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Training network in floating wind energy

Automated tape placement of carbon fibre reinforced thermoplastics for offshore wind turbine blades

Alejandro Jiménez del Toro

ÉireComposites

Technical University of Delft

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 860737.

Agenda

- Composites in wind turbine blades
- Laser-assisted tape placement
- In-situ consolidation
- Degree of intimate contact optimisation
- Conclusions
- References

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Composites in wind turbine blades

- Increasing size, weight and loads
- Structural integrity while minimising weight
  - Load bearing components
    - Spar cap: flap wise bending momentum
  - Peak and fatigue loads
- Carbon fibre composites
  - Higher specific properties than glass fibre composites
  - Micro-buckling sensitivity
    - Fibre alignment
- Thermoplastic composites (TC)
  - Reusable and Recyclable
  - Infinite shelf-life and in-situ consolidation
  - Expensive

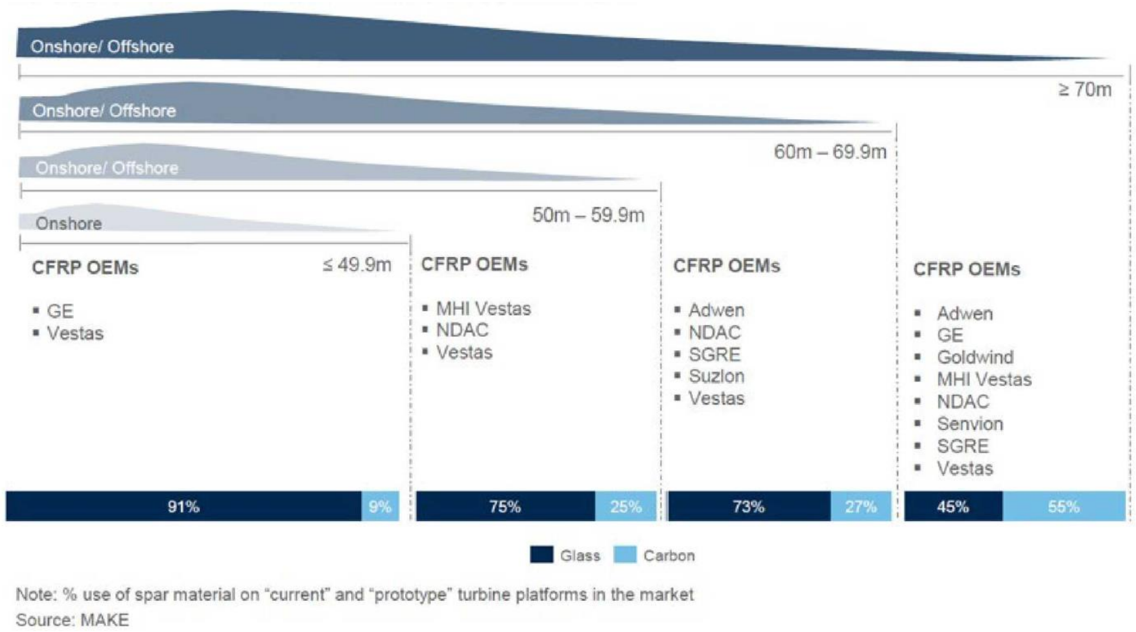

Figure 1. Use of carbon and glass fibre spar caps as a function of blade length [1]

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Laser-assisted automated tape placement (LATP)

- Advantages
  - Design flexibility and integration
  - In-situ consolidation
- Disadvantages
  - Expensive materials and technology
  - Current capabilities
- Pre-impregnated tapes (prepreg)

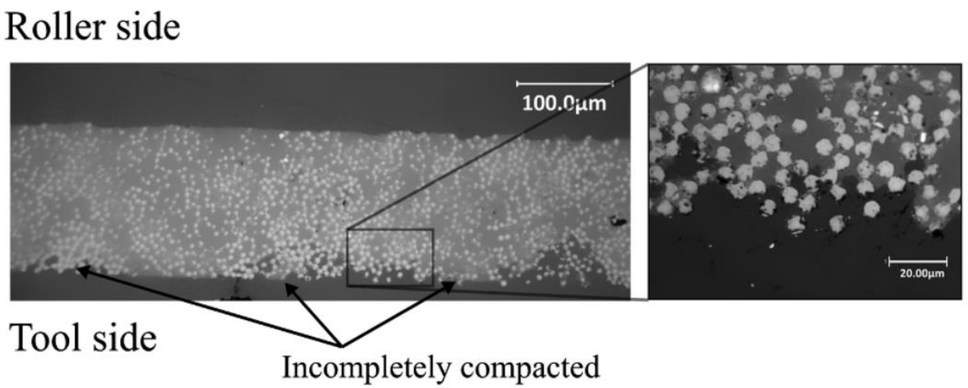

Figure 2. Dry fibre bundles on surface tape after compaction in LATP of CF/PEKK UD tapes[2] .

