Monitoring and Evaluation of In-situ Consolidation of Thermoplastic Composite Pipe Layers

Presented by

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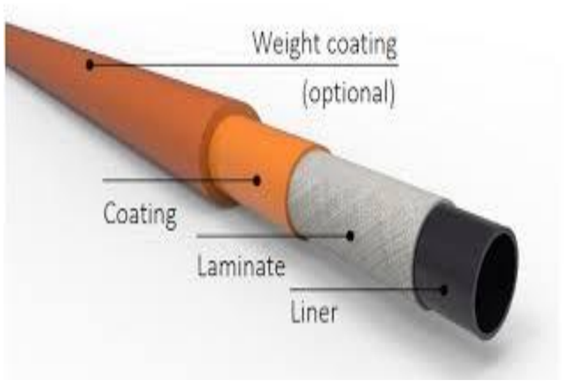
Outline

- Introduction
- Research aims & objectives
- Methodology Overview
- Discussion of results & other analyses
- Conclusion
- Acknowledgement

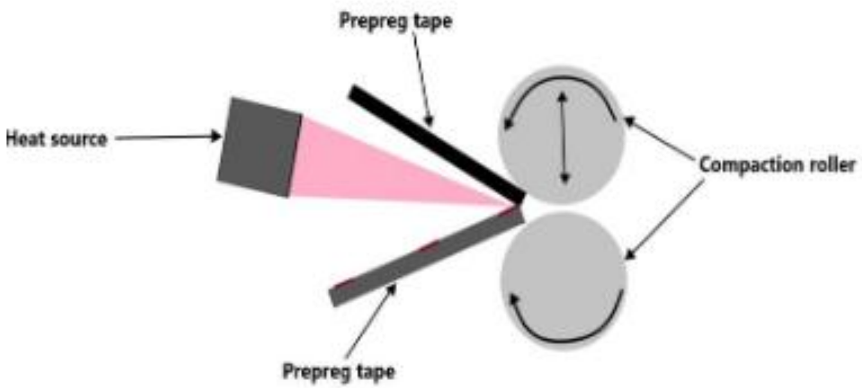
Introduction

- TCP benefits include being lightweight, no corrosion and modular.
- Thermoplastic composite pipes (TCP) manufacturing challenges.
- Need for smart, adaptive manufacturing.
- Real-time sensor integration during consolidation of polyethene (PE)/ glass fibre (GF) laminates.



TCP layer composition

A reeled TCP with end fitting about to be installed



Research aims & objectives

Aims: To demonstrate the potential and the influence of embedded sensors in accurately monitoring thermal and pressure distributions in real time to optimize the parameters to improve inter-laminar bond strength (ILBS).

Objectives:

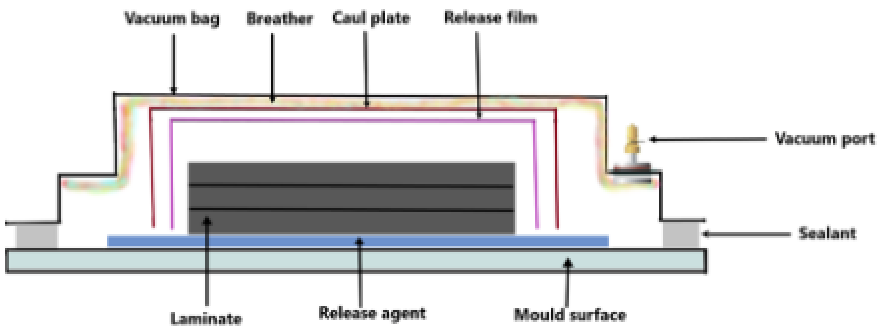
✓Monitor temperature and pressure in real-time

