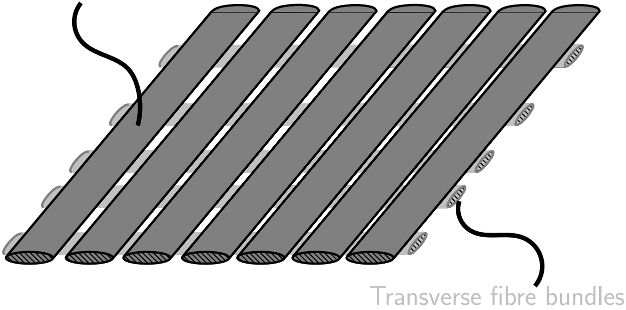
# Micro-scale damage from cyclic bending loads observed in UD Basalt/Epoxy composites

Ulrich A. Mortensen

Technical University of Denmark

*Department of Wind Energy , Section of Composites & Materials Mechanics*

# Fibre architecture of Non-crimp fabric

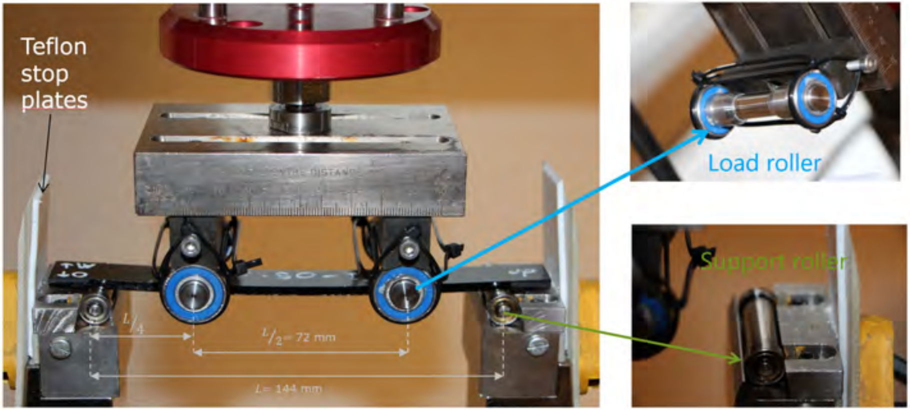



Top side - Longitudinal

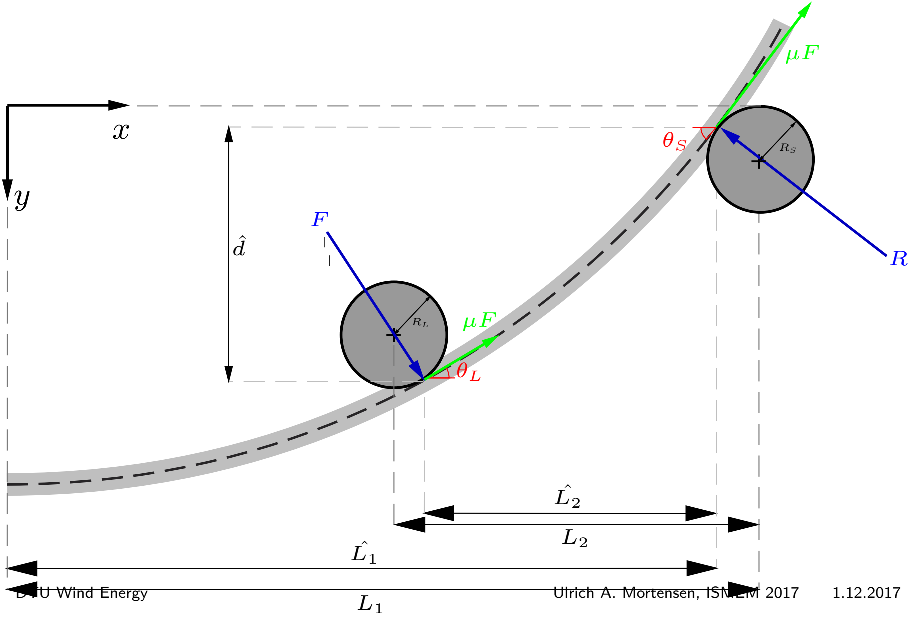
Bottom side - Transverse

- Transverse (backing bundles and sewing thread) bundles are needed for handling (also in Wind Turbine Industry)