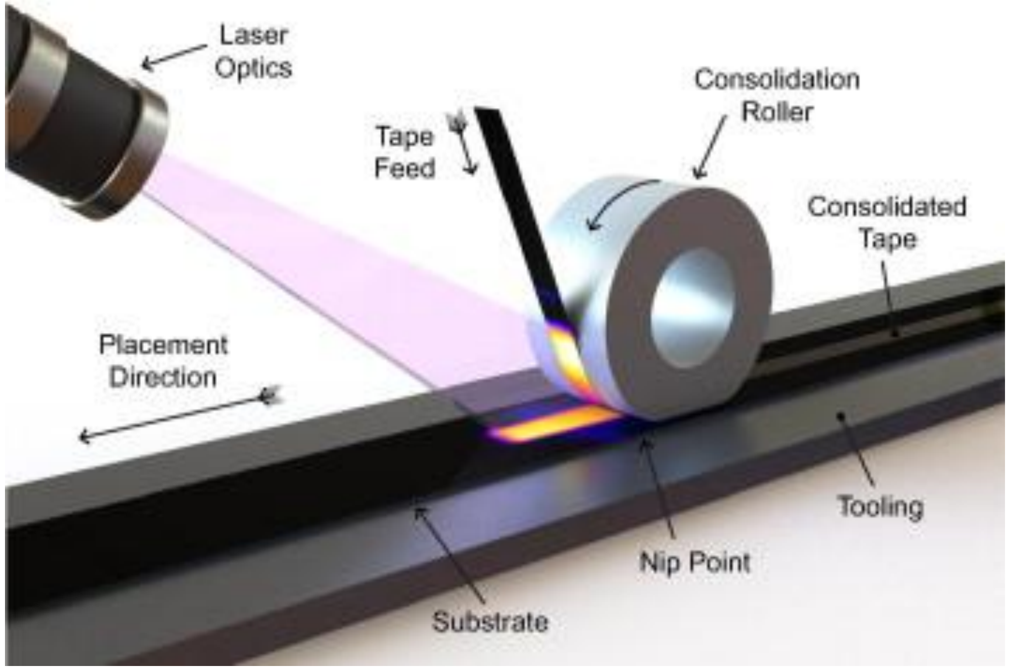

Figure 3. LATP main components and working principle scheme [3]

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Laser-assisted automated tape placement

- Placement speed vs. void content
- Simplified flat part
  - Part: 87.5 m x 600 mm x 40 mm
  - Tape thickness: 0.6 mm
  - Tape width: 300 mm
  - 20% extra time

Quality criteria	Void content (%)	< 2%
Manufacturing time	< 10 h	> 400 mm/s

Table 1. LATP quality criteria and manufacturing time estimated targets for a Simplified rectangular flat composite part.

