INVESTIGATION OF WOVEN COMPOSITE LATTICE REINFORCEMENTS FOR THERMOFORMING OF THERMOPLASTIC COMPOSITE STRUCTURES

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Introduction

- Thermoplastic composites seeing increased applications for automotive structures with modern passenger vehicle consisting up to 50% plastics and composites by volume[1].

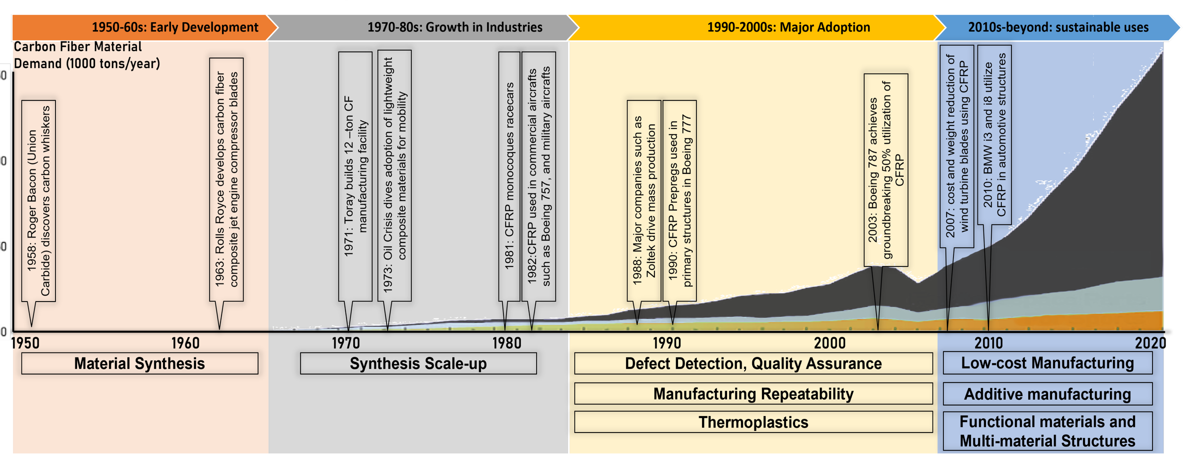

Figure 1 : Growth in CF and CFRP composites adoption in various industries with evolution of material and manufacturing technologies [2]

- Continuous fiber reinforced thermoplastic composites (FRTPC) have been successfully demonstrated for automotive structural applications[3],[4].
- Thermoforming is compatible with existing hot-stamping infrastructure and is able to process continuous fiber reinforced thermoplastic blanks.

