MECHANICAL BEHAVIOR OF UV-CURED COMPOSITE STEPPED LAP ADHESIVE JOINTS

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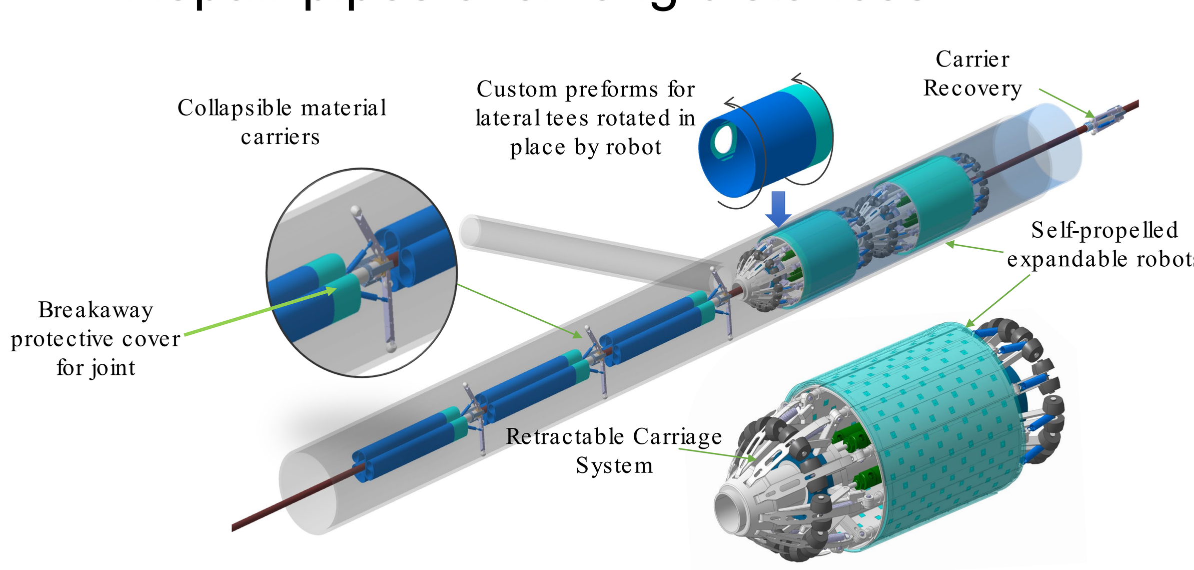
Introduction

- Natural gas important strategic resource for the U.S.
- Legacy cast iron and bare steel pipes failures
- Excavation and replacement costs $1-10M per mile and disrupts gas supply

Cast Iron | Coated Steel | Plastic | Excavation process

- Bladder expandable robotic system and UV-curable materials
- Create stand-alone structural pipe within existing pipe; no gas shut-down required
- Each preform of finite length is *co-cured* with the next segment using a highly efficient *scarf or stepped lap joint*
- Repair pipes over long distances

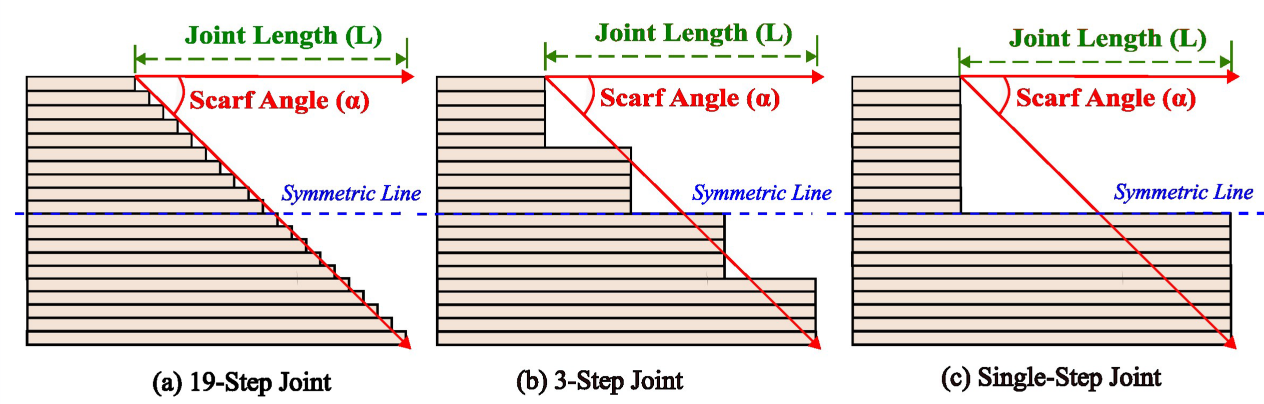


Objective of this Study

- Novel aspect of this research is the use of UV-cured vinyl ester resin for joint manufacture
- UV-curable resins are ideal for rapid curing at ambient temperatures
- Evaluating the static load performance of co-cured stepped-lap joints with varying stepped lap joint angles and number of steps