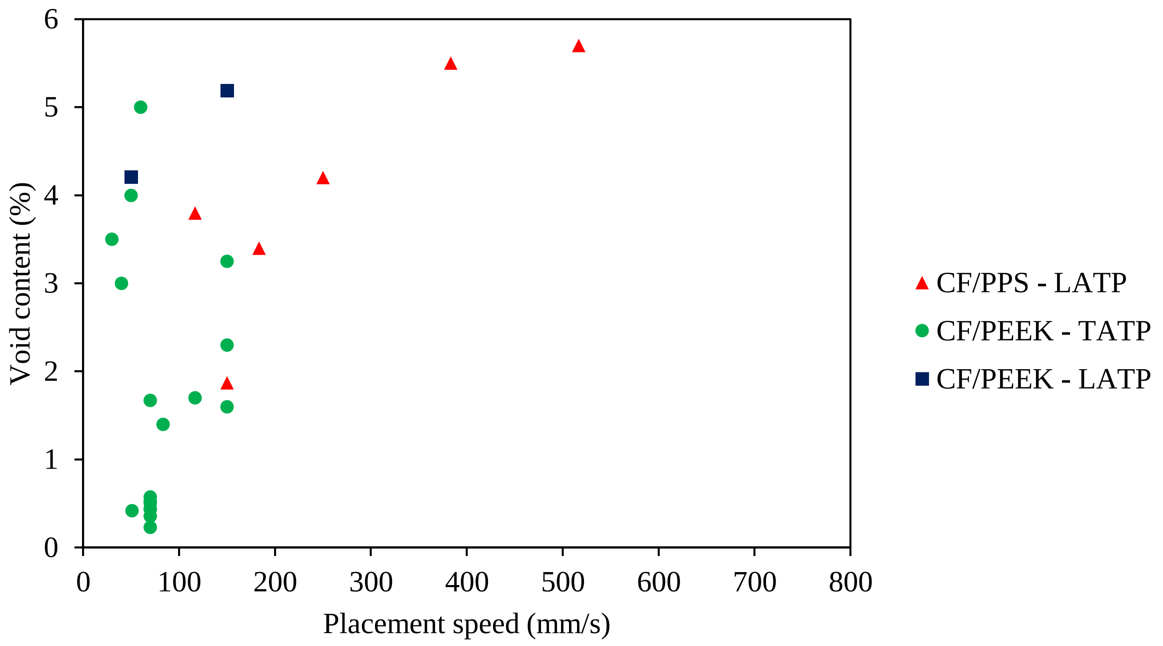

Figure 4. Summary of void content versus placement speed for CF/PEEK and CF/PPS UD composites manufactured by means of LATP and hot gas torch ATP (TATP).

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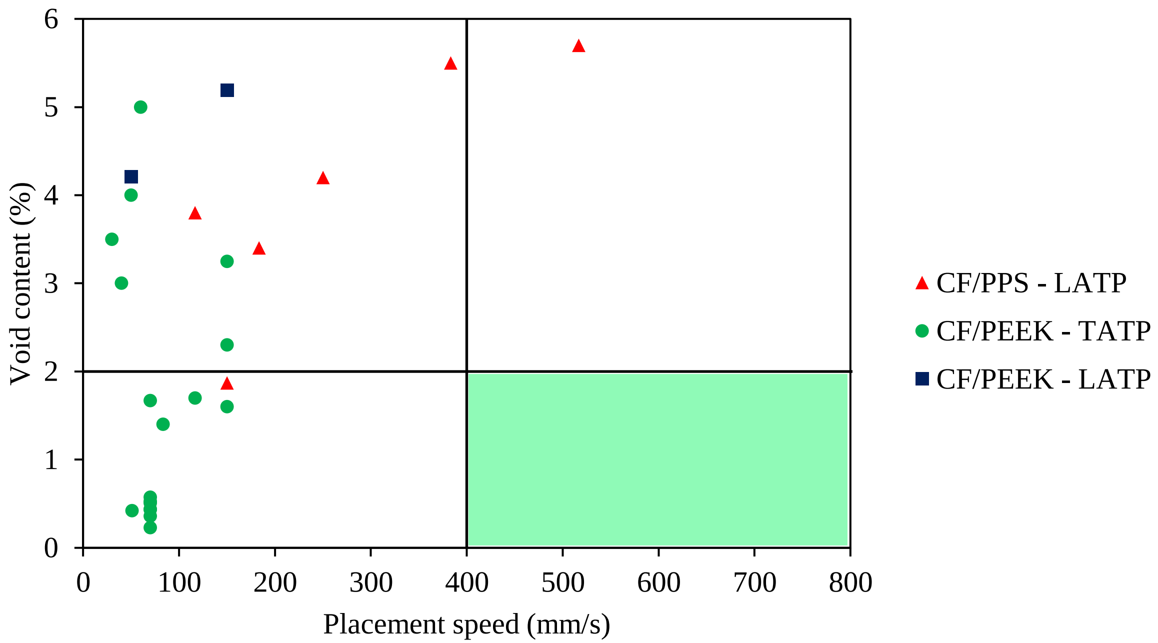

Figure 5. Summary of void content versus placement speed for CF/PEEK and CF/PPS UD composites manufactured by means of LATP and hot gas torch ATP (TATP).