✓Evaluation of effects of consolidation parameters

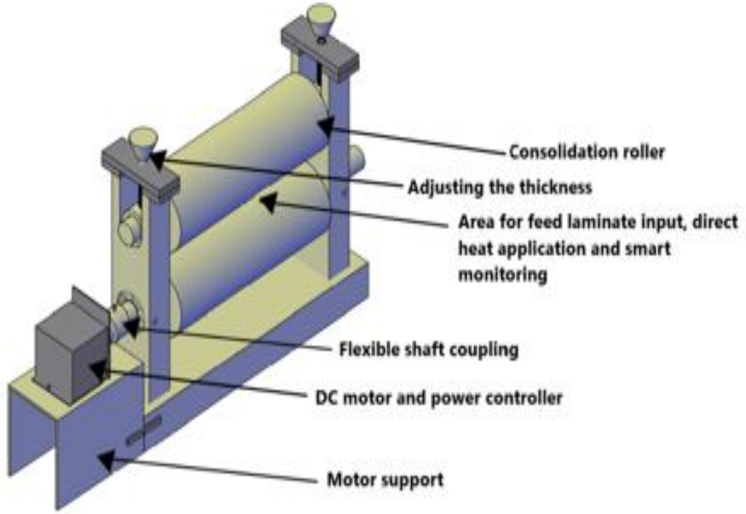
✓Improve inter-laminar bond strength (ILBS)

Methodology Overview

- Sensors: K-type thermocouples & 350 Ohm strain gauges
- Consolidation techniques: Dual roller, vacuum bag, post-heating.
- Dual roller and vacuum bag methods used.
- Post-treatment heating to reduce voids and improve strength.
- Parameters: Temperature (150°C, 200°C, 250°C), pressure, and time
- Data analysis: BBD model, PSO optimization, ANOVA