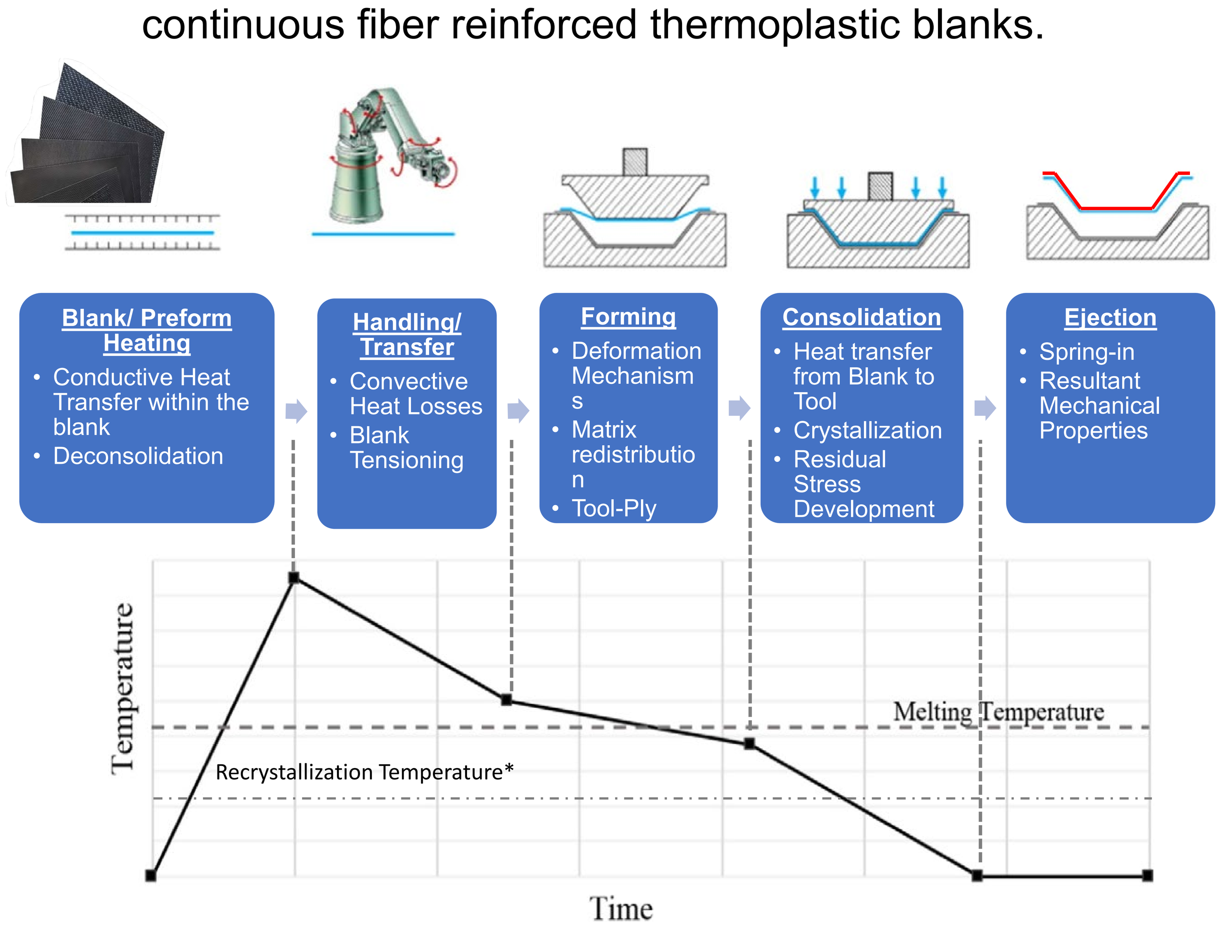

Figure 2: Thermoforming Process Discretized into distinct steps[5]

Objectives

The goal of the presented study is to:

- Develop designs with customizable woven fibers with tailorable spacing between tows
- Develop a manufacturing process for making blanks with such a highly tailored reinforcement
- Demonstrate that such designs are feasible from a cost and structural performance standpoint.

[1] https://doi.org/10.1016/B978-0-323-88667-3.00016-3
[2] https://doi.org/10.1016/j.compositesb.2022.110463
[3] https://doi.org/10.4271/2020-01-0203
[4] doi:10.4271/2021-01-0365.
[5] http://dx.doi.org/10.1016/j.matdes.2015.12.166

Materials and Lattice Designs

Design flexibility offered by woven lattice reinforcements:

A. Warp direction tow material
B. Weft direction tow material
C. Warp direction spacing
D. Weft direction spacing
E. Weave pattern
  A. UD
  B. BD plain weave
  C. Twill

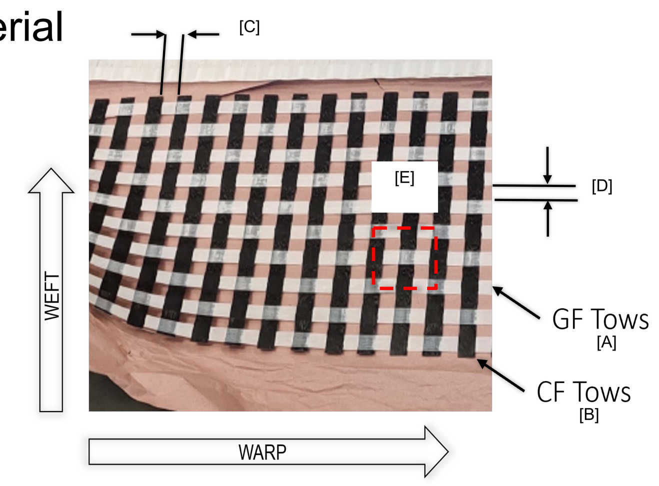

Figure 3 : Lattice Reinforcements

Table 1: Lattice Reinforcements Designs

Design	Warp	Weft
Baseline GF/PP	100 % CF	100 % CF
Design 2	100% CF	50% GF
Design 3	50 % CF	50% GF
Design 4	100% CF	50% GF
Design 7	50% GF	50% CF alternating with 50% GF