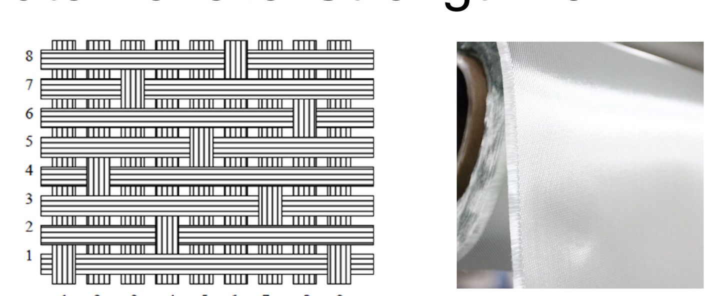
Stepped Lap Joint Configurations

- Co-cured stepped-lap joints; 20-ply laminates
- **Test Variables**
  - Number of steps: 19, 3, 1
  - Scarf angle: 0.9°, 1.2°, 2.9°, 5.7°



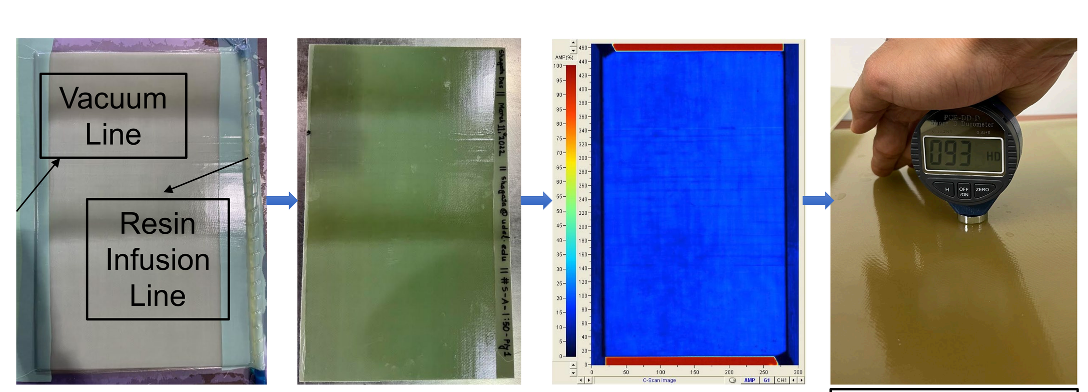
Materials

- 7781 E-glass 8-harness Satin Weave
- Commercial UV Curable Vinyl Ester Resin
- Modulus of the laminate: 23.3 GPa
- Ultimate Tensile Strength: 347 Mpa (50 ksi)



Methodology

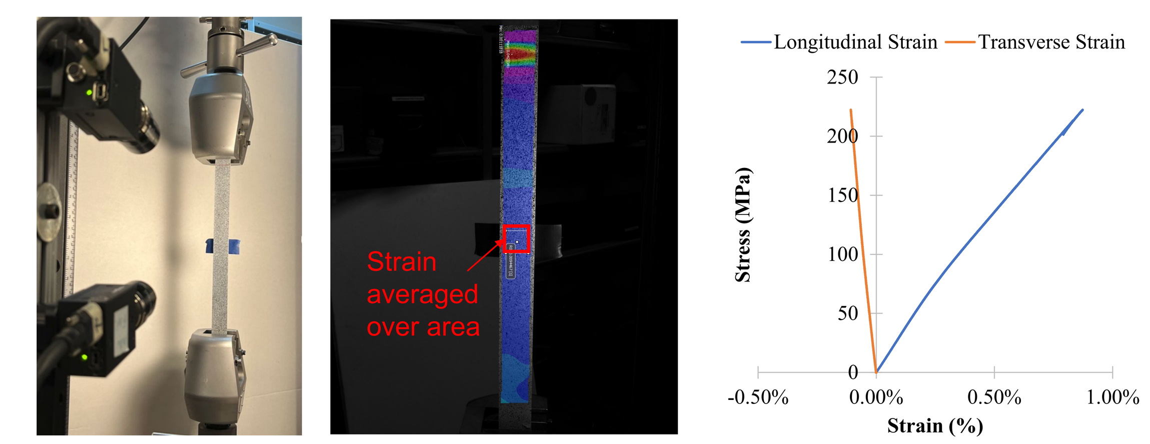
- Vacuum Assisted Resin Transfer Molding (VARTM)
- Fiber volume fraction was 50% on average and void content < 0.6%
- Panel was cured for 3 minutes using a 400-nm UV source