# Set-up and specimen shape



# Friction effects on the bending moment - I

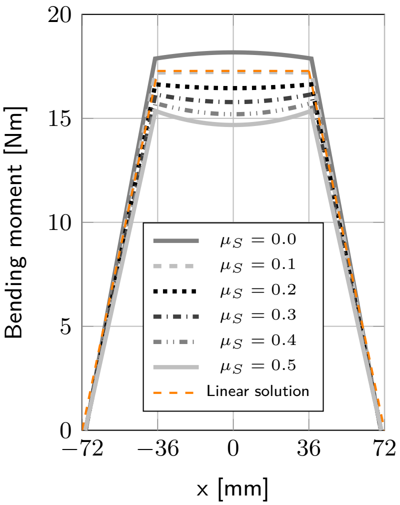


# Friction effects on the bending moment - II

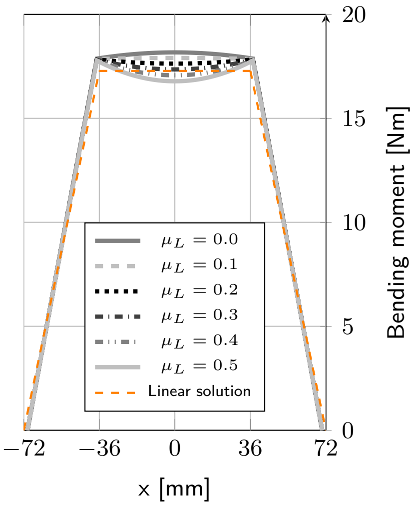
$$M = \frac{P}{2}\left[\hat{L}_1 - x + \underbrace{y\frac{\tan\theta_s - \mu_s}{1+\mu_s\tan\theta_s}}_{\text{Non-linear term}}\right] \quad \text{for} \quad x \in \left[\hat{L}_1 - \hat{L}_2\ ;\ \hat{L}_1\right] \qquad (1)$$

$$M = \frac{P}{2}\left[\hat{L}_2 + \underbrace{y\frac{\tan\theta_s - \mu_s}{1+\mu_s\tan\theta_s} - \left(y - \hat{d}\right)\frac{\tan\theta_L + \mu_L}{1-\mu_L\tan\theta_L}}_{\text{Non-linear terms}}\right] \text{for } x \in \left[0\ ;\ \hat{L}_1 - \hat{L}_2\right] \qquad (2)$$