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In-situ consolidation and intimate contact

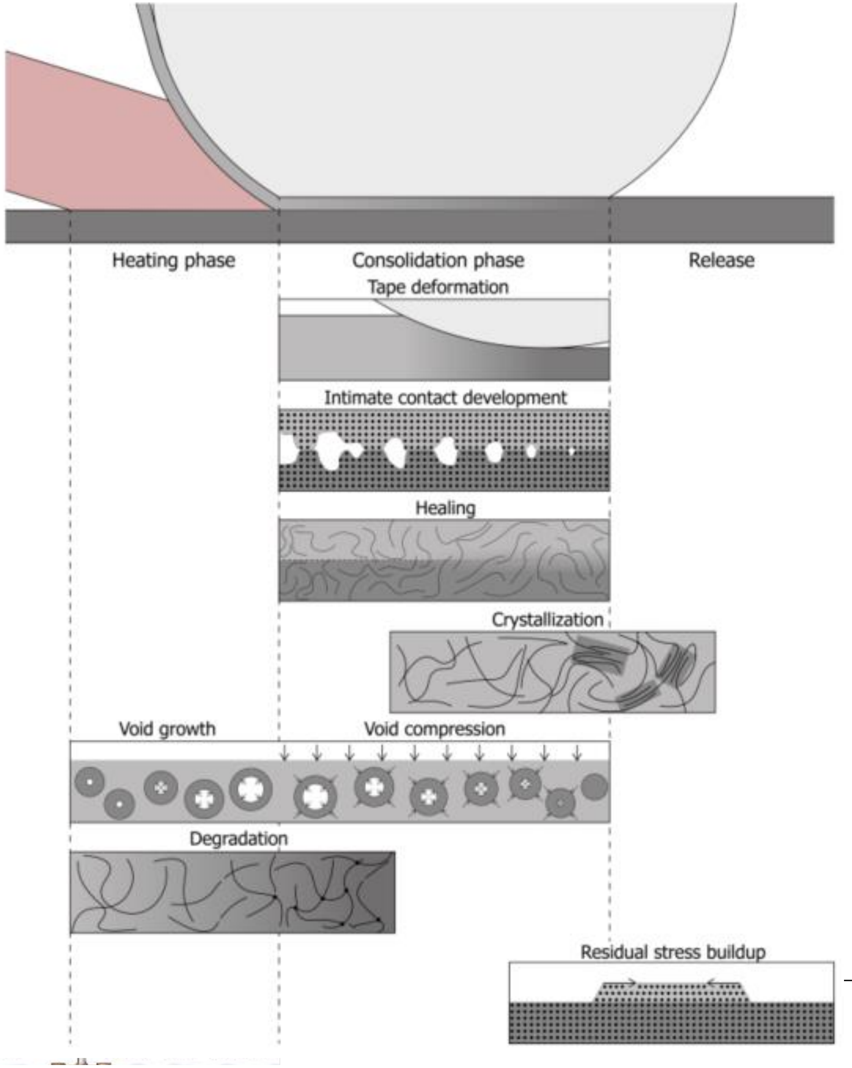

Figure 6. LATP in-situ consolidation governing mechanisms [4]

