North American Pultrusion Conference 2023
Chicago, Ill, May 16 – 18, 2023.

Field-bendable Thermoplastic Pultruded Rebar

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Advanced Structures & Composites Center

- The University of Maine's Advanced Structures and Composites Center (ASCC) is an interdisciplinary center for research, education, and economic development encompassing material sciences, manufacturing, and engineering of composites and structures.
- The ASCC is housed in a 100,000 ft^2, ISO 17025-accredited testing laboratory with more than 320 full and part time personnel.
- The ASCC is a leading expert in advanced additive manufacturing techniques, and is currently expanding to include a new, two-bay manufacturing facility referred to as the "Factory of the Future".

204
Patents Secured

2600+
Students Employed

500+
Global Partners

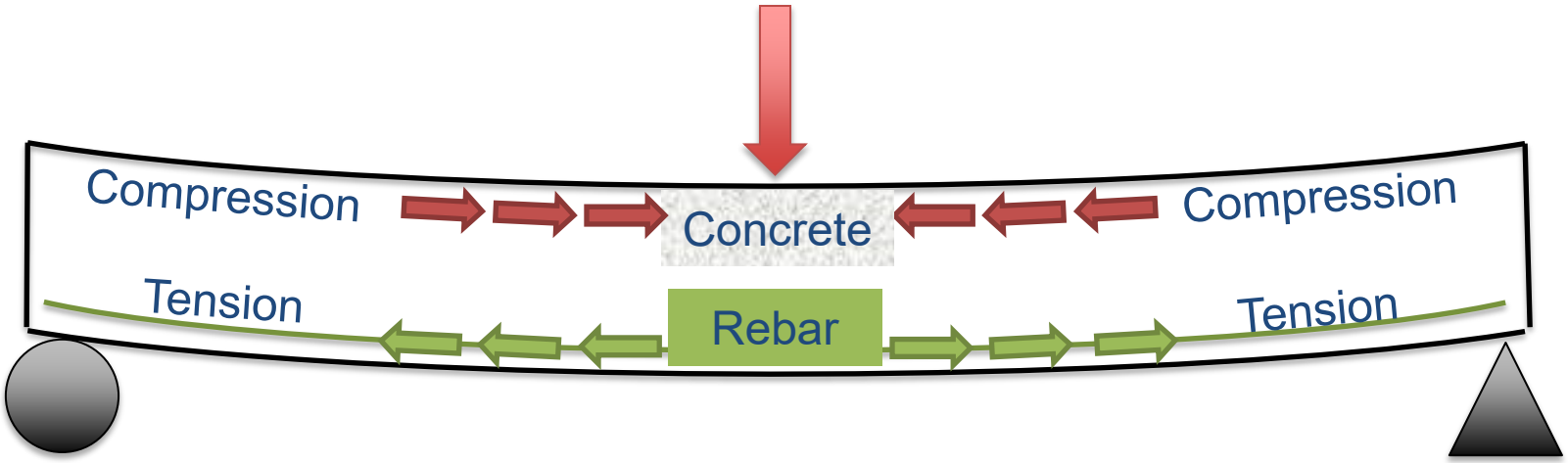
15
Spinoff Companies

771
Journal Publications

Team Members

Team Member	UMaine Team
Cody A. Sheltra	***R&D Program Manager, Technology Lead***
Dr. Roberto Lopez-Anido	***Professor***
Dr. William Davids	*Professor*
Zane Dustin	*Research Engineer*
Michael Hunter	*Project Manager/Research Engineer*
Sam Heathcote	*Project Manager/Research Engineer*
Jordan Duffy	***Research Engineer***
Jacob Clark	***Research Engineer***
Noah Pringle	*Graduate Student*