# Friction effects on the bending moment - III

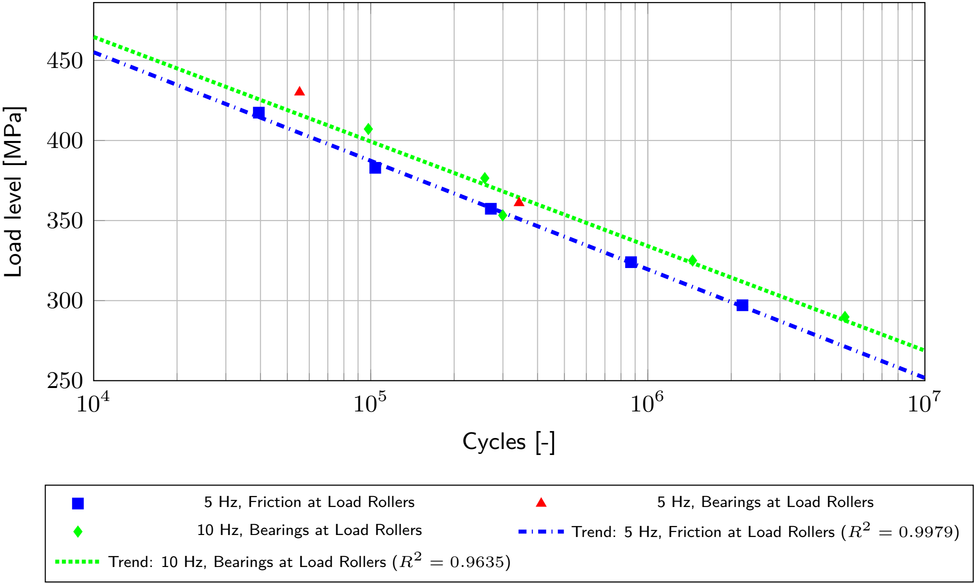



**(a)** $\mu_S \in [0.0; 0.5]$ and $\mu_L = 0.0$

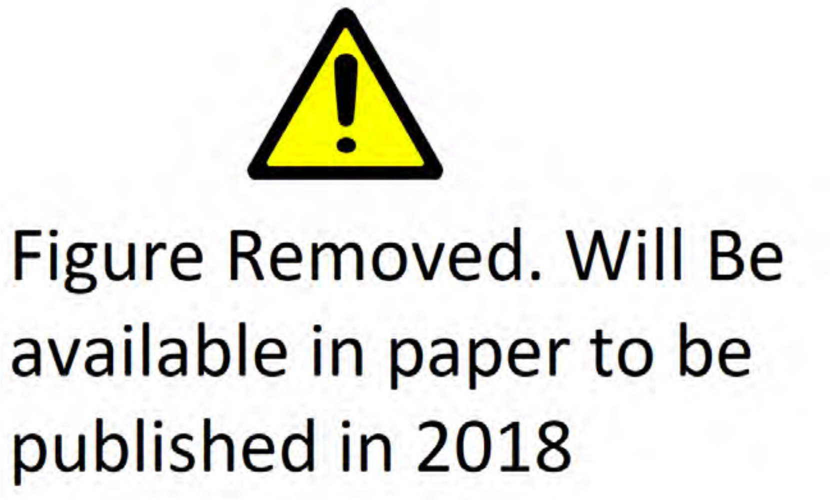



**(b)** $\mu_L \in [0.0; 0.5]$ and $\mu_S = 0.0$

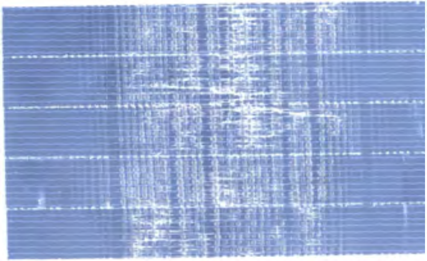
# S-N Curve


450
400
350
300
250
Load level [MPa]
$10^4$
$10^5$
$10^6$
$10^7$
Cycles [-]
5 Hz, Friction at Load Rollers
5 Hz, Bearings at Load Rollers
10 Hz, Bearings at Load Rollers
Trend: 5 Hz, Friction at Load Rollers ($R^2 = 0.9979$)
Trend: 10 Hz, Bearings at Load Rollers ($R^2 = 0.9635$)

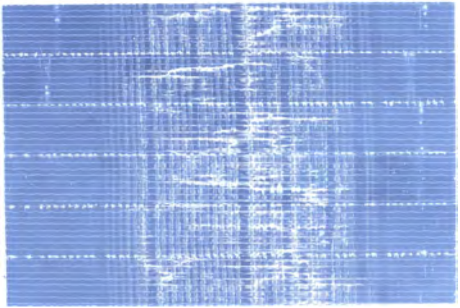
## Macro-scale damage from cyclic four point bending