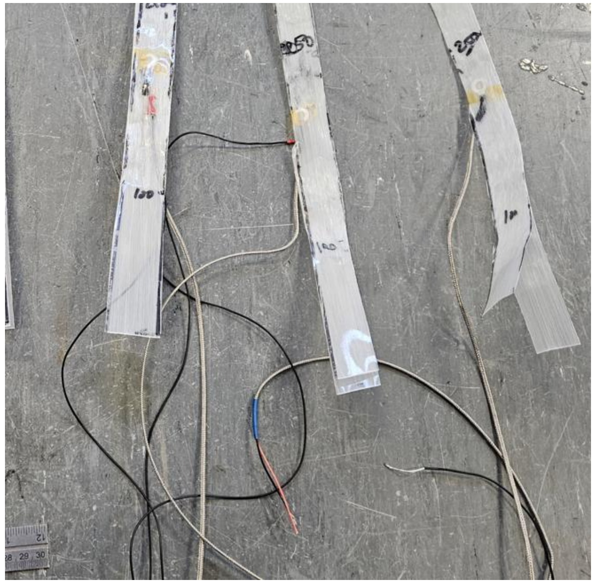
Vacuum bag consolidation



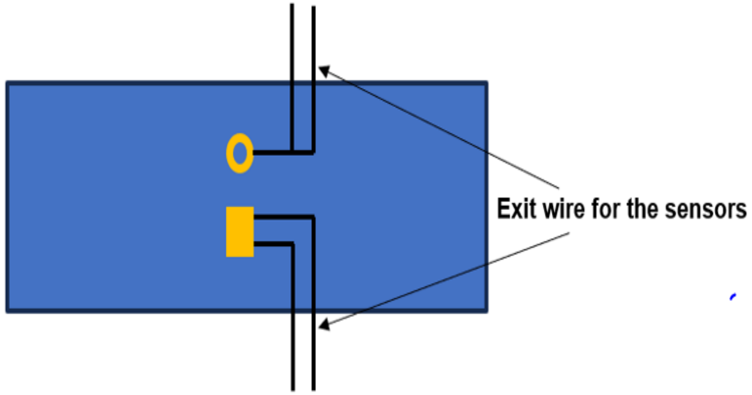
Dual roller consolidation

Sensor Embedment & Monitoring

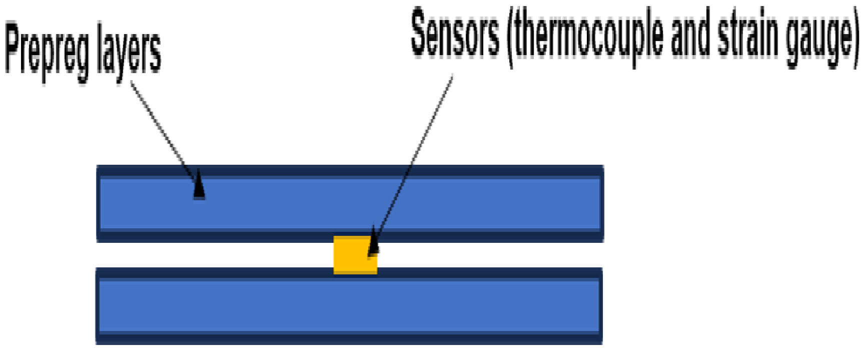
- Thermocouples & strain gauges embedded in centre of laminate interface
- Kapton tape for thermal insulation
- Sensors monitored real-time pressure and temperature
- Influences on ILBS evaluated



Embedded sample



Sample stack



Sensor within the prepreg sample

Mechanical testing

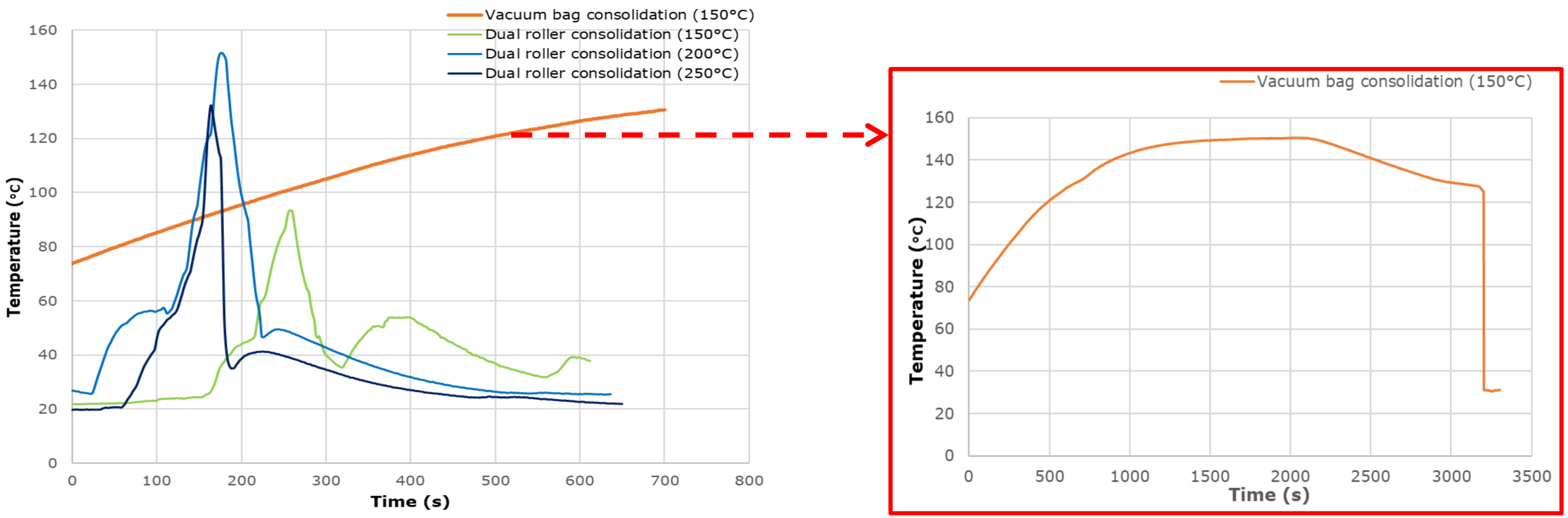
- Tensile Test (ISO 527-4): Measured strength, ductility, modulus
- T-Peel Test (ASTM 1876-01): Measured inter-laminar bond strength
- Instron 3382 with 100kN load cell
- 18 tensile and 36 peel test samples
- Analysed with SEM and ImageJ software

