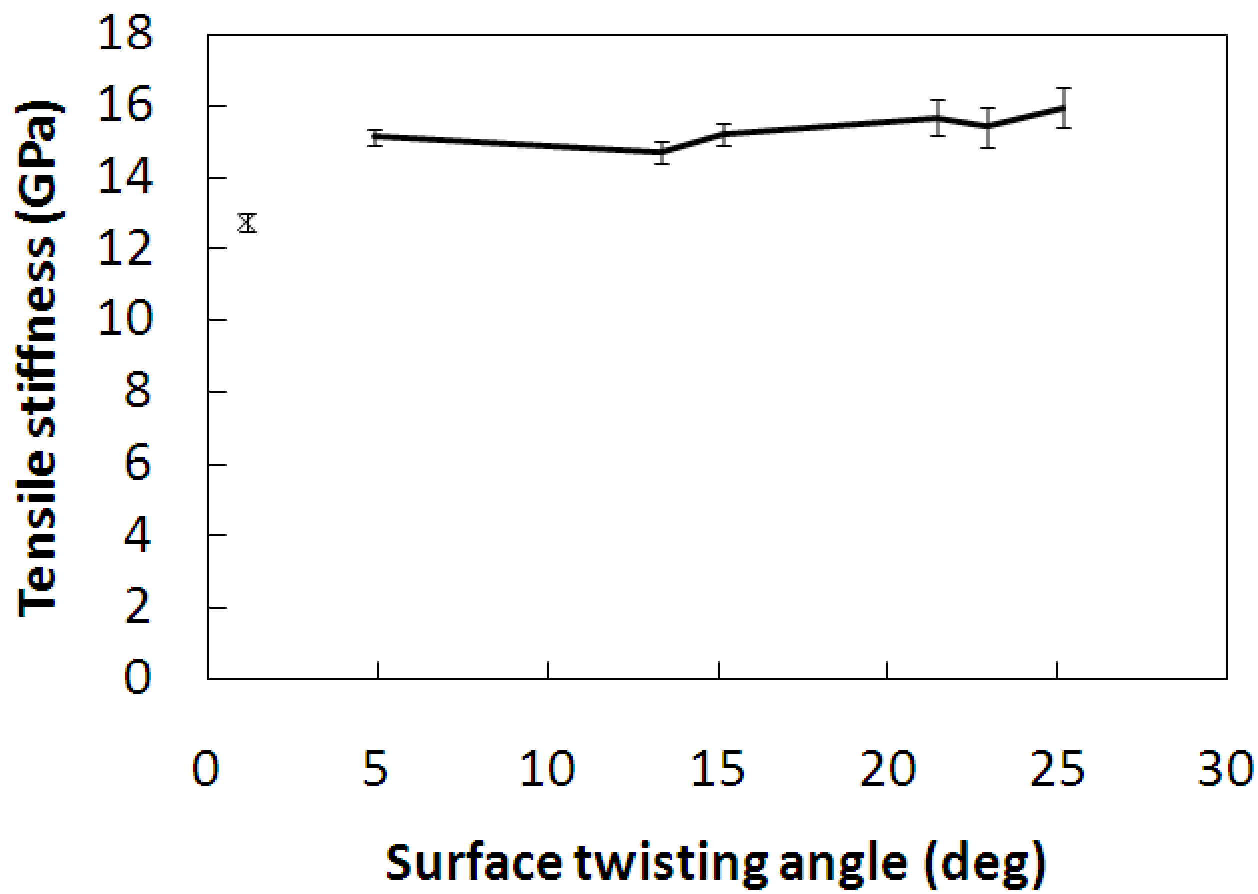
Unidirectional natural fibre yarn composites – Effect of fibre twisting angle



Source: Rask (2011), NATEX project

Unidirectional natural fibre yarn composites

– Effect of fibre twisting angle



Source: Rask (2011), NATEX project

Conclusion

- Work on fibre twisting is ongoing
- We need models relating fibre twisting to composite performance
- We will make further experimental studies and also use a FEM approach

References

Madsen B et. al. (2008). "Hemp yarn reinforced composites – I. Yarn characteristics". Composites Part A 38 2194-2203.

Pegoraro L (2010) "Investigations of the influence from the manufacturing process and the resulting microstructures on mechanical properties of biocomposites", Master thesis project.

Rask M (2012) "Microstructure and fracture mechanical properties of aligned natural fiber composites". Ongoing ph.d. project.

Tsai SW and Hahn HT (1980). "Introduction to composite materials". Technomic Publishing, Westport, USA. p. 142.