# Macro scale damage due to patterns of transverse fibre bundles



**(a)** Batch A, small friction at load rollers



**(b)** Batch B, No friction at load rollers

# Large Field of View Microscopy

**Figure:** Large Field of View Microscopy. 28 mm by 3.6 mm captured with 700-800 images.

# Large Field of View Microscopy

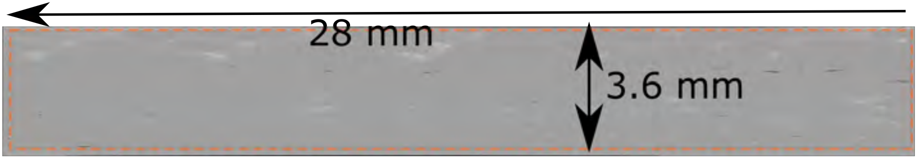



**Figure:** Large Field of View Microscopy. 28 mm by 3.6 mm captured with 700-800 images.

# Large Field of View Microscopy

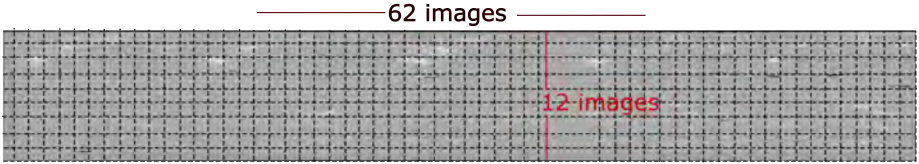
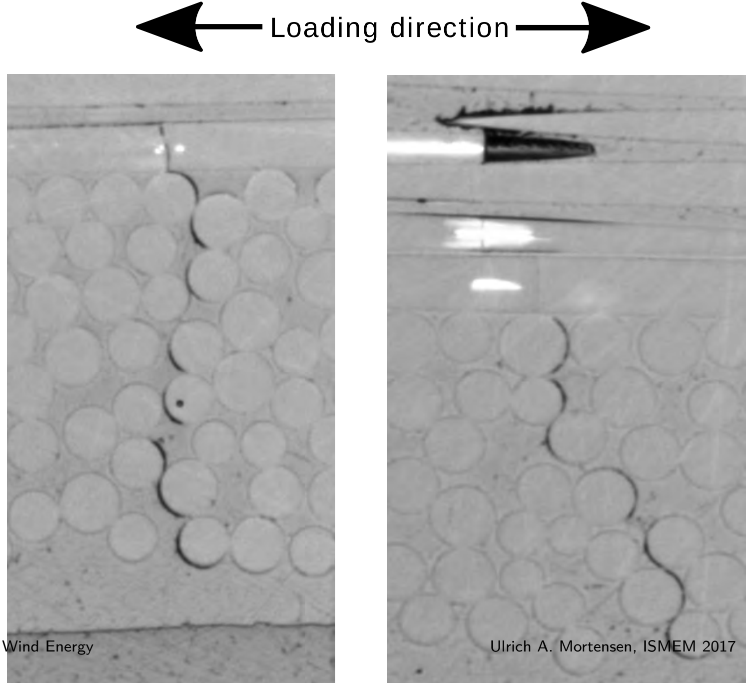



**Figure:** Large Field of View Microscopy. 28 mm by 3.6 mm captured with 700-800 images.

# Examples of micro-scale matrix cracks and fibre breaks



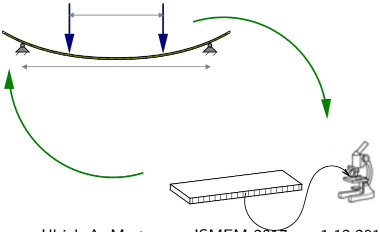
# Examples of micro-scale matrix cracks and fibre breaks

Figure Removed. Will Be available in paper to be published in 2018

# Examples of micro-scale matrix cracks and fibre breaks 2

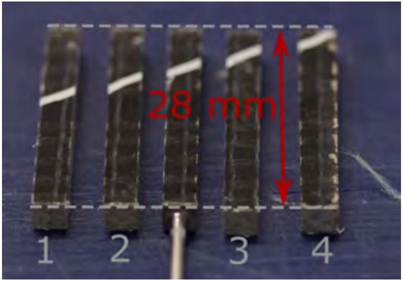
# Ex-Situ

- Size: 9.7 mm by 3.6 mm, 386 images stitched together
- $[1 - 15] \cdot 10^3$ with $10^3$ cycles per interval
- $[15 - 95] \cdot 10^3$ with $10^3$ cycles per interval
- $[15 - 95] \cdot 10^3$ with $10^3$ cycles per interval
- $[95 - 225] \cdot 10^3$ with $25 \cdot 10^3$ cycles per interval
- $[225 - 1225] \cdot 10^3$ with $250 \cdot 10^3$ cycles per interval