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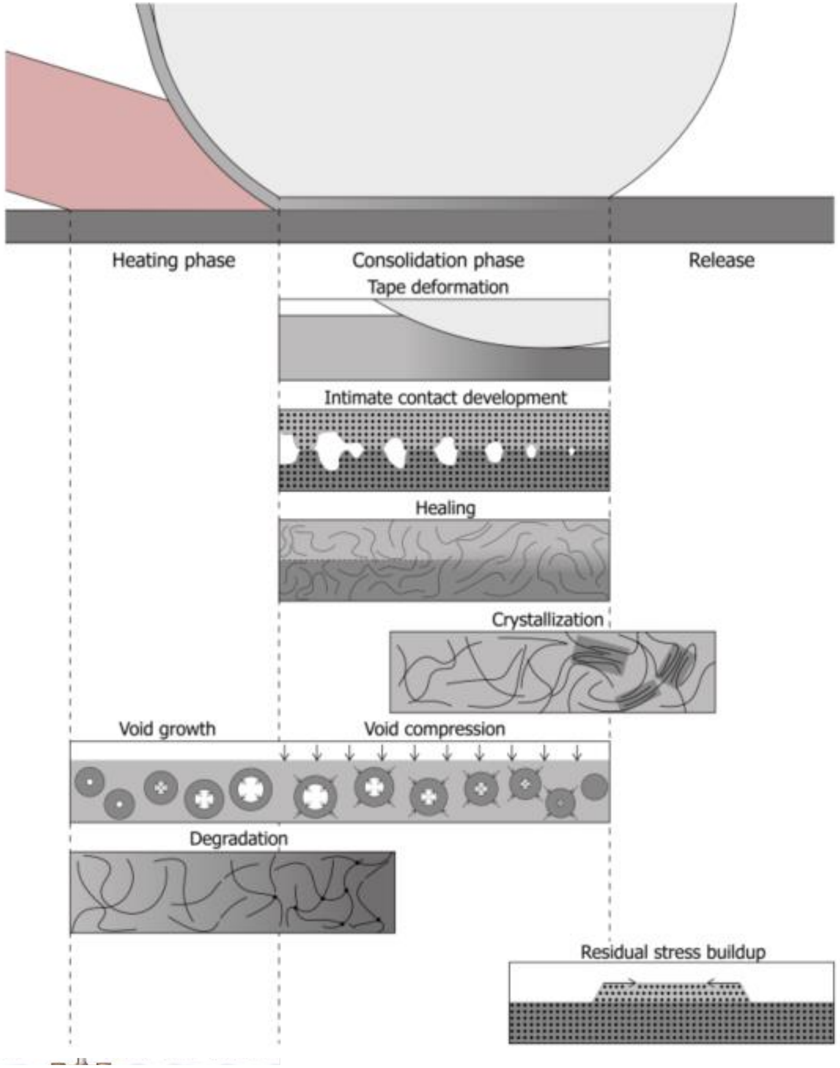
In-situ consolidation and intimate contact



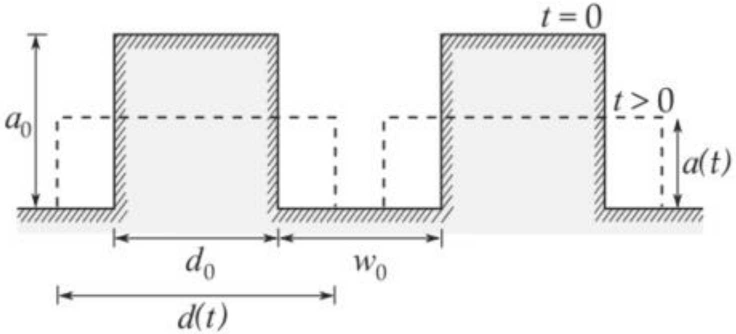


Figure 7. Surface roughness flattening representation from Lee, W et al. [5], adapted by Grouve, W. et al. [6] .

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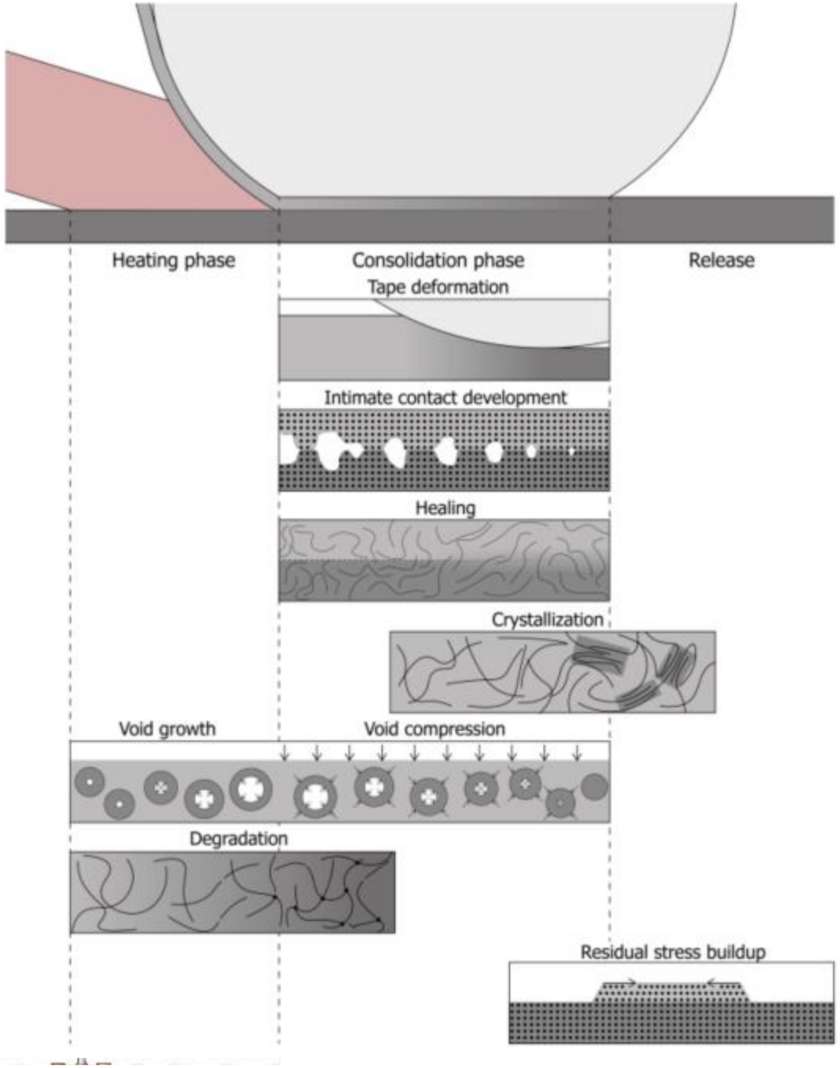

