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Nonmetallic Reinforcement in Concrete What Engineers Should Know

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Outline

- **Why Nonmetallics in Construction?**
- **Introduction to NEx**
- **NEx Projects Progress**
- **Background on Nonmetallic Reinforcement**
- **What is FRP rebars**
- **GFRP rebars**
- **GFRP Mechanical Properties and Behavior**
- **Standards and Guidelines**
- **Benefits and Limitations**
- **GFRP rebar applications**
- **Concluding Remarks**
- **Potential Collaboration**

Why Nonmetallics in Construction?

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- Construction industry accounts for 38% of CO₂ emissions
- Concrete 2nd largest material used globally and responsible for 6 -10 % of global CO₂ Emission
- Steel accounts for 6.7% of world's total CO₂

- **Nonmetallic Composites** support significant reduction of CO₂ emission
- Potential to reduce concrete curing water
- Support recyclability and reusability

Reduce Carbon Footprint

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- Cost of corrosion for highways bridges estimated at **8.3 Billion** annually
- Limited structure life
- Significant increase to **replace or repair**, often due to corrosion
- Ineffective material in some environments e.g., coastal and high humidity regions

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- Extend service life & reduce maintenance requirements
- Nonmetallic based structures expected to have significantly longer life
- Enhance building efficiency and quality

Reduce Carbon Footprint

Improve Sustainability

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- Large market and enormous material consumption size
- Huge opportunities for new technologies and material
- Interest and support from private sector and governments

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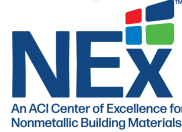
- Encourage development of new construction materials and technologies
- Accelerate deployment of new technologies

Reduce Carbon Footprint

Improve Sustainability

Support Innovation

Partnership Drives Action



WHAT WE DO?

Collaborate globally to expand and accelerate the use of nonmetallics in the built environment to drive innovation, research, education, awareness, adoption, and deployment



HOW WE DO?

- Standards and Guidelines
- Research and Development
- Professional Development
- Advocacy and Awareness



ACHIEVEMENTS

- NEX funded 12 projects for 2022 – over \$575,000
- In the process to fund 22 projects for 2023- over \$700,000.



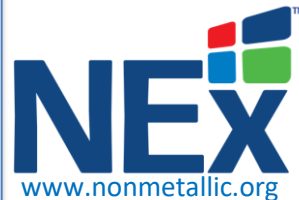
HEADQUARTERS

Founded in 2020, we are located within American Concrete Institute, Farmington Hills, Michigan, USA

www.nonmetallic.org



ExxonMobil



NEx: Scope

The Center of Excellence will serve as a catalyst for the use of nonmetallics in construction applications, including but not limited to:

- FRP reinforcement
- Polymer concrete
- FRP structural members
- Construction chemicals
- FRP building components and systems
- Soil beneficiation
- Additive manufacturing

Core Functions



An ACI Center of Excellence for
Nonmetallic Building Materials

**Standards and
Specifications**

**Technical
Committee
Acceleration**

**Professional
Development**

**Certification of
Personnel**

**Plant
Audit/Certification**

**Research and
Development**

**Advocacy and
Technical Support**

**International
Outreach**

NEx 2022 projects

- NEx is funding total of 12 projects in 2022

Standards & Guidelines

1. Develop design manual & guideline for GFRP rebar
2. Develop recommended practice design manual for pre-engineered projects
3. Develop standards & specifications for polymer concrete manholes
4. Develop design & selection guidelines for NM pultruded structures

Professional Development

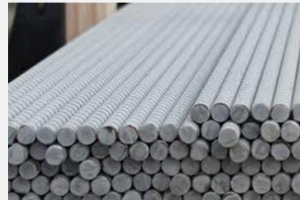
1. Develop training course for new GFRP design using ACI 440 code
2. Develop certification for GFRP Rebar inspector

Advocacy & Awareness

Three advocacy projects for local and international market

Research & Development

1. Improvement of inferior properties of aggregates in construction
2. Enhance the use of carbon fibers in civil infrastructure
3. Investigate high dosage of admixtures on concrete durability and cost -USA
4. Investigate high dosage of admixtures on concrete durability and cost -India



NEx 2023 projects

- NEx is funding total of 22 projects in 2023

Standards & Guidelines

1. Develop Polymer Soli Stabilization Guidelines and Materials Specification
2. Develop Guideline and Materials Specification for Bendable Concrete
3. Develop Guideline and Materials Specifications for FRP DOWELS
4. Develop Guideline and Materials Specifications for FRP Composite Mesh
5. Develop Design and Selection Guideline for NM Pultruded Structures (Phase 2 & Phase 3)

