Steel Rebar

Steel rebar is the standard method of reinforcing concrete structures.

Steel rebar has a long history.

It is appropriate for more than 80% of applications.

But, what about those situations where steel rebar is not appropriate?
What about the other 20%?
Corrosion

As long as we reinforce concrete with steel, it will rust.

Traditionally, concrete structures crack and expose the steel reinforcement to chloride intrusion. This triggers premature corrosion ultimately resulting in the spalling (or blow out) of concrete pieces to the point where the structure is deemed fully failed.

Conclusion: Service life of a structure is dramatically reduced by corrosion.

Problem is Rusting Steel Rebar

Reinforced concrete with Steel Rebar is the cause of the failing infrastructure.

Corrosion occurs when moisture or salt come in contact with the steel reinforcement bar.

Steel rebar expands 10x in diameter, it rusts and causes concrete to crack and fail.

Corrosion weakens metal, putting additional pressure on the concrete and compromising the structure.
How Corrosion Occurs?

Corrosion is an electrochemical reaction between a metal and its environment. Corrosion occurs when steel reacts with chloride ions (Cl\(^{-}\)), CO\(_2\) in presence of toxic environment. This is the most expensive chemical reaction in the world.

$$4Fe + 3O_2 + 6H_2O \rightarrow 4Fe(OH)_3 - \$$$

The Cost of Corrosion

All steel reinforced concrete worldwide is at risk due to corrosion PLUS corrosion is the single largest cause of concrete repair.

The global cost of corrosion is estimated to be US$2.5 trillion.

FACT: According to FHWA, 1 in 3 bridges in the United States are structurally deficient.

National Association of Corrosion Engineers (NACE) estimates the cost of corrosion of concrete structures in the USA to be approximately $100 billion per year.
The Traditional Solutions to Corrosion

- Regular Maintenance and Repairs
- Admixtures
- Increase Concrete Cover
- Alter Concrete Mix
- Membranes & Overlays
- Epoxy-Coated or Galvanized Steel

The Solution: GFRP

TUF-BAR Fiberglass Rebar is THE solution
Fiberglass Products

Fiberglass is used in a wide variety of products. Made from a mixture of silica, limestone and other materials. This mixture is heated and extruded into fine strands which are collected into bundles called rovings.

What is GFRP?

GFRP – Glass Fiber Reinforced Polymer composite material.

A composite material system made of Fibers + Resin.

Pultrusion method is used to manufacture bars, with thousands of E-CR Glass Fiber rovings being pulled through a Vinyl-Ester resin bath.

Bars are coated in sand to improve the bonding surface between the bar and concrete.

Impervious to chloride ion and chemical attack. Manufactured in sizes #2 - #12 (45 GPa to 60 GPa).

Bends are manufactured at TUF-BAR.
Benefits

100% Corrosion Resistant: no need for 3" cover, corrosion inhibitor or sealants
Non-Magnetic: transparent to magnetic fields and radio frequencies
Non-Conductive: Electrically and Thermally
Lightweight: ¼ the weight of steel – saving in transportation, labor and carbon footprint
Superior Tensile Strength: high strength-to-weight ratio
Cost Effective: saving in construction, maintenance and repair costs over the service life of the structure
Longer Service Life: because GFRP will never rust, the concrete will last longer.
100% Recyclable

Non Metallic – No Rust!
Corrosion-Free Fiberglass Rebar
No need for 3" cover, corrosion inhibitors or sealants.
Lightweight

1/4 the weight of steel: 1.0" bar at 20' length weighs less than 15lbs
Significant savings in transportation and carbon footprint
Substantial labor savings on construction site
Easier and safer to install

Tensile Strength

2x the Tensile Strength of Steel
Non-Conductive

Contains zero metal or ferrous material making TUF-BAR non-magnetic and non-conductive
- Safety in High Voltage Areas
- No Electro-magnetic induction
- No Electrical Interference

GFRP as a Thermal Insulator

Does not conduct heat or transfer cold:
- Insulated Concrete Sandwich Panels
- Refrigerated Warehouses
- Concrete Balconies
**Boring / Tunneling**

*Perfect Solution for Soft Eye Application*

TUF-BAR takes advantage of its "anisotropic" property, meaning they are strong along the main axis, but can be "consumed" by excavation equipment such as Tunnel Boring Machines.

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**100% Recyclable**

*Ease of Demolishing*

TUF-BAR is 100% recyclable and easy to demolish, ensuring environmental sustainability and operational efficiency.
Sustainable & Environmentally Friendly

- Canada Green Building Council Member
- 100% Recyclable
- TUF-BAR® contributes:
  - 6 LEED® Credits in Canada
  - 7 LEED® Credits in USA

Applications

1. Concrete structures susceptible to corrosion.
2. Concrete structures requiring non-ferrous reinforcement due to electro-magnetic considerations or thermal non-conductivity.
3. Where machinery will “consume” the reinforced concrete member (mining/tunneling).