Resin infusion using VARTM process | Cured scarf joint panel | C-scan of the scarf joint panel | Hardness measurement using Shore D Durometer

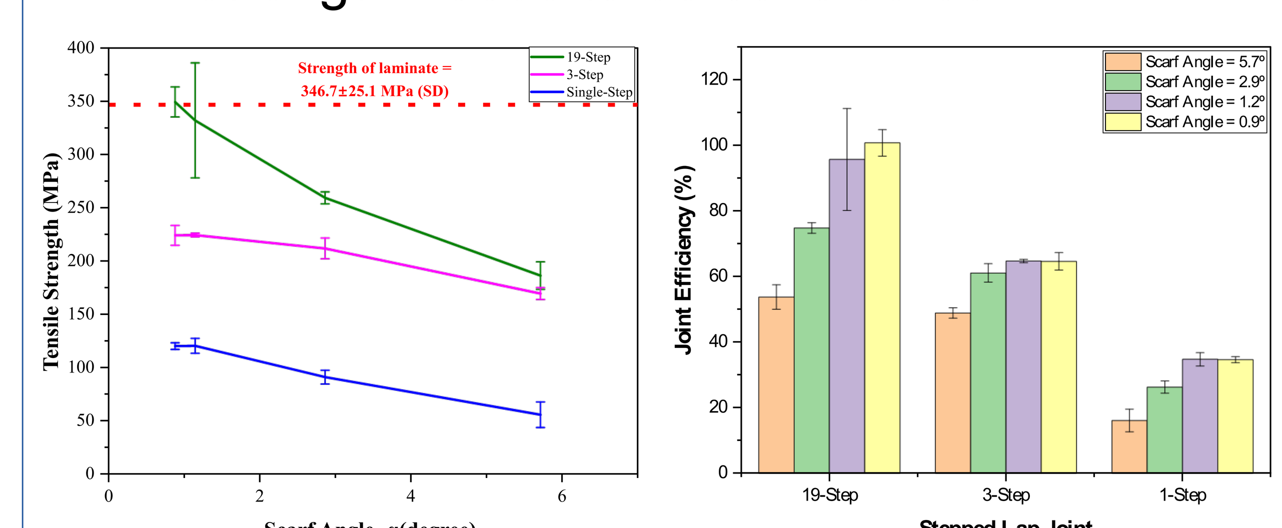
Tensile Testing

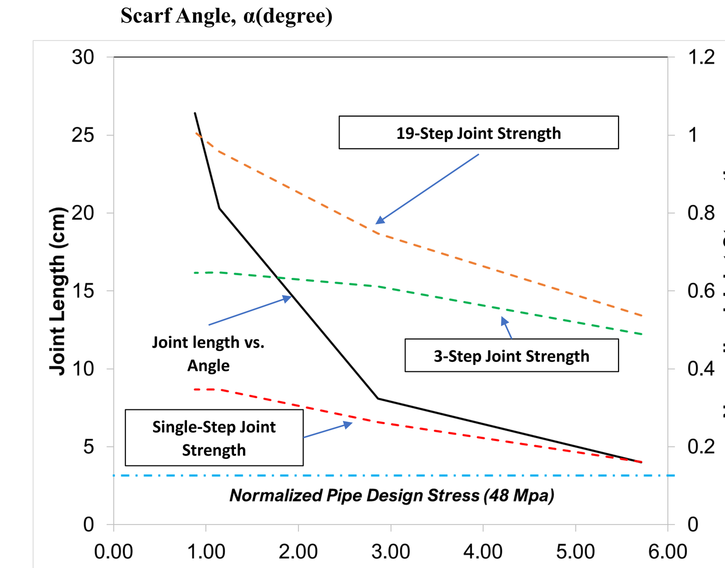
- Displacement rate of 1.27 mm/min
- 3D Digital Image Correlation (DIC) system to record strain data
- Longitudinal and transverse strains were averaged over an area of 1.9 x 1.9 cm



Tensile Testing Result

- Tensile strength of the joint increased as the scarf angle decreased
- Joint efficiency of 100% was achieved
- Tradeoff between joint length and strength needs to be considered