Professional Development

1. Develop ACI CODE-440.11 certificate program (for engineers)
2. Develop/deliver guest lecture for universities on nonmetallics in B&C
3. Develop a 5-day course for nonmetallics in Building & Construction

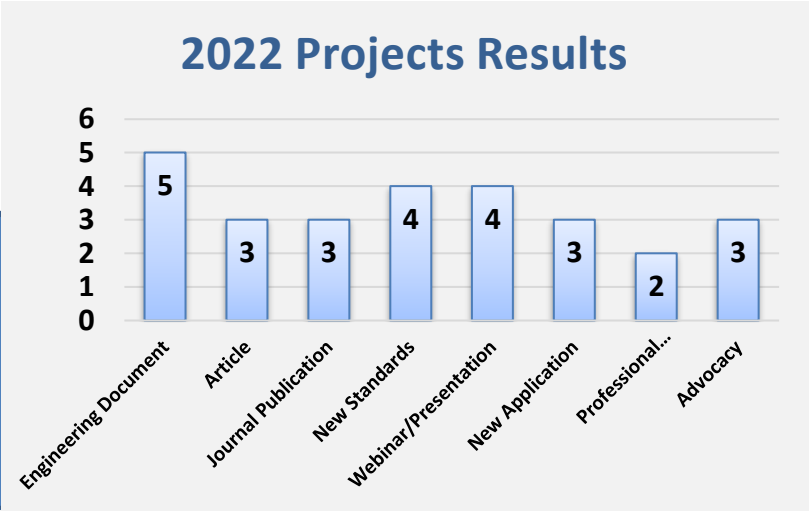
Advocacy & Awareness

Three advocacy projects for local and international market

Research & Development

1. Proposed Testing and Acceptance Criteria for GFRP Bar Couplers
2. The Use of Synthetic Macrofibers to Improve Crack Control and Water Tightness in Environmental Structures
3. Investigate ICF wall construction meeting the requirements of NFPA 285
4. Conduct State of the art and develop recommendation to address fire endurance/resistance of Pultruded Structural Members
5. Study and improve on fire endurance/resistance of polymer modified concrete.
6. Develop plan for Fire Testing FRP Structural Concrete
7. Enhance the use of carbon fibers for civil infrastructure (Phase 2)

How NEx Projects Provide Values



Development of Standards

1. Professional design
2. Accessibility to designers
3. Create more utilization
4. Optimize construction cost
5. Define manufacturers specifications
6. Resolve corrosion and environment



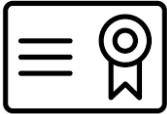
Advocacy and Awareness

1. Create more utilization
2. Increase awareness
3. Link users with manufacturers



Professional Development

1. Trained workforce
2. Quality workmanship
3. Less rework and failure
4. More confidence



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Nonmetallic Reinforcement in Concrete Construction – What Engineers Should Know



Background - Non-metallic Reinforcement

- Conventional reinforcement corrodes
- 1960s - use of Fiber Reinforced Polymer (FRP) reinforcing bars is explored as a solution to corrosion
- 1980- significant development in FRP research
- New technology or building material-critical to ensure safety and resilience of the structure



Background for Non-metallic Reinforcement

Developed material specifications for GFRP -**ASTM D7957**:Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement

Published **ACI 440.11-22**- Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars

2022

2017

2022

(updated)- **ACI SPEC 440.5-22** - Construction with Glass Fiber-Reinforced Polymer Reinforcing Bars provides mandatory language construction requirements that can be directly referenced by project specifications

What is FRP rebar?

Fiber Reinforced Polymer



- A composite material system made of: Fibers + Resin
 - Resins: Epoxies and Vinyl esters
 - Fibers: Glass fibers, Carbon fibers, Basalt fibers
- Volume fraction =
$$\frac{\text{Volume of fibers}}{\text{Total Volume of composites}}$$
- Typically, FRP materials have 70% to 80% of Volume fraction
- Higher Volume fractions yields higher tensile properties

