Studying Crystallinity Gradients in High Performance Thermoplastic Composites Manufactured by Automated Tape Placement

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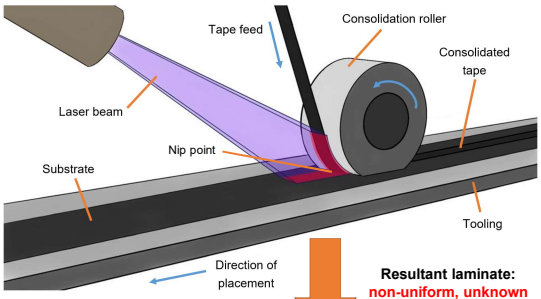
Manufacturing of High-Performance Thermoplastic Composite Components: State-of-the-Art

- Forecasted increase in demand in the aerospace industry calls for action to be taken to tackle **environmental impact** without compromising performance.
- Inclusion of **high performance composites** is key in achieving this.

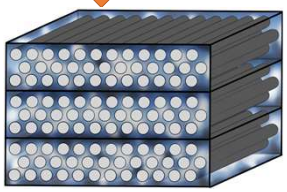
Industry challenge: Components require post-processing due to non-uniformity and uncertainty regarding material quality after undergoing Automated Tape Placement, increasing costs.

Automated Tape Placement

Automated tape placement (ATP) uses **computed-guided robotics** to place and consolidate composite tape.



Resultant laminate: non-uniform, unknown crystallinity distribution

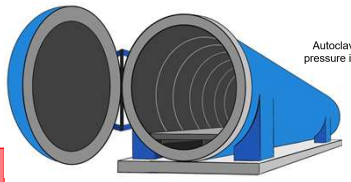


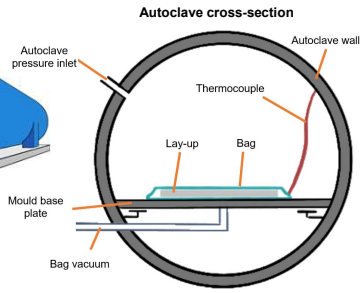
- ✓ In-situ consolidation
- ✓ Higher production speeds
- ✓ Superior accuracy and precision
- ✓ Suitable for complex geometries
- ✓ Automation
- ✓ Waste reduction
- × Non-homogeneous consolidation – **needs post-processing**

Post-processing currently required

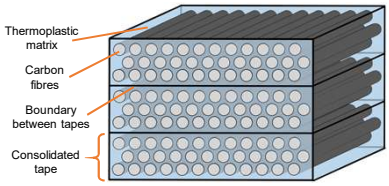
Autoclave

Autoclaves are large vessels that offer control of the pressure, temperature and environment inside the chamber.





Resultant laminate: Uniform, controlled crystallinity distribution



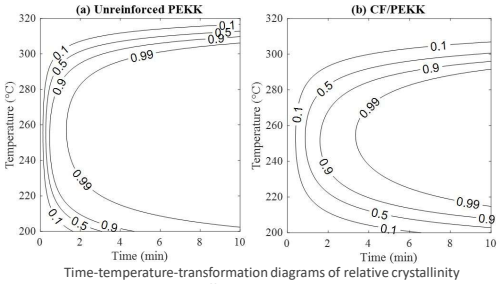
- ✓ Very high, even consolidation – **the "gold" standard**
- × **High cost**
- × Long processing times

Proposed Research

Objective and desired outcome: Study crystallinity distribution and gradients across ATP-manufactured laminates, to ultimately enhance the reliability of this manufacturing process and **deliver high quality parts** at a competitive cost, **without the need of post-processing.**

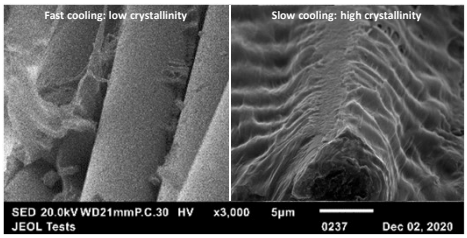
Material characterisation

- **Differential scanning calorimetry** of unreinforced and CF/PEKK samples. Evaluation of crystallinity %, morphology, kinetics and modelling.



Time-temperature-transformation diagrams of relative crystallinity development over time at different isothermal holds. A relative crystallinity of 1 means the material has achieved its full crystallisation potential.

- **Scanning electron microscopy** of CF/PEKK samples to observe differences in crystal morphology as a consequence of thermal history



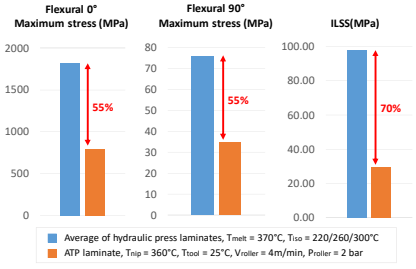
- **Parallel plate rheometry** to study the effect of processing temperature on viscosity and flow of PEKK matrix (ongoing work).

Laminate manufacturing

- **Hydraulic press** at the University of Edinburgh. Tested parameters: holding temperature in the melt, isothermal temperature below the melt.
- **Automated Tape Placement** at University of Limerick. Tested parameters: temperature at nip point, lay-down speed, roller pressure, use of a heated tool.

Mechanical testing

- **Flexural 0°, Flexural 90°, ILSS.**
- **Results:**



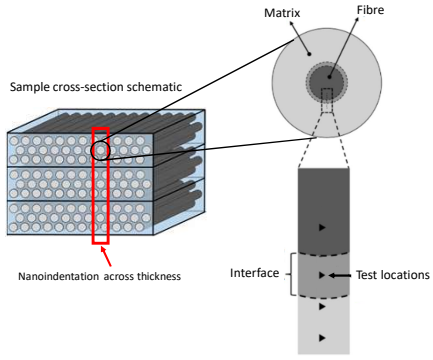
Main conclusions

- All hydraulic press laminates performed similarly.
- Longer holding times at crystallisation temperatures results in a higher crystallinity content, resulting in a stronger and stiffer response of the hydraulic press laminates than the ATP laminates.
- Longer holding times at higher temperatures and pressures allows for better laminate consolidation between the plies, resulting in a significantly better performance in ILSS.
- In-plane shear testing will provide further insight into matrix performance.

Laminate through-thickness property evaluation

Different characterisation techniques are used to indirectly study **crystallinity variation** across the thickness of the laminates, as well **as trans-crystallinity** at the fibre/matrix interphase.

This is achieved by testing properties such as hardness or elastic modulus, which is expected to differ between crystalline and amorphous regions (ongoing work).



Published work

- Crystallinity studies of PEKK and carbon fibre/PEKK composites: A review. https://doi.org/10.1016/j.compositesb.2021.109127
- Crystallisation behaviour and morphological studies of PEKK and carbon fibre/PEKK composites. https://doi.org/10.1016/j.compositesa.2022.106992

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