Tensile test

T-peel test

Discussion - Consolidation findings

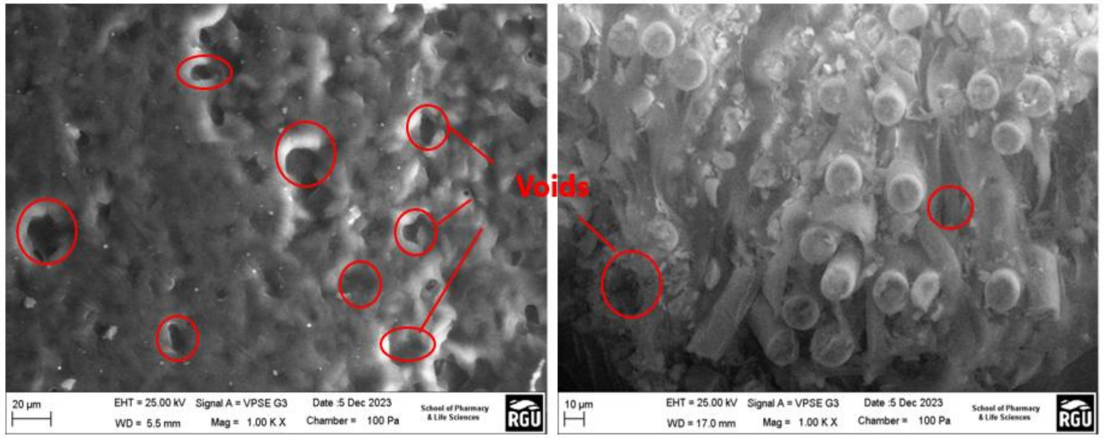
- Sensor data captured thermal and pressure profiles.
- Best consolidation at 200°C: Optimal melt flow and bond for balance between bonding and degradation.
- 150°C: Poor bonding, voids
- 250°C: Matrix degradation observed
- Post-treatment improved tensile strength by 9.52% and ILBS by up to 74.27%



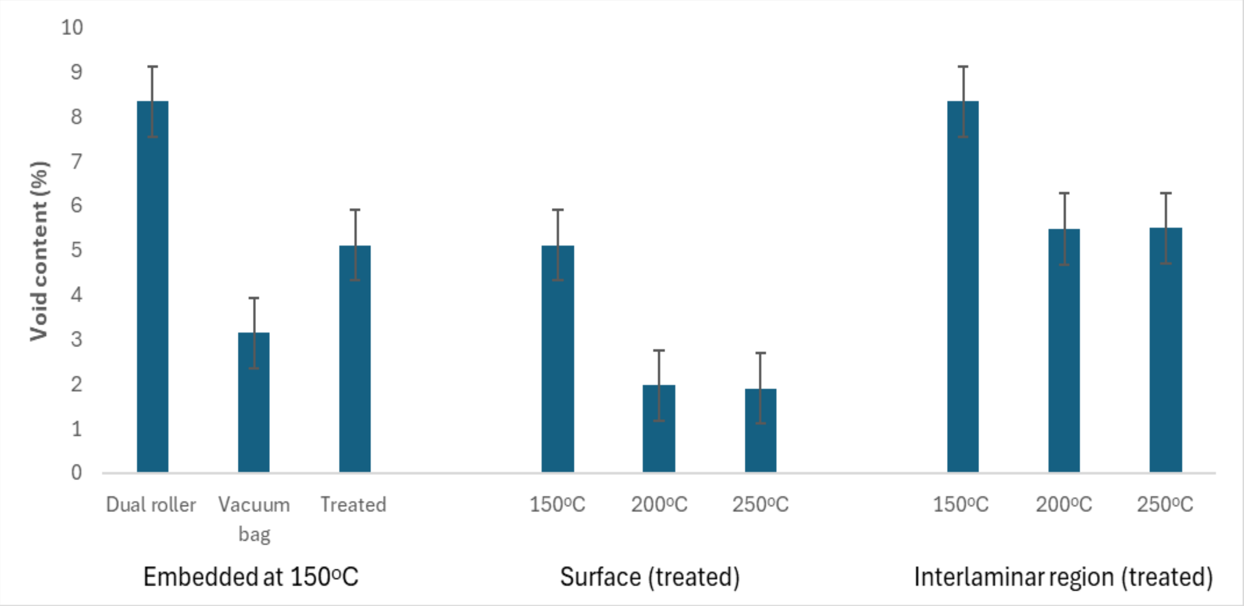
Temperature distribution for both methods