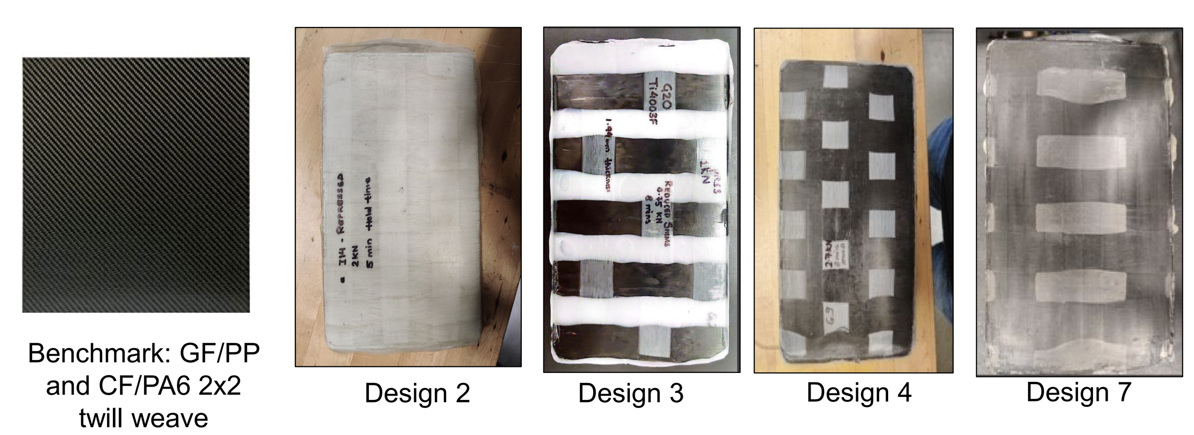

Figure 4 : Consolidated blanks with woven lattice reinforcement designs

Manufacturing

- The flat panel pressing was:
  - Constant force-driven
  - Displacement was dynamically controlled
  - Specific consolidation force maintained.
- Varying cooling possible at:
  - 0.1 ˚C/min
  - 1 ˚C/min
  - 20 ˚C/min
  - 40 ˚C/min

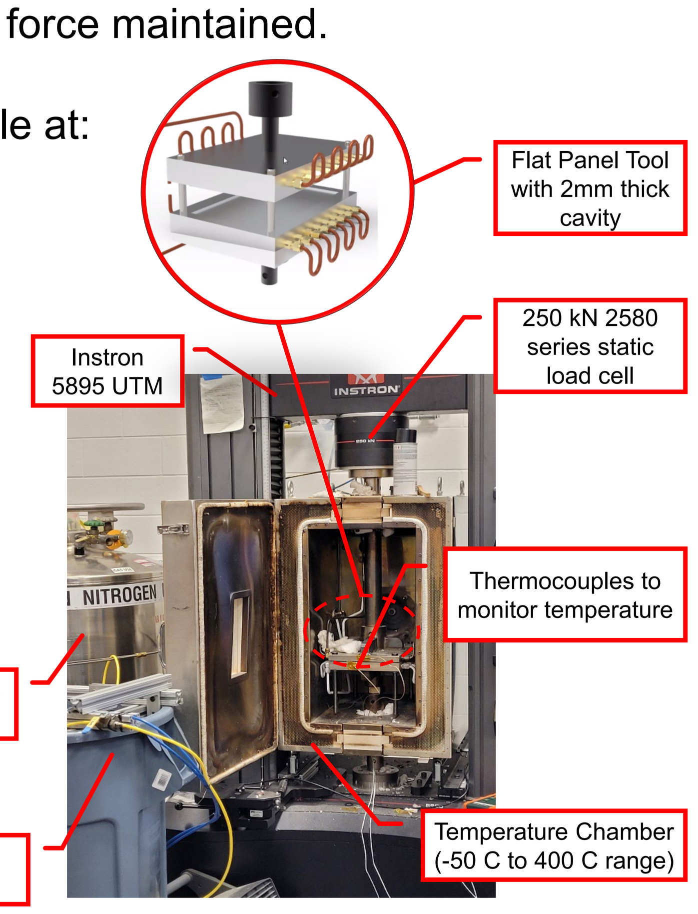

Figure 5: Blank consolidation setup

Evaluation

Flexural properties were evaluated at a coupon level.

- Flex testing per ASTM D 790-17.
- 3-pt. flexure on servo electric Instron 10 kN UTM with 10 kN load cell.
- Cross Head rate of ~5 mm /min.
- Deflection measured using contact probe and video extensometer.