Reinforced Concrete Structural Mechanics

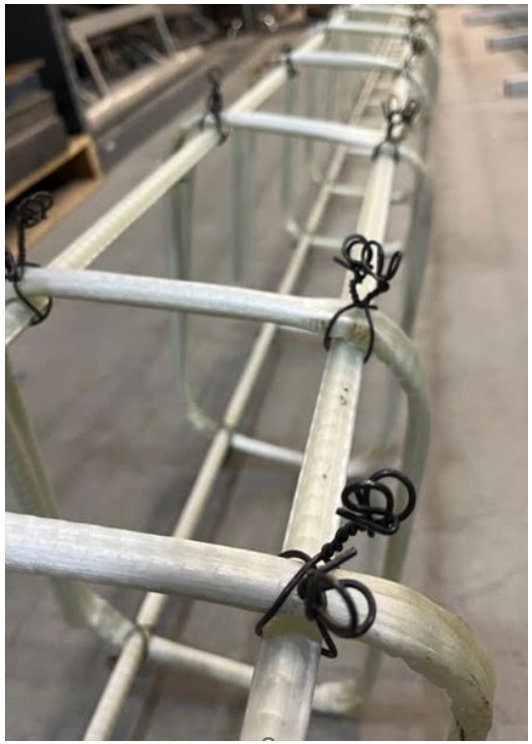


What is the problem that needs to be solved?

- There is a need for non-corrosive reinforcement of concrete in civil infrastructure.
- Adaptability of rebar for internal reinforcement of concrete during construction.
- Rebar needs to be bent at the job site after initial fabrication for common configurations: hooked bars, stirrups and spirals
- A bendable rebar reduces construction cost.

Solution for transportation infrastructure

- Bendable thermoplastic composite rebar for concrete reinforcement



Required reinforcement properties

- Non-corrosive
- Low emissions during manufacturing
- Field-formable
- Economical
- High specific strength
- Recyclable

https://www.becosan.com/spalled-concrete/

https://www.forconstructionpros.com/concrete/equipment-products/rebar-accessories-equipment/article/10703351/

Existing rebar options for concrete reinforcement

Stainless Steel Rebar

- Field formable
- Corrosion resistant
- Recyclable
- Fast manufacturing method known as hot rolling
- Low specific strength
- Higher cost than mild steel rebar

Thermoset Rebar

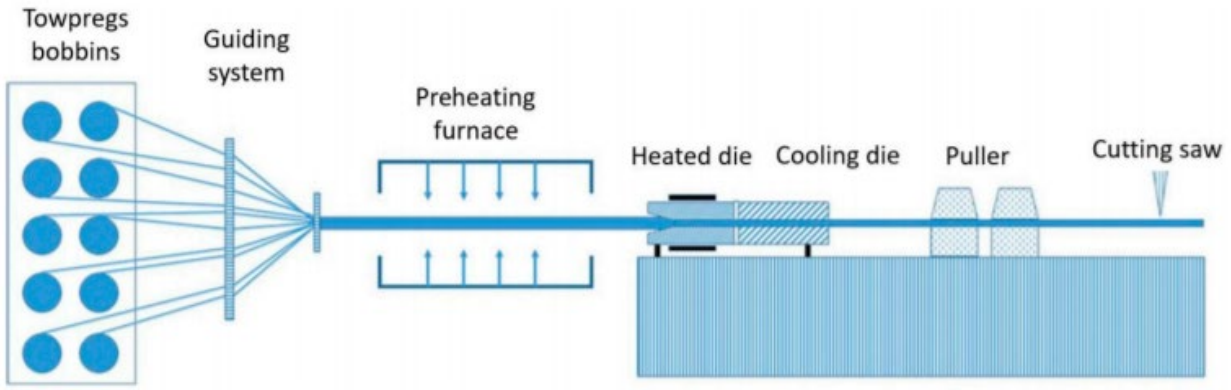
- High specific strength
- Anti-corrosive
- Fast and automated manufacturing process with thermoset pultrusion
- Not field formable
- Expensive custom shapes
- Not recyclable