Void Analysis

- SEM and Image J used for void quantification
- Void content for 200°C consolidation reduced by 60% with post-heating
- Dual roller at 150°C had highest voids
- 250°C risk of matrix degradation



Void analysis through SEM

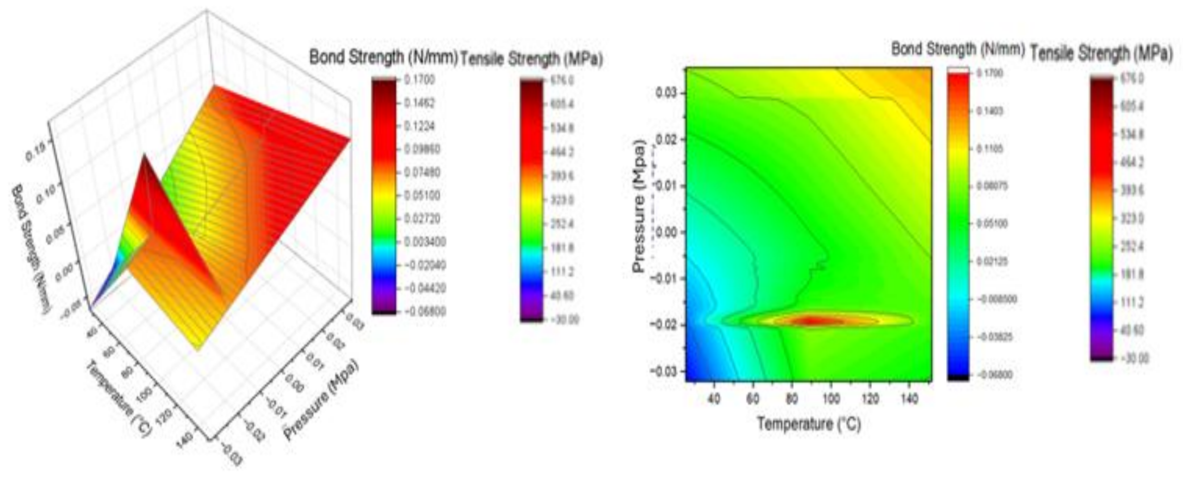


Void content for the consolidated samples

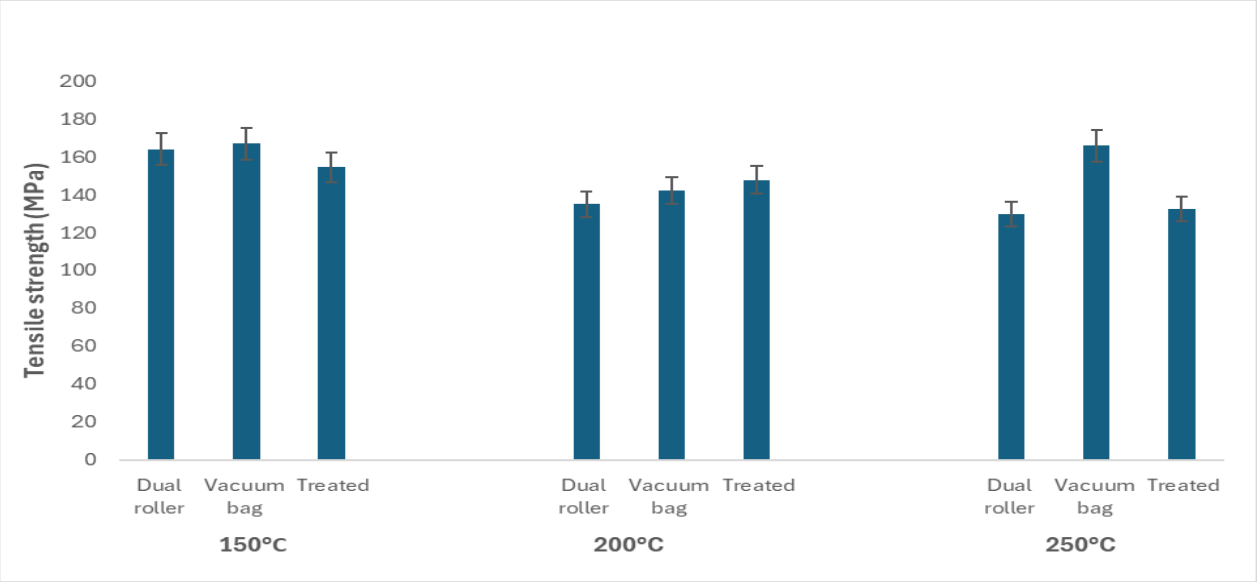
Effect of consolidation parameters on performance