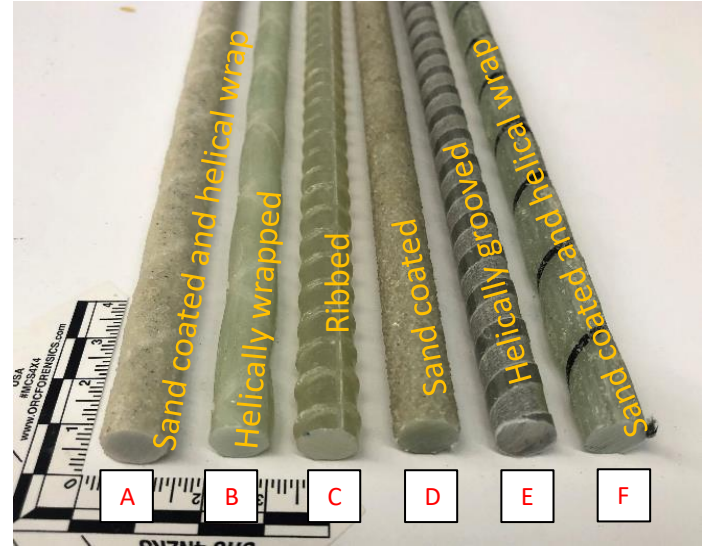
Type of Fibers in FRP bars

- Carbon Fiber Reinforced Polymer (CFRP)
- Glass Fiber Reinforced Polymer (GFRP)
- Basalt Fiber Reinforced Polymer (BFRP)
- Aramid Fiber Reinforced Polymer (AFRP)

GFRP bars

- Glass Fiber Reinforced Polymer (GFRP) bars as alternative reinforcement for concrete

Straight bars



Bent bars



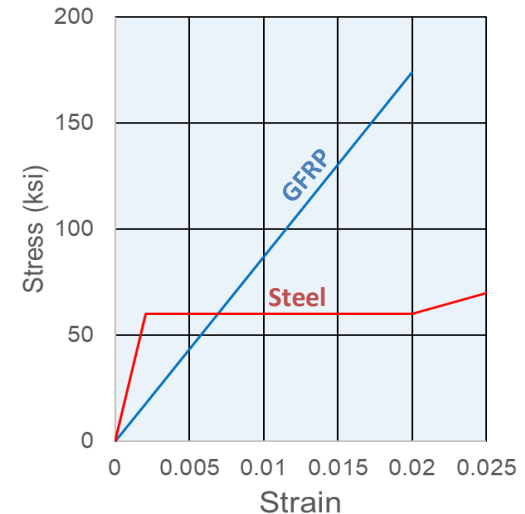
Spirals



GFRP Mechanical Properties and Behavior

- **Higher tensile strength, but less stiff than steel**
 - ✓ Provides less confinement to concrete and RC members have more deflection than steel-RC
- **Anisotropic behavior**
 - ✓ High strength in the fiber direction
 - ✓ Low shear strength and dowel action (resin dominated)
- **Elastic up to failure - no ductility**
 - ✓ Cannot be used in seismic areas, no plastic hinges formed in RC members

Tensile Stress-Strain Characteristics





Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement¹

This standard is issued under the fixed designation D7957/D7957M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers glass fiber reinforced polymer (GFRP) bars, provided in cut lengths and bent shapes and having an external surface enhancement for concrete reinforcement. Bars covered by this specification shall meet the requirements for geometric, material, mechanical, and physical properties described herein.

1.2 Bars produced according to this standard are qualified using the test methods and must meet the requirements given by **Table 1**. Quality control and certification of production lots of bars are completed using the test methods and must meet the requirements given in **Table 2**.

1.3 The text of this specification references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables) shall not be considered as requirements of the specification.

1.4 The following FRP materials are not covered by this specification:

1.4.1 Bars made of more than one load-bearing fiber type (that is, hybrid FRP).

1.4.2 Bars having no external surface enhancement (that is, plain or smooth bars, or dowels).

1.4.3 Bars with geometries other than solid, round cross sections.

1.4.4 Pre-manufactured grids and gratings made with FRP materials.

1.5 This specification is applicable for either SI (as Specification D7957M) or inch-pound units (as Specification D7957).

1.6 The values stated in either inch-pound units or SI units are to be regarded as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

¹ This specification is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.10 on Composites for Civil Structures.

Current edition approved Aug. 1, 2017. Published August 2017. Originally approved in 2017. DOI: 10.1520/D7957_D7957M-17.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*²

A615/A615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

C904 Terminology Relating to Chemical-Resistant Nonmetallic Materials

D570 Test Method for Water Absorption of Plastics

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

D2584 Test Method for Ignition Loss of Cured Reinforced Resins

D3171 Test Methods for Constituent Content of Composite Materials

D3878 Terminology for Composite Materials

D7205/D7205M Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

D7617/D7617M Test Method for Transverse Shear Strength of Fiber-reinforced Polymer Matrix Composite Bars

D7705/D7705M Test Method for Alkali Resistance of Fiber Reinforced Polymer (FRP) Matrix Composite Bars used in Concrete Construction

D7913/D7913M Test Method for Bond Strength of Fiber-Reinforced Polymer Matrix Composite Bars to Concrete by Pullout Testing

D7914/D7914M Test Method for Strength of Fiber Reinforced Polymer (FRP) Bent Bars in Bend Locations