www.structuralguide.com/rebar/

https://www.aitcomposites.com/gbar

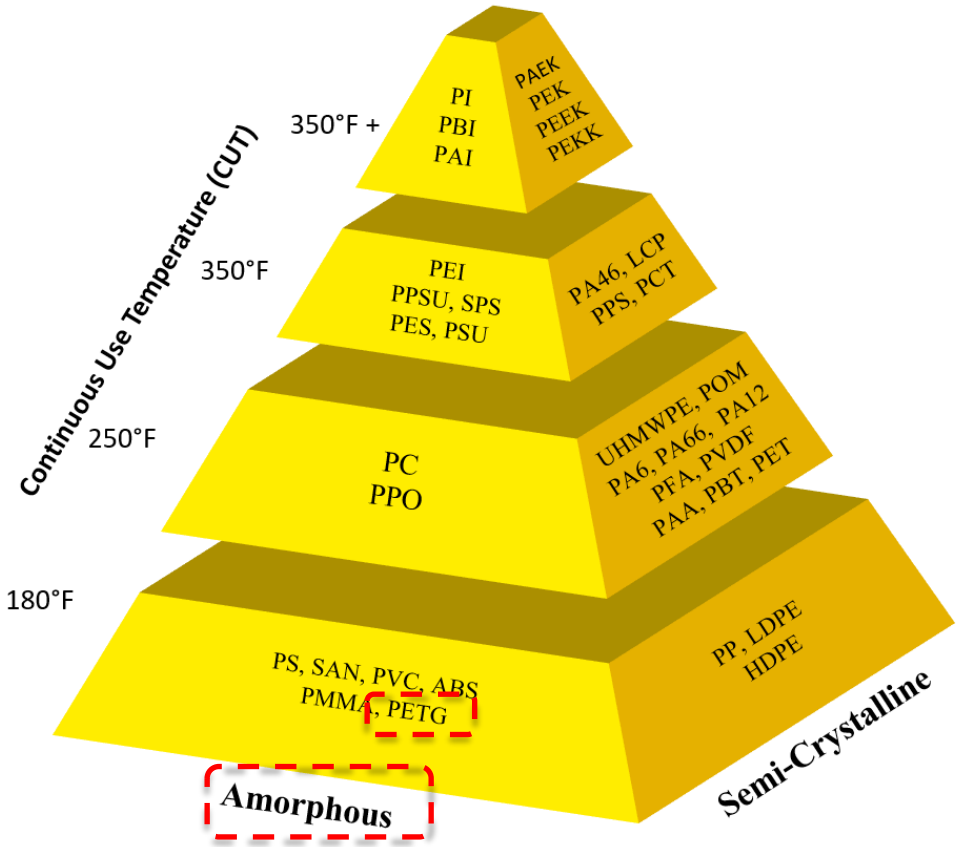
Nonreactive thermoplastic pultrusion

- Towpregs: pre-impregnated or polymerized fibers
- Towpregs fed into guiding system
- Preheated
- Heated past the polymer's melting point to reduce the time the reinforcement stays in the heated die and to ensure uniform impregnation of reinforcement
- Consolidation by a cooling die
- Lineal profile cut to desired length



Minchenkov et al. (2021)

Thermoplastic material selection



Advanced Engineering (AE) Polymers

High Performance (HP) Polymers

Engineering Polymers

Commodity Polymers

Amorphous Commodity Polymers are Low temperature, low strength and have good bonding good machinability & good formability at low cost.

Semi-Crystalline Commodity Polymers are low temperature and low strength with good chemical resistance and low moisture content.

Polyethylene terephthalate-glycol (PETG)

Polyethylene terephthalate-glycol (PETG)

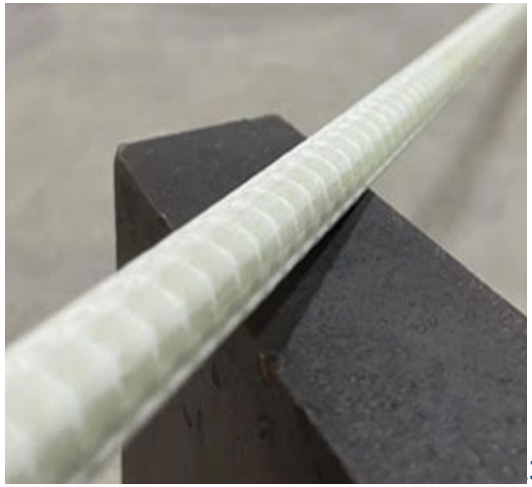
- PETG is an amorphous copolymer of PET.
- PETG is highly durable and formable, resistant to degradation from chemicals, oxidation, and gamma radiation, highly recyclable, and maintains a low forming temperature
- PETG is a practical thermoplastic for thermoplastic pultrusion
- Suitable for structural applications.
- Continuous reinforcing material for PETG: E-glass fibers.