- High pressure needed at 150°C due to high viscosity.
- At 200°C, balance of melt and strength.
- 250°C: Matrix degradation risk, uniformity of properties.
- Proper tuning needed to avoid defects.

$BS = 0.4517 - 0.0142A - 0.0373B + 0.0015AB + 0.0001A^2 - 0.0027B^2$



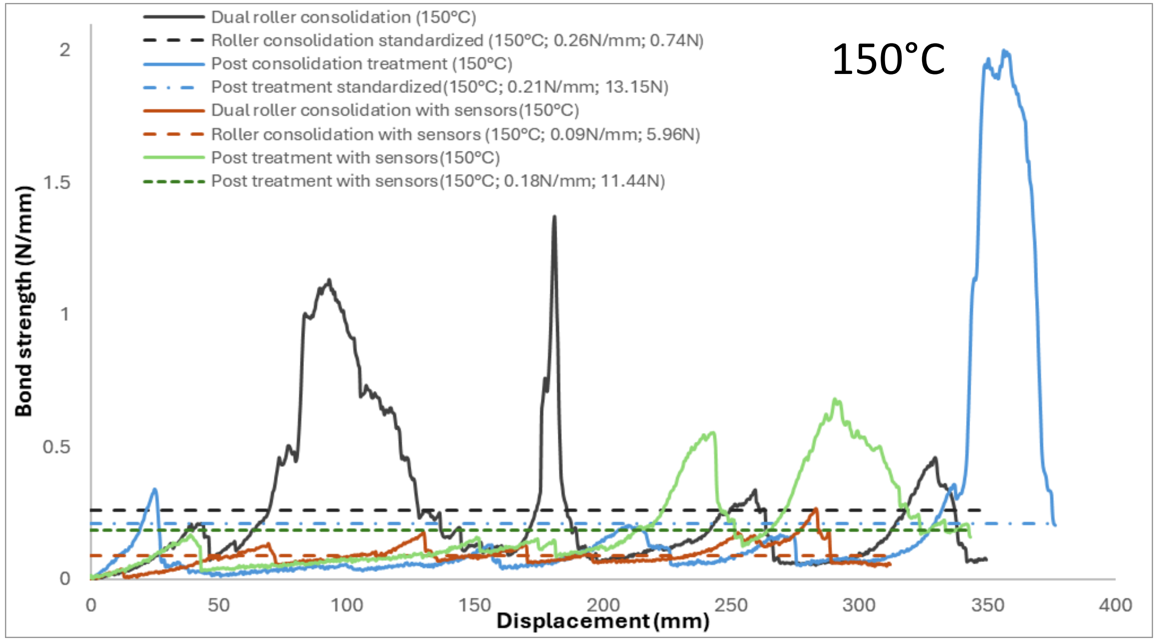
The effect of the processing parameters on the performance