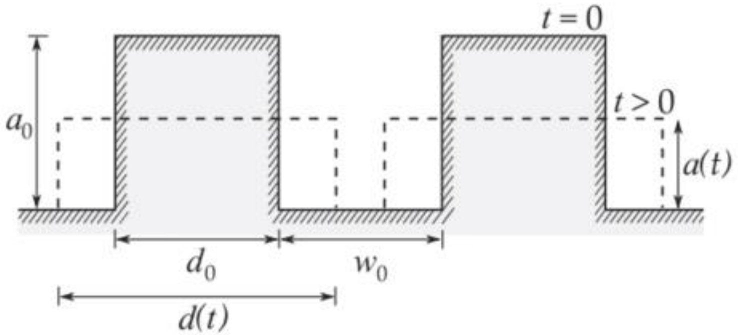

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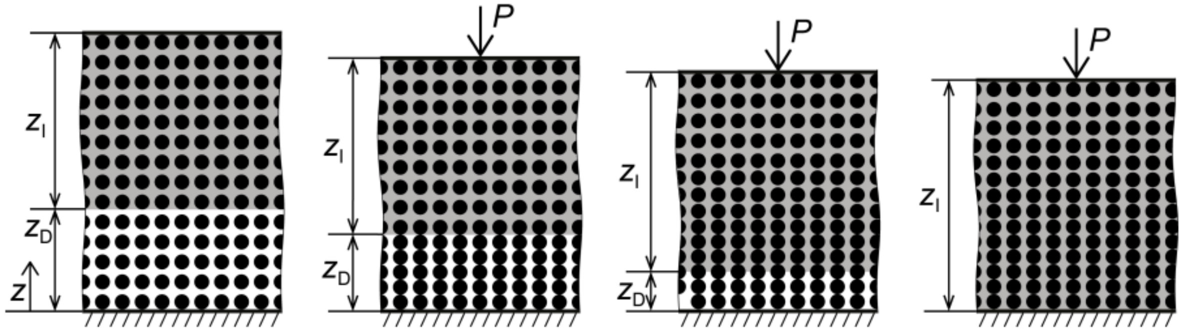

Figure 8. Schematic representation of percolation flow of a molten resin through a fibre bed, following Darcy's law [4].

Figure 6. LATP in-situ consolidation governing mechanisms [4]

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Degree of intimate contact optimisation

- Squeeze flow

$$\bar{t}_{ic} = \left(D_{ic,0}^{-5} - 1\right)\left(\frac{1}{5}\frac{d_0^2}{\left(1+\frac{w_0}{d_0}\right)a_0^2}\right)\frac{\eta_0(T)}{P_{\mathrm{app}}}$$

$P_{\mathrm{app}}(t)$: Applied pressure
$\eta_0(T(t))$: zero−shear viscosity
t_c: compaction time
a_0, d_0, w_0: surface roughness