Feedstock: thermoplastic towpreg

- Unidirectional prepreg tapes
- E-glass/PETG

Thermoplastic composite rebar

- High specific strength resulting in reduced transportation, storage and installation logistics
- Non-corrosive for use in harsh environments
- Field formable for rapid and inexpensive on-site fabrication and customization
- Recyclable for extended lift cycle.
- "FRP Rebar manufacturing CO2 emissions 25% lower than for typical steel rebar" (ACMA 2023).



Continuous Forming Machine (CFM)

Nonreactive thermoplastic pultrusion

Continuous forming machine (CFM)

What is thermoplastic pultrusion with CFM?

CFM aims to overcome traditional scalability and production issues of other thermoplastic pultrusion processes by using pre-impregnated or comingled thermoplastic material, such as unidirectional prepreg tapes.

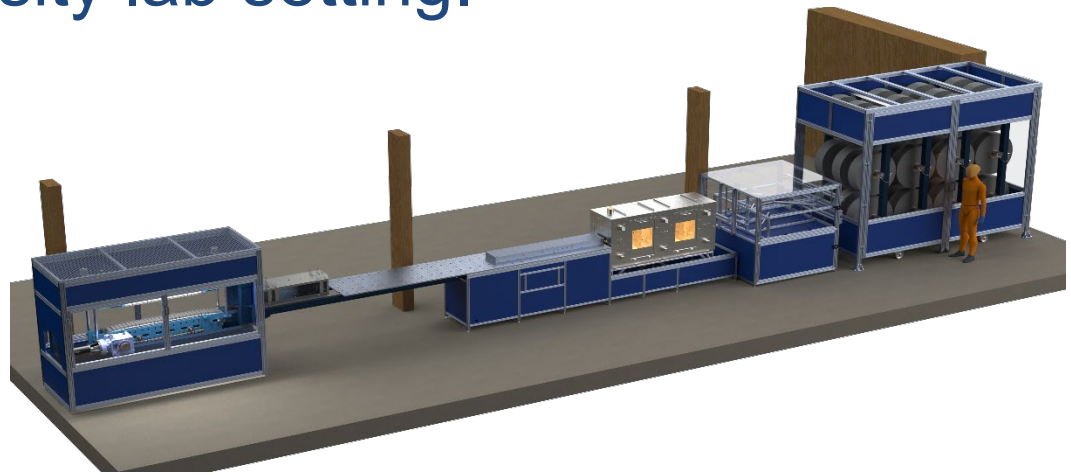
Thermoplastic pultrusion with CFM

What are the features of thermoplastic pultrusion with CFM?