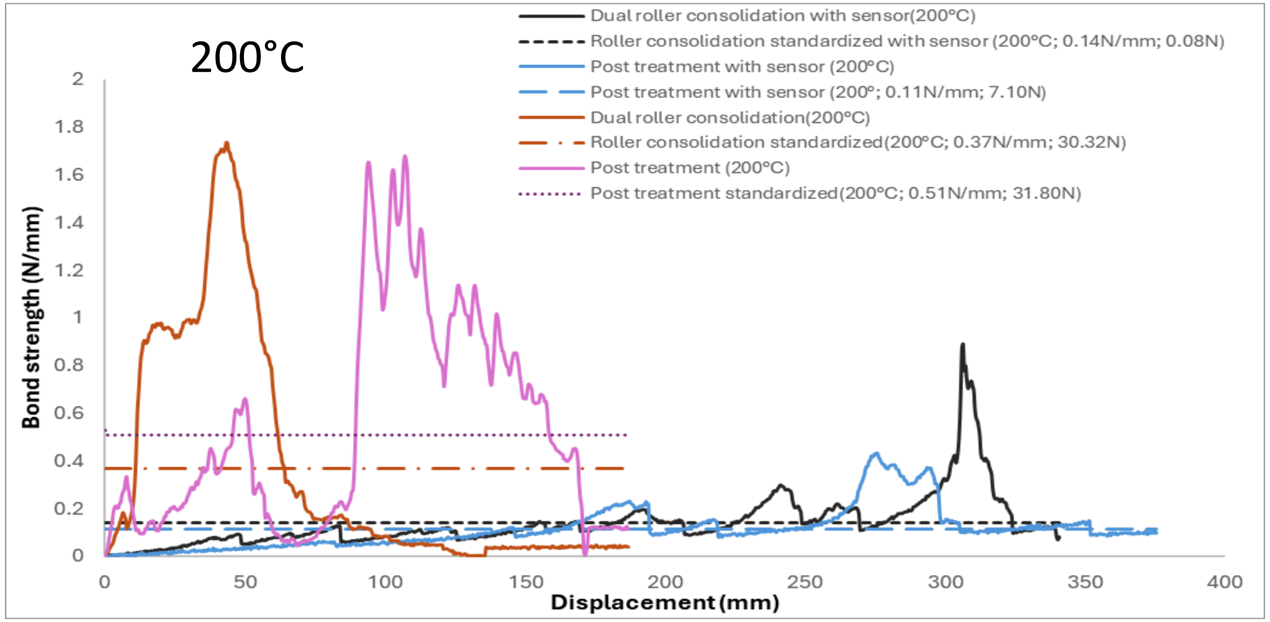


Tensile properties

Influence of sensor integration

- Reduced bond strength due to embedded sensors
- Mid-layer is optimal position for sensors – advocate for more locations
- Post-heating mitigates strength loss from sensor embedment
- Calibration of sensor and data acquisition needed to avoid inaccuracies