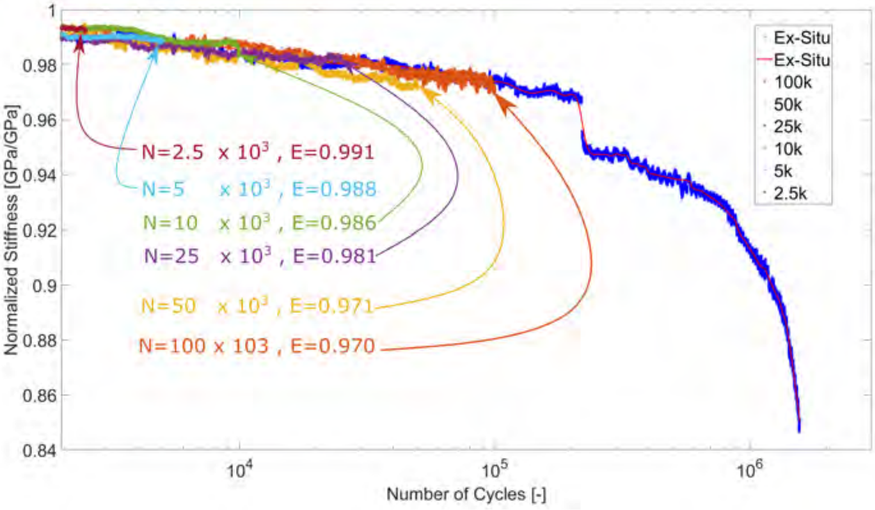


# Destructive Microscopy Test

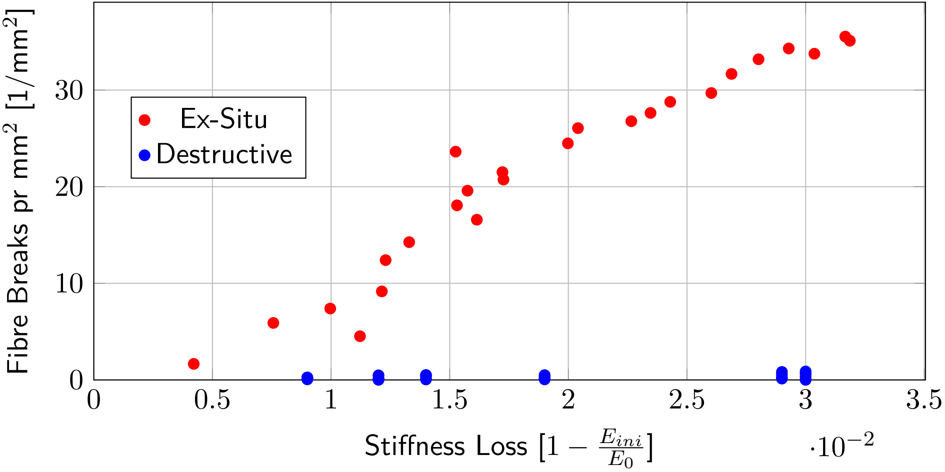
- Six specimens cut adjacent to each other
- All loaded with 325 MPa maximum stress at surfaces
- No. of loadings $N = [2.5\ ,\ 5\ ,\ 10\ ,\ 25\ ,\ 50\ ,\ 100]\ \cdot 10^3$