- Bridge Decks/Approach Slabs
- Marine & Waterfront: Seawalls, Docks, Boat Ramps
- Light Rail Transit
- Water Treatment Facilities
- Parking Garages
- Concrete Balconies
- Box Girders
- Barriers, parapets, sidewalks
- Box Culverts
- Tunneling / Soft Eye
- MRI Rooms

Pre-Cast Applications:
- Columns
- Stairs
- Blocks (lifting anchors)
- Bridge Girders
- Barriers
- Shear Walls
- Parking Curbs
- Underground Utility Boxes
GFRP Shapes

- Straight Bars
- Bends
- Spirals
- Hoops
- Hooked Bar
- Headed Bar
- Coiled Bar

TUF-BAR Shapes

- C1: 90 Degree Bent
  Steel Type 2, 17
- C2: >90 Degree Bent
  Steel Type 3
- C3: 90 Degree Bent
  Steel Type 15, 21, 30
- C4: Hooked Bar
  Steel Type SPI
- C5: U/C Shape Bar
  Steel Type 2, 17
- C6: Open U
  Steel Type 3D, 4C, 14AB, 22B
- C7: Hoop
  Steel Type T3
- C8: Dual Hooked
  Steel Type 1
- C9: Paperclip
  Steel Type - None
- C10: Closed U/C Shape Bar
  Steel Type S6
- C11: Rectangular Spiral
  Steel Type - None
Long-Term Durability

According to field performance of existing GFRP reinforced concrete structures over the last 20 years and numerous research studies, the corrosion resistant nature of this alternative has demonstrated its ability to **extend the service life** of concrete structures to more than 100 years.

Cores from a 17-year old bridge show **no sign of damage**.

Cores from five concrete structures in Canada 12 to 15 years old showed similar performance.

More than 750 projects in US and Canada have used GFRP rebar.

GFRP is a more durable, proven and successful reinforcing alternative to heavy, corrosive steel.

1st Bridge with GFRP

McKinleyville, WV (1996)

The McKinleyville Bridge was the first vehicular bridge in the U.S. to be constructed with a concrete deck reinforced with GFRP rebar. The bridge is 177 feet long by 30 feet wide and accommodates two lanes of traffic.

**Original surface, no repairs required in 20+ years.**
Specifications & Design Guides

ASTM D7957-17 Material Specifications
ACI 440.1R-15 Design with FRP rebars
ACI 440.5-08 Construction with FRP rebars
AASHTO LRFD Bridge Design Guide Specifications
CSA 807-19 Specification for Fibre Reinforced Polymers
CSA 806-12 Design and Construction of Building Components
CSA S6-19 Highway Bridge Design Code

GFRP Software & Tools

FRPpro™ Engineering Calculator is an advanced software package for structural and civil engineers used to calculate the strength and adequacy of concrete structural members reinforced with fiber reinforced polymers (FRPs).

The goal of the FRPpro Engineering Calculator is to give specifiers, concrete design engineers and precasters a reliable tool for converting conventional steel reinforcement into non-corrosive composite reinforcement.
Material Certification & Traceability

High Embedment Strength Material test certs are available for any production lot of TUF-BAR.

The certs are traceable to the bar by means of a series of bar marks imprinted along the length of the bar in intervals showing the manufacturer’s name, bar size & diameter, grade designation and applicable codes.

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Method</th>
<th>Limits - metric</th>
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<tbody>
<tr>
<td>Tensile Strength</td>
<td>ASTM D7505</td>
<td>ASTM D7507 Table 2</td>
</tr>
<tr>
<td>Ultimate Elongation</td>
<td>ASTM D7505</td>
<td>ASTM D7507 Table 2</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>ASTM D7505</td>
<td>ASTM D7507 Table 2</td>
</tr>
<tr>
<td>Interlaminar Shear</td>
<td>ASTM D4775</td>
<td>≥ 25 MPa for Grade 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 45 MPa for Grade 2</td>
</tr>
<tr>
<td>Fiber Content</td>
<td>ASTM D5084</td>
<td>≥ 3% by weight</td>
</tr>
<tr>
<td>Core Ratio</td>
<td>ASTM E2360</td>
<td>≥ 95%</td>
</tr>
<tr>
<td>Glass Transition Temp</td>
<td>ASTM E136</td>
<td>± 100 Degrees Celsius</td>
</tr>
<tr>
<td>Measured Cross-Sectional Area</td>
<td>ASTM D7505</td>
<td>ASTM D7507 Table 3</td>
</tr>
<tr>
<td>24-hour Moisture Absorption</td>
<td>ASTM D595</td>
<td>≤ 0.15% mass increase</td>
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</tbody>
</table>

Each individual sample taken must meet the property limits. Test certifications are available for any production lot upon request. Bars are given a designation that is unique to each production lot for traceability.