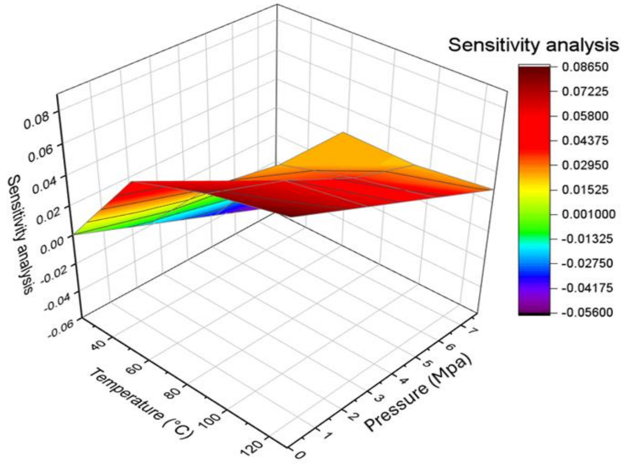




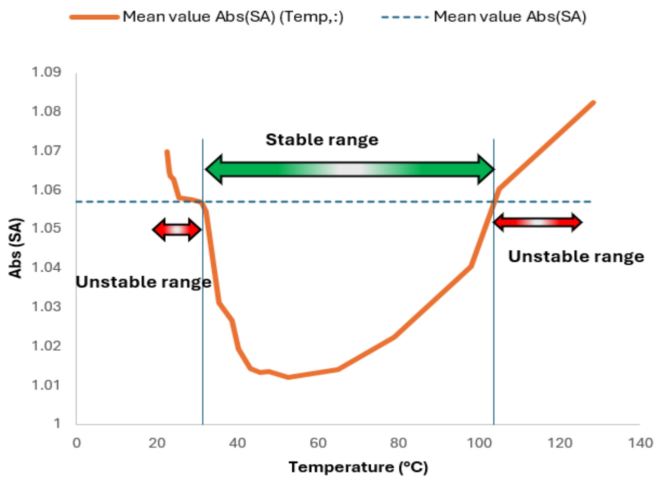
Normalized bond strength plot

Sensitivity and optimization analysis

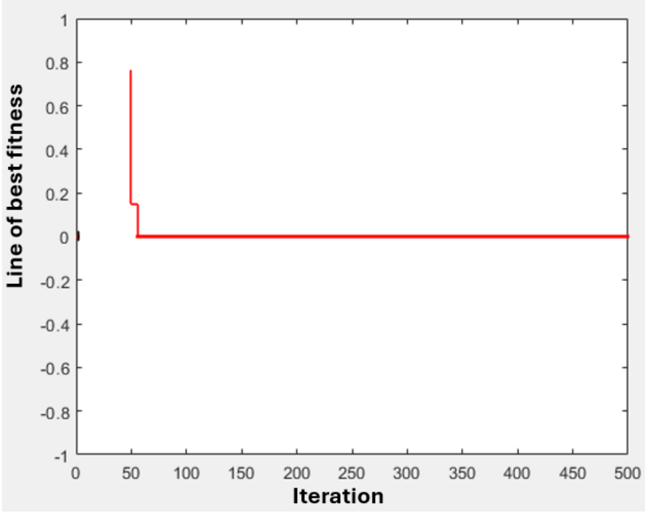
- Box-Behnken Design and ANOVA used for statistical model development.
- Sensitivity analysis showed stable windows and identified temperature as the dominant parameter.
- Stable domains: 31.5–105°C, 0.4–6.6 MPa
- PSO optimized parameters: 101.68°C, 6.09MPa → 0.77 N/mm ILBS.
- $v_i^{t+1} = Wv_i^t + c_1 r_1^t\,(P_{best}^t - x_i^t) + c_2 r_2^t(g_{best}^t - x_i^t)$
- PSO iterations for the best fit, 68 iterations required for optimal solution using MATLAB



Sensitivity of the temperature distribution



Stability range for temperature distribution



Iteration of best fit

Conclusion

- ✓ 200°C is identified as the optimal consolidation temperature
- ✓ Post-treatment is essential for void and strength optimization.
- ✓ Post-treatment and optimized parameters enhance ILBS
- ✓ PSO and sensitivity analysis validated 0.77 N/mm ILBS
- ✓ Embedded sensors enable adaptive manufacturing process control.
- ✓ Foundation for smart TCP manufacturing.

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THANK YOU !!!

Comments, Suggestions and Questions