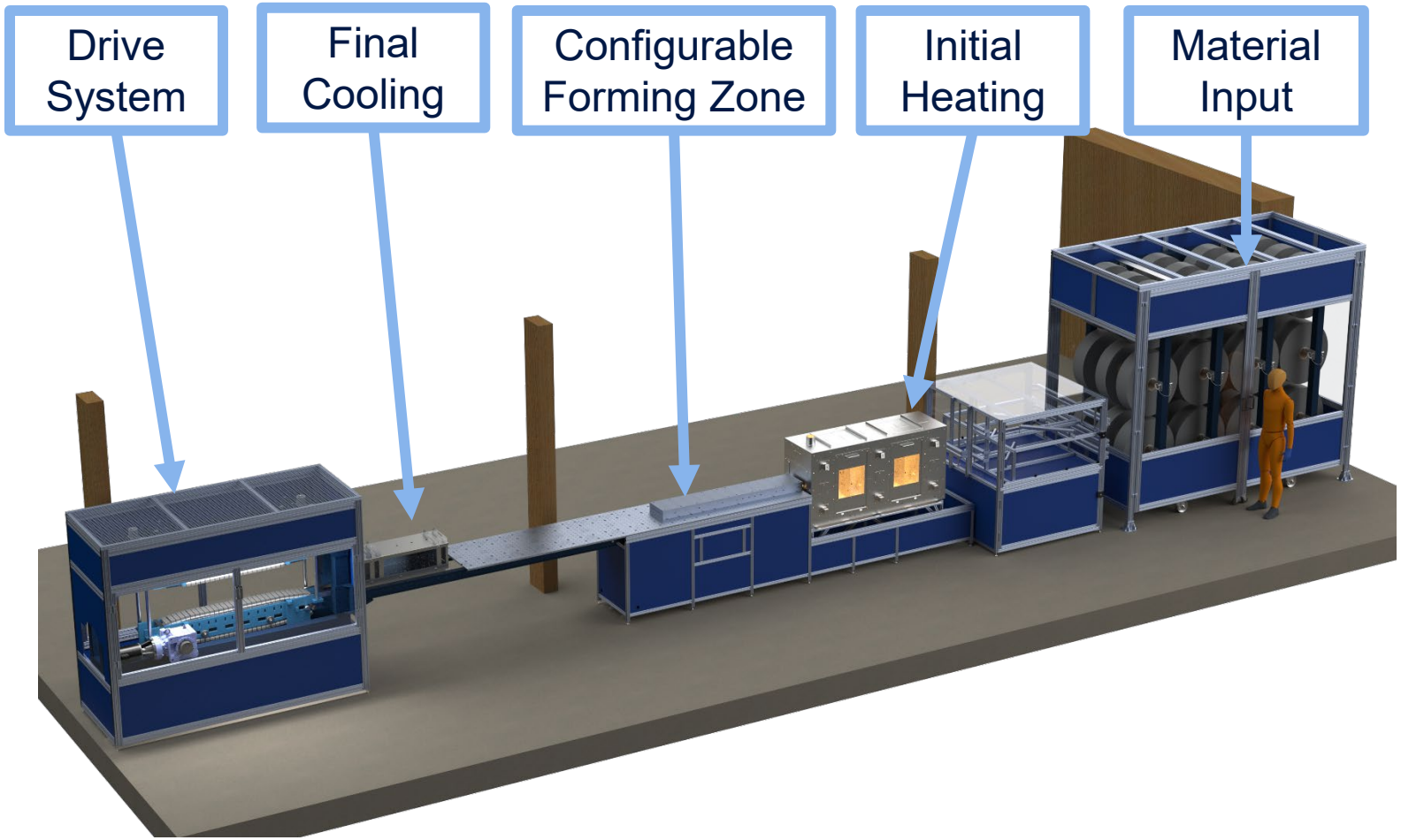
- Provides a fast and automated manufacturing process for efficient manufacturing of thermoplastic rebar or lineal profiles
- Uses thermoplastic towpregs as feedstock materials which are lightweight, tailorable to desired properties,
- Lineal profiles can be reheated and reshaped i.e. field formable
- Material is recyclable.
- Adaptable to multiple processes such as in-situ roll forming, and filament winding.

CFM: Environmentally friendly manufacturing method

- Nonreactive thermoplastic pultrusion is a low-VOC continuous manufacturing method
- Reduced environmental impact and health risks.
- Ideal for prototyping and product development in a University lab setting.



CFM modular layout



CFM capabilities

- Fast and automated manufacturing process (10+ ft/min in house with lab scale machine).
- Wide range of production parameters for customizable thermoplastic material combinations
- Configurable for a variety of different forming methods