- Percolation flow

$$t_{\mathrm{imp}} = \frac{(1-V_f)L^2}{2K_{\perp,\mathrm{hex}}(V_{\mathrm{f}},R)}\frac{\eta(T)}{\Delta P(P_{\mathrm{app}})}; \quad K_{\perp,\mathrm{hex}} = \frac{16}{9\pi\sqrt{6}}\left(\sqrt{\frac{V_{f_{max}}}{V_f}}-1\right)^{\frac{5}{2}}R^2$$

$\Delta P(P_{\mathrm{app}})$: pressure difference
$\eta(T)$: dynamic viscosity
V_f: fibre volume fraction
$K_{\perp,\mathrm{hex}}$: fibre bed permeability
L: impregnation distance
R: fibre tow radius

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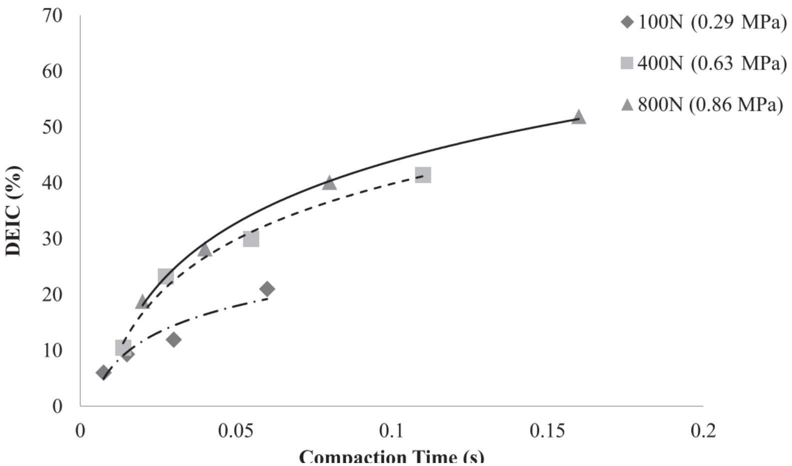

Figure 9. DEIC as a function of placement speed and compaction force on CF/PEKK UD tapes[2] .

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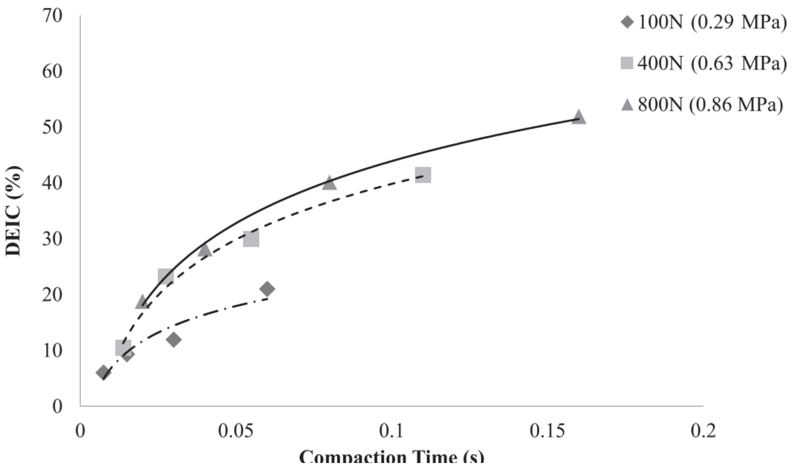

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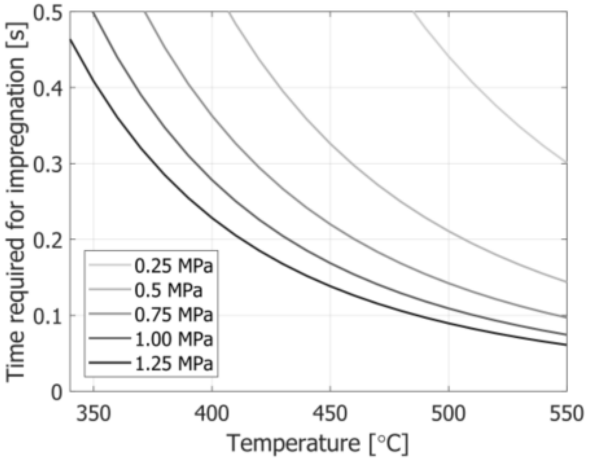

Figure 10. Time of impregnation as a function of nip point temperature and compaction pressure in LATP of CF/PEEK UD tapes[4] .