# Stifness Degradation



# Fibre Break Density



# Distances from Fibre breaks to Transverse fibre bundles - Ex-Situ - $N = 10 \cdot 10^3$

**Figure:** Fibre break positions in Ex-Situ study

# Distances from Fibre breaks to Transverse fibre bundles - Ex-Situ - $N = 10 \cdot 10^3$

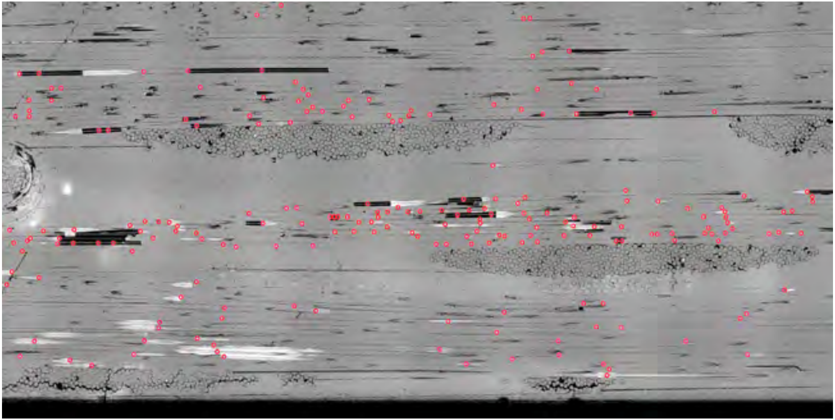


**Figure:** Fibre break positions in Ex-Situ study

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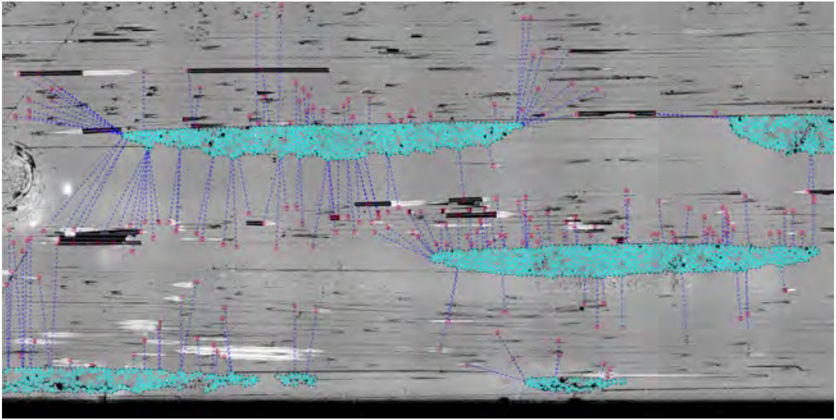


**Figure:** Fibre break positions in Ex-Situ study

# Distances from Fibre breaks to Transverse fibre bundles - Destructive test - $N = 10 \cdot 10^3$

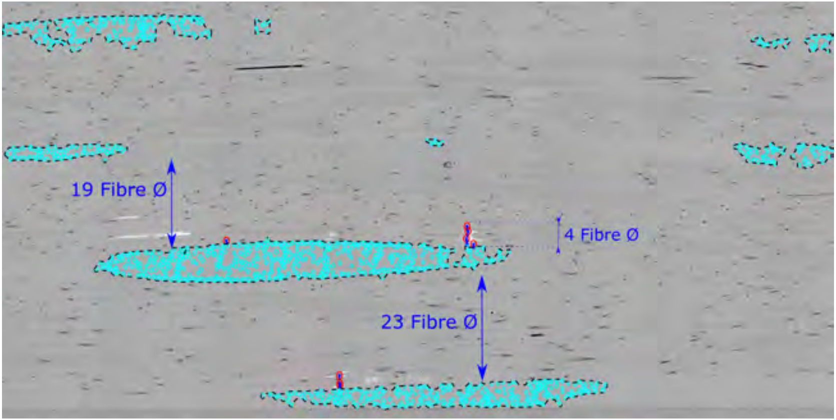
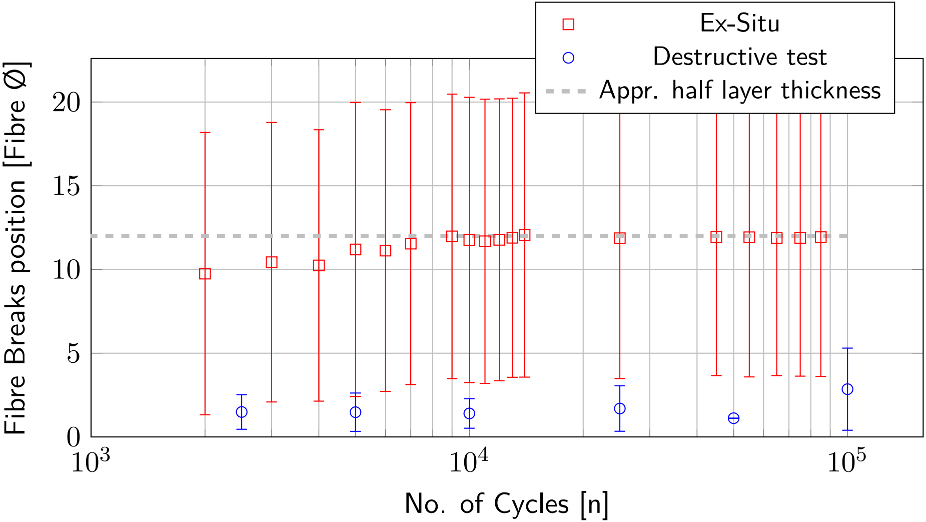



**Figure:** Fibre break positions in Destructive testing

# Fibre Break Density



# Conclusion

- Edge-effects makes Ex-situ study microscopy studies quantitatively unreliable, but may give some qualitative insight into damage mechanisms
- Transverse Matrix cracks in transverse fibre bundles are the main driver for breakage of fibres in the load carrying fibre bundles in uni-directional non-crimp glass fibre fabric.

## Questions ?

# Thank You!