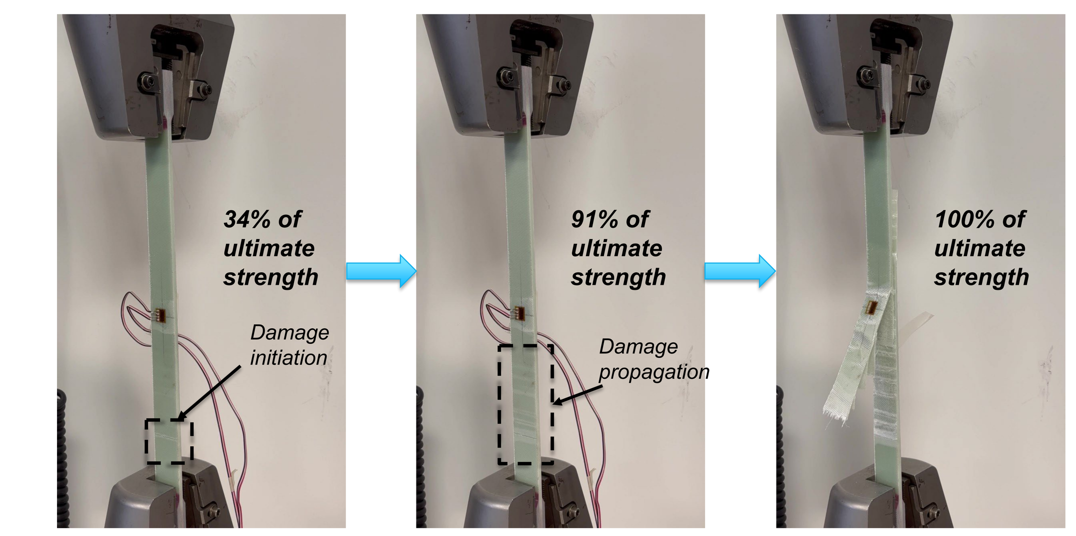




Design chart of the Stepped Lap Joints

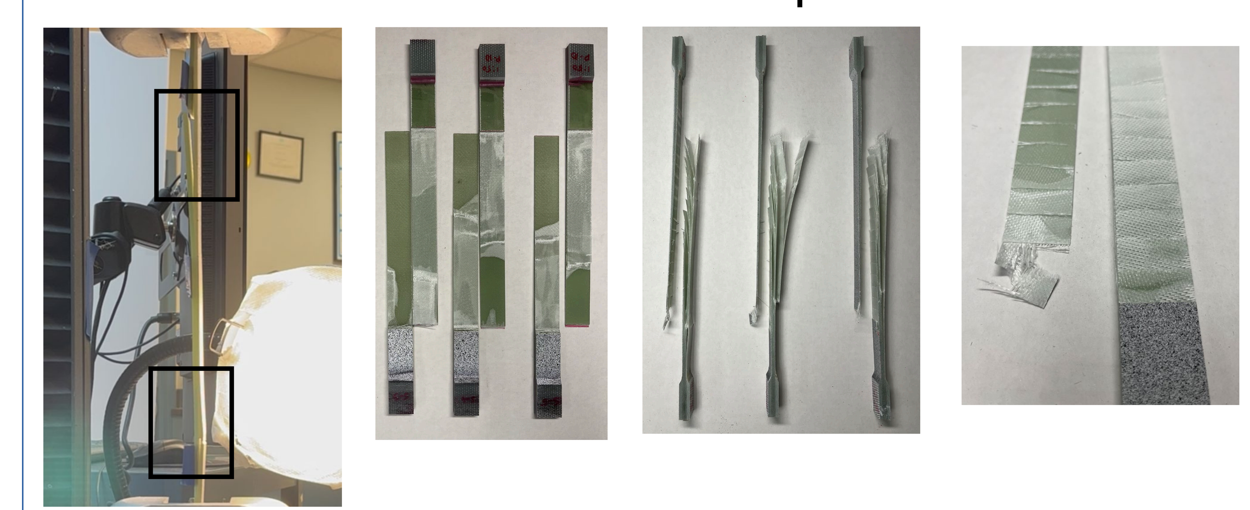
Failure Mechanism

- Failure initiated at the end of the overlap at the surface
- Propagation of damage occurs gradually



Failure Modes

- Delamination and rupture in 19-step joints
- Fiber-matrix interface separation



Peeling action | *Failure at fiber-matrix interface* | *Delamination* | *Rupture*

Conclusion

- The joint tensile strength is inversely proportional to the scarf angle
- The efficiency of tested joint configurations ranged from 15 to 100%
- 19-step joints exhibited evidence of fiber rupture
- A progressive failure was observed

Ongoing Work

- Numerical simulations and analytical modeling
- Effect of different sizing formulations on the overall joint performance
- Fatigue performance
- Microstructural characterization and Scanning electron microscope (SEM)

Acknowledgements

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