CFM Rebar Development

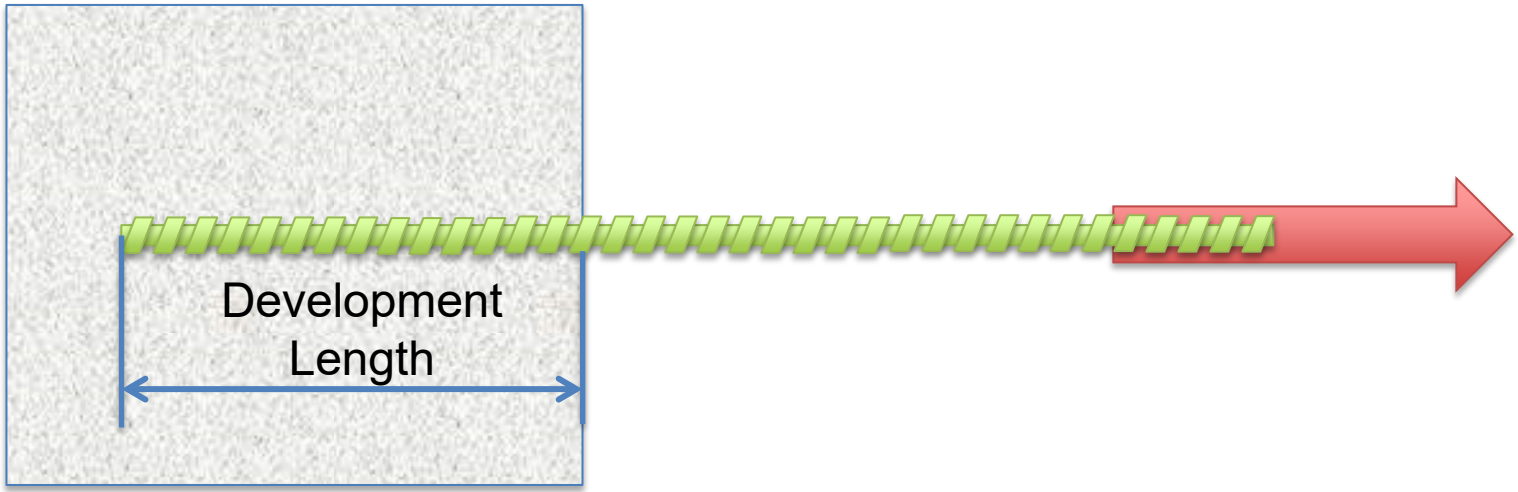
Manufacturing & Testing

Bond strength & development length

Shear transfer between the rebar and concrete

Pull-out Resistance Mechanisms

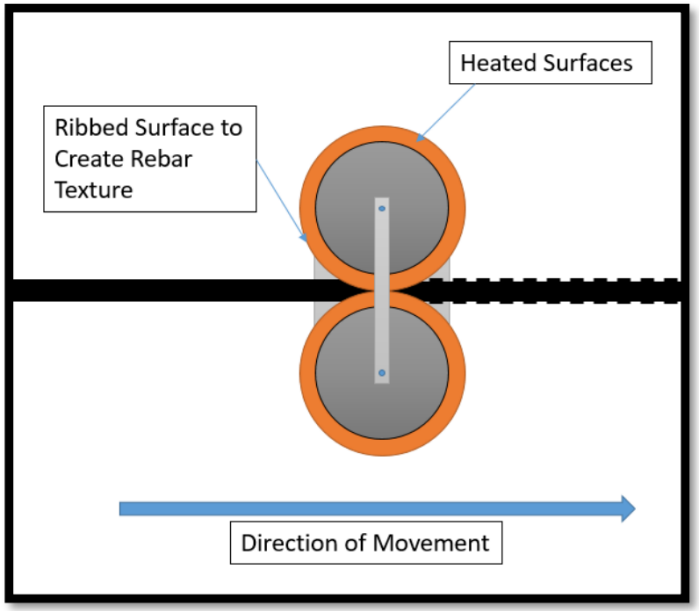
- Interlocking between concrete and rebar deformations
- Friction between concrete and rebar
- Chemical adhesion between concrete and rebar