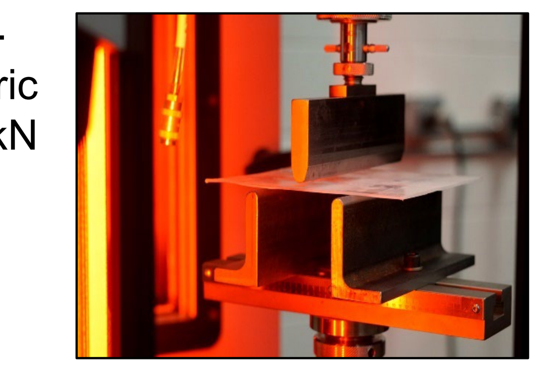

Figure 6: 3-point flexural testing

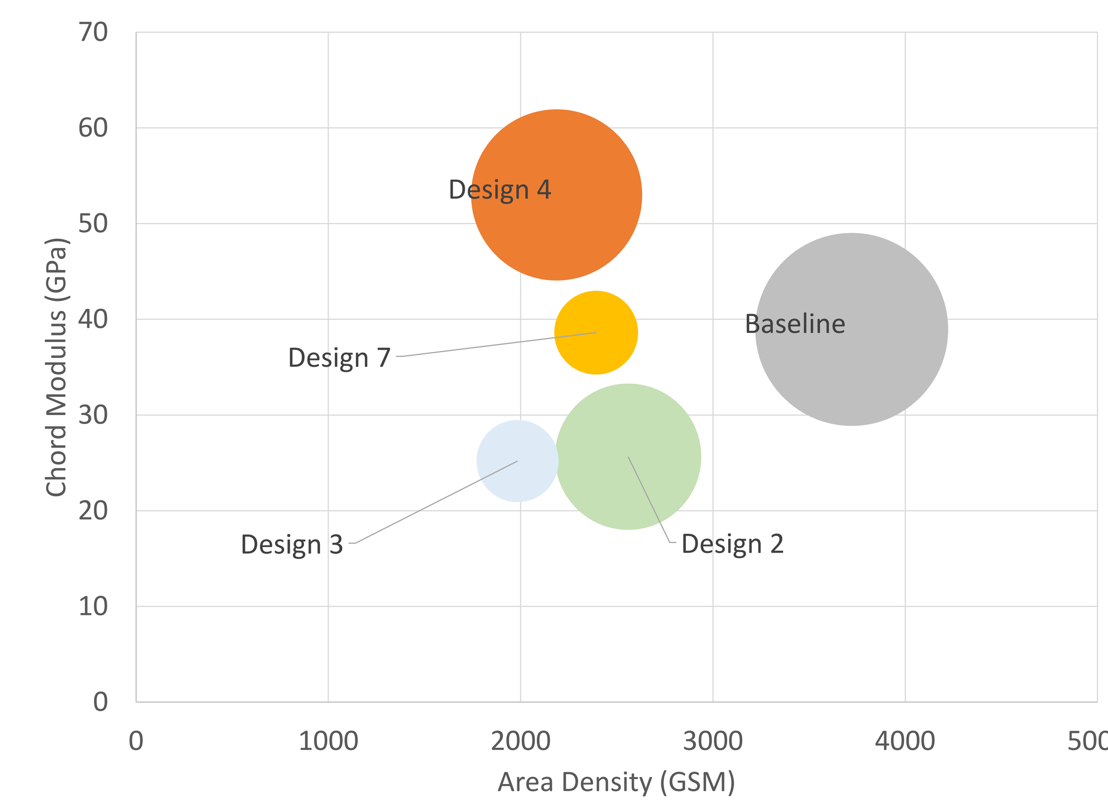

Figure 7: Chord Modulus v/s area density for various lattice designs

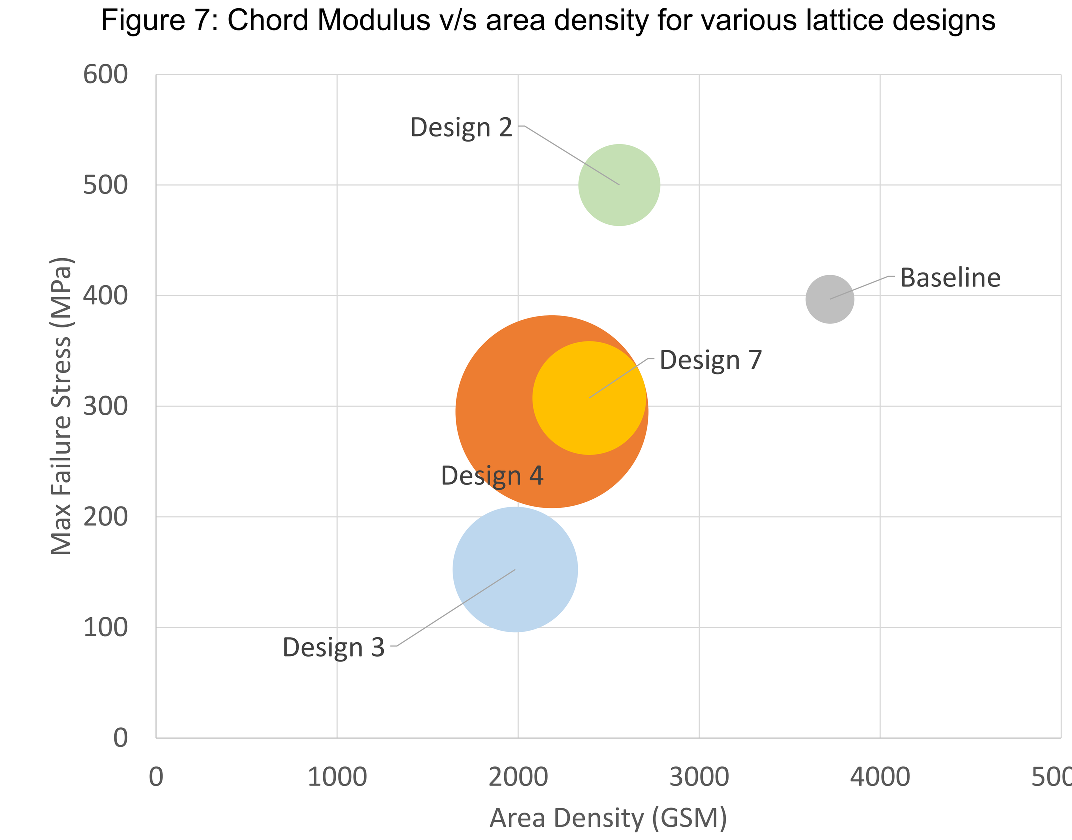

Figure 8: Max. Failure Stress v/s area density for various lattice designs

- FEA was performed on ANSYS to simulate 3-pt. flex to calibrate material cards to match experimental behavior.

Table 2: FEA simulation v/s Experimental behavior

Design	Panels tested	Avg chord modulus (Experimental)	FEA avg chord modulus (Simulation)	Percentage difference (%)
Design 2 - 100% GF 50% GF	4	25.64±4.014	25.98	1.3
Design 3- 50% CF 50% GF	4	25.198±1.279	27.23	7.4
Design 4 - 100% CF 50% GF	4	52.99±5.523	55.5	4.5
Design 7 - 50% GF warp, 50% CF 50% GF weft	3	38.7±1.325	44.5	13%

Next Steps

Coupon Level Microstructure Study

- Quantification of fiber distortion
- Understanding of failure mode during flex testing

Sub-component Level

- FEA simulation to match experimental behavior

Full Scale Component

- Draping and thermoforming process simulation
- Overlaying microstructure properties onto FEM
- Coupled Analysis