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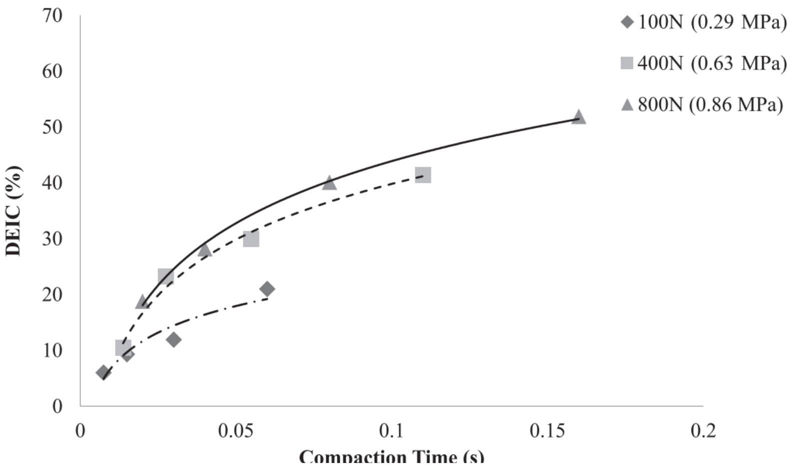

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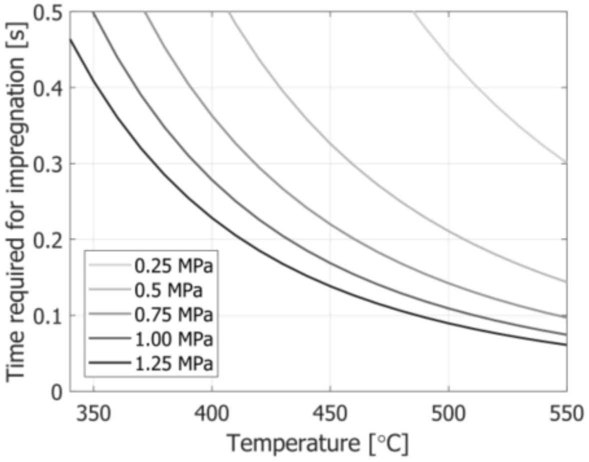

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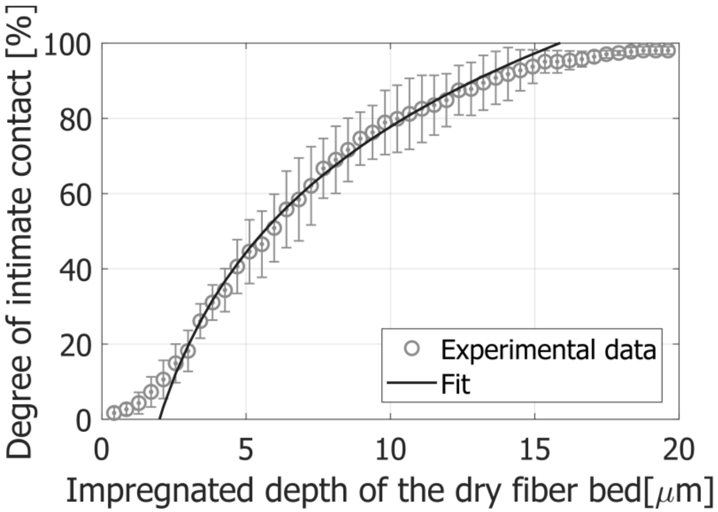

Figure 11. D_{ic} contact as a function of impregnated depth of the dry fibre bed in LATP of CF/PEEK UD tapes[4] .

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Conclusions

- Current achievable LATP placement speeds of thermoplastic composites cannot satisfy wind energy industry needs
- Technology and raw material costs are elevated – economy of scale
- Percolation and squeeze flow coexist during in-situ consolidation
  - Degree of intimate contact is a function of the dry fibre bed depth
  - Heavier tows ease fibre bed impregnation, while carbon fibre hinders intra-tow impregnation.
- In-situ consolidation optimisation requires:
  - Process optimisation
    - Optimum pressure: favour squeeze and percolation flow vs. increase fibre volume fraction
    - Optimum temperature: minimise viscosity vs. thermal degradation
  - Material optimisation
    - Matrix viscosity
    - Surface roughness
    - Dry fibre bed depth

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