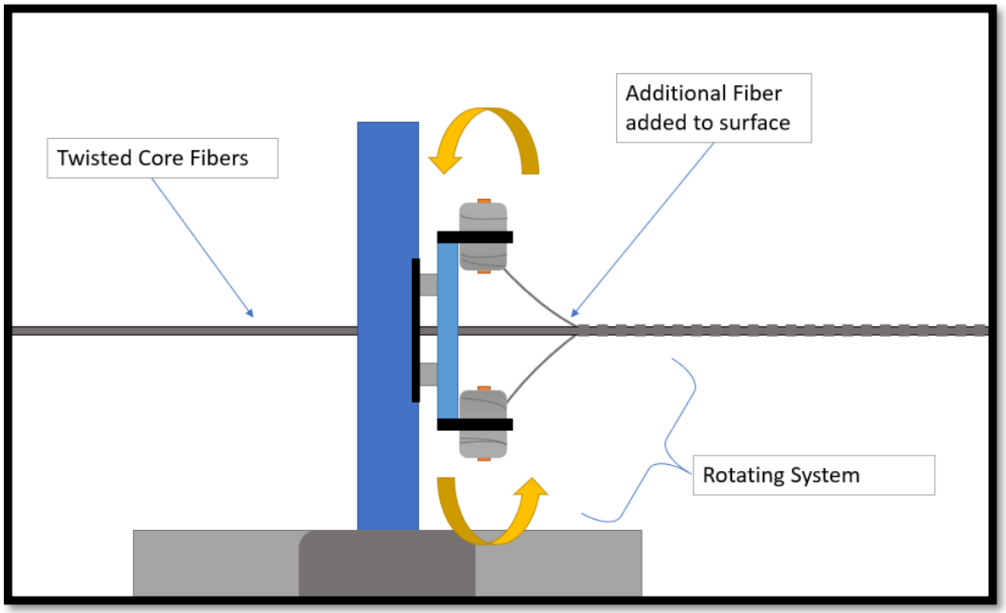


Manufacturing surface deformations

Potential Surface Deformation Manufacturing Processes

- Filament winding
- Roll forming
- Sand coating





Prototype rebar tension testing

Tension Testing

- Longitudinal tensile properties of CFM manufactured thermoplastic rebar.

Initial results for GF/PETG rebar

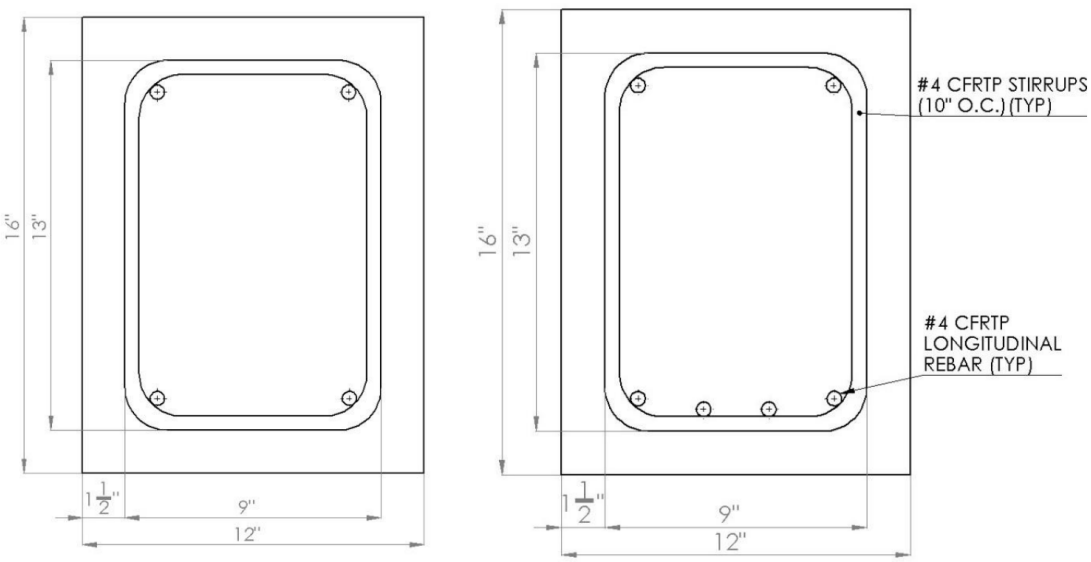
- Tensile strength = 104 ksi
- Elastic Modulus = 4,400 ksi

Ongoing Tensile Testing

- Determining the properties of thermoplastic rebar with different diameters and materials

Reinforced concrete beam performance test

- Reinforced concrete beams cast to demonstrate performance of thermoplastic composite rebar.
- Two sets of beams, one designed to fail by reinforcement tensile rupture, one designed by concrete crushing.
- Beams designed based on AASHTO provisions for GFRP-Reinforced Concrete



Reinforced concrete beam test results

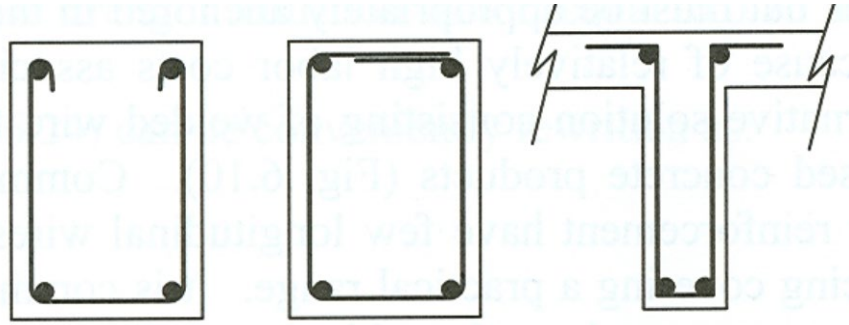
- Beams loaded in four-point bending.
- Thermoplastic composite rebar successfully carried tension across cracks in concrete.
- Reinforced concrete beams with thermoplastic rebar resulted in 16% increase in load capacity compared with design assumptions for steel reinforced beams.