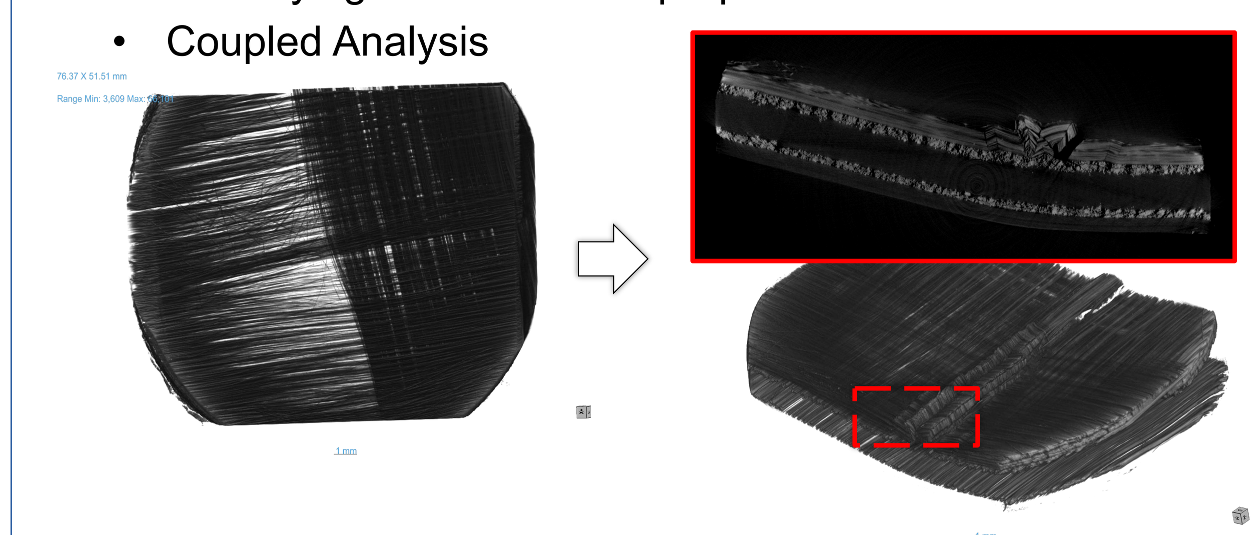

Figure 9: Micro CT evaluation of flex tested specimens before and after flex testing

Relevance and Future Scope

Generation of experimental and simulation data for FRTPCs with optimization at the scale of warp and weft tows to meet cost and performance targets.

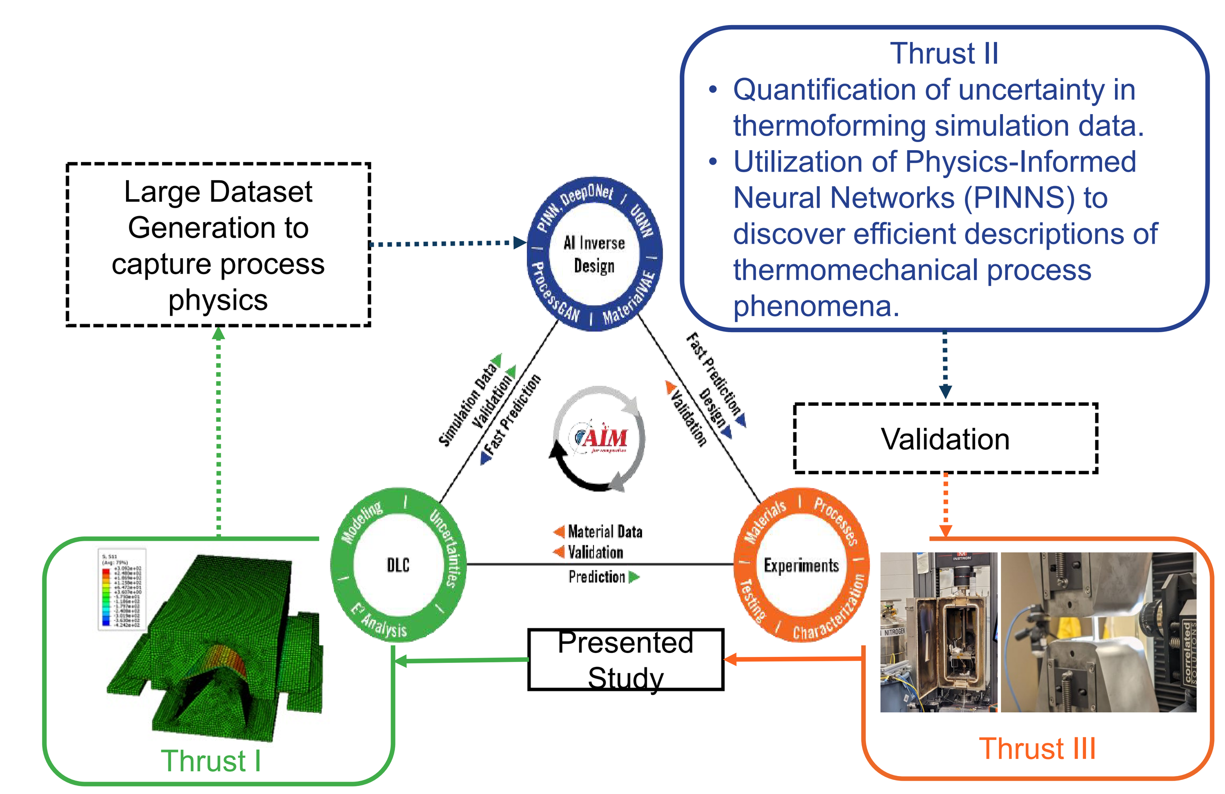

Figure 10: Relevance and future scope of presented work

Acknowledgements

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