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

Standards and Guides Material Specification

- ASTM D7957 – Standard Specification for Solid Round GFRP Bars for Concrete Reinforcement
 - Glass fiber, vinyl ester resin bars only
 - Manufactured by pultrusion process
 - Specified material properties
 - Specified durability properties

IN-LB

Inch-Pound Units

An ACI Standard

Construction with Glass Fiber-Reinforced Polymer Reinforcing Bars— Specification

Reported by ACI Committee 440

ACI SPEC-440.5-22



Standards and Guides Construction Specification

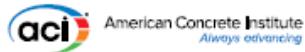
- ACI SPEC 440.5-22 Construction with Glass Fiber-Reinforced Polymer Reinforcing Bars
 - Like ACI 301 Section 3, but covers GFRP bars

ACI CODE-440.11-22

An ACI Standard
An ANSI Standard

Building Code Requirements
for Structural Concrete
Reinforced with Glass Fiber-
Reinforced Polymer (GFRP)
Bars—Code and Commentary

Reported by ACI Committee 440



IN-LB Inch-Pound Units

Standards and Guides Code Requirements

- The new **ACI CODE 440.11-22** Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars
 - Dependent on ACI 318-19
 - Same layout and chapters as 318-19
 - Consistent numbering with 318-19 where possible

Standards and Guides

The new ACI CODE 440.11-22

Code **DOES** cover

- Beams
- One-way and two-way slabs
- Columns
- Walls
- Foundations
- Joints/Connections between members
- Strength evaluation of existing structures

Standards and Guides

ACI CODE 440.11-22 Limitations

Code **does not** currently cover

- Hybrid reinforcement
- Seismic category D-F totally excluded
- Seismic category B-C if part of the lateral load resisting system
- Fire rated constructions

Benefits and Limitations

PROs

- High longitudinal strength to weight ratio
- Corrosion resistant
- Electro-magnetic neutrality
- High fatigue endurance
- Low thermal and electrical conductivity
- Light weight
- Easily cut onsite

CONs

- No yielding before failure
- Low transverse strength
- Relatively low modulus
- Susceptible to fire and smoke production
- High coefficient of thermal expansion perpendicular to fibers
- Can not be field bent

Benefits

Easy to Cut and Handle



- GFRP reinforcing bars are relatively **easy to cut** using a circular saw with a carborundum blade.
- torches or shearing-type tools such as bolt cutters should never be used to cut FRP bars



Light-weight material with a unit density of $1/3$ to $1/4$ that of mild steel

GFRP -Applications

- **Concrete structures susceptible to corrosion**
 - Steel corrosion by chlorides
 - Environments that lower concrete pH
- **Concrete structures requiring reinforcement due to**
 - Electro-magnetic considerations
 - Thermal non-conductivity
- **Where machinery will “consume” the reinforced concrete member (i.e., mining and tunneling)**



GFRP- Applications

Concrete exposed to chlorides:

- Bridge decks
- Approach slabs
- Seawalls
- Barrier walls
- Railroad crossings
- Salt storage facilities
- Retaining walls
- Parking Garages



Applications

Electromagnetic Transparency

- MRI rooms in hospitals
- Airport radio & compass calibration pads
- Electrical high voltage transformer vaults
- Concrete near high voltage cables and substations
- Cable Duct Banks
- Toll Road Inductance Loops



Concluding Remarks

- Publication of ACI 440.11-22 – allows engineers to confidently and safely design with GFRP rebars
- ACI SPEC 440.5-22 Construction with Glass Fiber-Reinforced Polymer Reinforcing Bars– allows contractors to build with GFRP rebars confidently and safely
- ACI CODE 440.11-22 is available at ACI bookstore



ACI 440.11-22

Develop design manual (handbook) for GFRP rebar

Develop guidelines and recommended practice manual for pre-engineered projects with FRP rebar

Develop a Certification Program for FRP Reinforcing Bar Inspector

Full-day seminars to educate engineers and students on Designing Concrete Structures Reinforced with GFRP Bars

Workshop on Designing Concrete Structures Reinforced with FRP Bars using ACI 440.11-22

NEx Potential Collaboration

- NEx is working through collaboration with academia, industrial partners, and governmental organizations, and non-profit organizations in the following areas:
 - **Standards & Guidelines**
 - **Research and Development**
 - **Advocacy and Awareness**
 - **Professional Development**
- NEx welcomes proposals and discussions year-round

Research Collaboration



Collaborate, Cooperate, Co-Create

THANK YOU

Talks

Concrete

Talks

Facilities
Management

Talks

Geotechnical
& Engineering

Talks

HVAC R

Talks

Offsite
& Modular

Talks

Project
Management

Talks

Solar

Talks

Stone Design

Talks

Technology

Talks

Urban Design
& Landscape