Future CFM manufacturing capabilities

- Filament winding
- Roll forming
- Manufacturing lineal profiles: flat-sheet, channel and angle shapes

Moving Foreword: Demonstrate bending of the rebar at the site

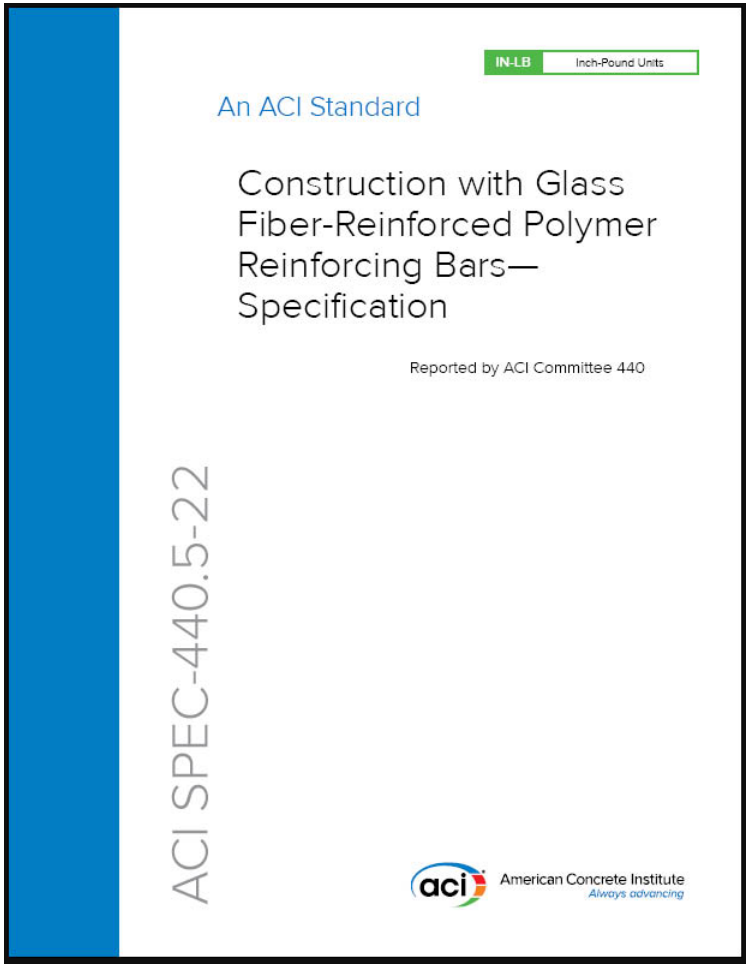
- Demonstrated in a lab setting that the thermoplastic composite rebar can be bent with a heat gun and simple tools.
- Need to develop practical guidelines for field bending at the site that can be implemented by a bridge contractor.



Moving Foreword: Industry Acceptance

Develop design guide specifications

- Tensile strength
- Development length
- Fatigue life
- Fire resistance
- Chemical resistance (alkaline)
- Thermal expansion
- Creep



Final Thoughts

- Thermoplastic composite rebar provides efficient tensile reinforcement for concrete
- Thermoplastic pultrusion with the modular CFM is an adaptable and effective manufacturing method for prototyping pultruded rebar
- The thermoplastic rebar has demonstrated the required structural performance for internal reinforcement of concrete.
- Thermal formability of the thermoplastic rebar enables bending in the field for customized geometries.
- Nonreactive pultrusion with CFM allows for a wide range of thermoplastic towpreg materials as feedstock.
- Thermoplastic pultrusion with CFM has potential for manufacturing lineal profiles

Thank you for your attention