Fatigue Resistance

Steel: 20,000 cycles
GFRP: 420,000 cycles

Lasts 20x longer under cyclic loads
- Truck Traffic, Wave Action, Seismic

60 Ton Loading Fixture
A. El-Ragaby, E. F. El-Salakawy and B. Bemmokrane
Fire Rating: Bridge Slabs

Over 3 Hours Fire Rating Test
NRC Laboratories - Ottawa Canada
40 mm concrete cover
&
60 mm concrete cover

GFRP Mechanical Properties

Higher Tensile strength, but less stiff than steel
Anisotropic behavior
- High strength in the fiber direction
- Low shear strength and dowel action
GFRP is linear elastic up to failure
- no ductility
- 2% elastic deformation
Glass Creep - not recommended for Pre-Tensioning, Post-Tensioning, Dead Loads (max 25% UTS)
Modulus of Elasticity - ¼ that of Steel (45 to 60 GPa)
Things to Know

High Embedment Strength
- Rough Surface
- Sand Coating

$K_b$ Factor
- Crack Width < 0.023 in
- Sand Coating $K_b = 0.8$
- 20% Less Bar Required

\[
 w_{cr} = 2 \frac{f_{FRP}}{E_{FRP}} \frac{h_2}{h_1} k_b \sqrt{d_c^2 + (s/2)^2}
\]

Design and Construction Considerations

Concrete Crushing as preferred failure mode

Lower modulus

Lap splices longer

Support chairs at 2/3 conventional spacings

Bid by foot rather than by pound

Recommend using PVC coated Tie-Wire

60 GPa Bends – reduces congestion in the stirrups by 30%
**Project Cost Savings**

- Less Concrete Cover: GFRP placed closer to the surface
- Fewer Concrete Additives
- No Concrete Treatments and no Protective Membranes
- Lightweight
  - Lower Transport Costs
  - Less Handling
  - Less Injuries (WCB/OSHA)
- Fast Installation – Easier and Safer
  - Easy to work with and improves installation efficiency
  - Cuts with Chop Saw or Grinding Disc in Seconds

**Maintenance Costs**

TUF-BAR rebar dramatically reduces the maintenance, inspection and repair costs over the life cycle of the structure.
Life Cycle Cost Analysis

Save money in the long run: GFRP is indeed initially more expensive than traditional black steel rebar.

However, it offers HUGE advantages over these materials and has a much LOWER overall cost of ownership.

Research Study - Composites Innovation Centre University of Manitoba.

- GFRP 70% cost savings over 100 years
- Repairs start in 10-15 years
- More expensive as time goes on

Cost Comparisons

Cost Estimate – Reinforcing Steel

<table>
<thead>
<tr>
<th>Description</th>
<th>Qty</th>
<th>Unit</th>
<th>Unit Cost</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete Class IV, Bulkhead</td>
<td>336.8</td>
<td>CY</td>
<td>$659.78</td>
<td>$222,214</td>
</tr>
<tr>
<td>Concrete Additives</td>
<td>336.8</td>
<td>CY</td>
<td>$40.00</td>
<td>$13,472</td>
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<tr>
<td>Reinforcing Steel, Bulkhead</td>
<td>45,468</td>
<td>LB</td>
<td>$1.03</td>
<td>$46,832</td>
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</table>

Initial Cost = $282,518

Maintenance (25% Total Cost) = $70,629

TOTAL = $353,147

Cost Estimate – Glass Fiber Reinforced Polymer Bars

<table>
<thead>
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<tbody>
<tr>
<td>Concrete Class IV, Bulkhead</td>
<td>336.8</td>
<td>CY</td>
<td>$659.78</td>
<td>$222,214</td>
</tr>
<tr>
<td>Reinforcing Steel, Bulkhead</td>
<td>43,303</td>
<td>LF</td>
<td>$2.00</td>
<td>$86,606</td>
</tr>
</tbody>
</table>

TOTAL = $308,820

Overall Project Savings of 14.35%
Steel vs TUF-BAR®

<table>
<thead>
<tr>
<th></th>
<th>Black Steel</th>
<th>Stainless Steel</th>
<th>TUF-BAR®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>10x Black Steel</td>
<td>≃ Galvanized Steel</td>
<td>≃ Epoxy Coated Steel</td>
</tr>
<tr>
<td>Corrosion</td>
<td>Susceptible</td>
<td>Susceptible</td>
<td>Non-Susceptible</td>
</tr>
<tr>
<td>Weight</td>
<td>1/4 of Steel</td>
<td></td>
<td>2x Steel/Stainless</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>200 GPa</td>
<td>200 GPa</td>
<td>45, 60 GPa</td>
</tr>
<tr>
<td>Modulus</td>
<td>8-11 MPa</td>
<td>8-11 MPa</td>
<td>14 MPa</td>
</tr>
<tr>
<td>Bond Strength</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Electrical Conductivity</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Magnetic</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Why TUF-BAR?

- 100% Corrosion Resistant:
- Non-Magnetic
- Non-Conductive
- Lightweight
- Superior Tensile Strength
- Much LOWER overall cost of ownership.
- 100% Recyclable
- NSERC Industrial Research Chair
- We help set the standards
Teed Bridge
Pre-Cast Deck Slab

Perry’s Creek Bridge
Peace Bridge

Huntley Bridge
Neils Brook Bridge

Water Treatment Plant
La Chancelière Parking Garage

Conclusions

Save Money with GFRP and live without Corrosion.

- Eliminate expensive repair and maintenance costs created by black steel reinforcement.
- Reduce concrete cover and corrosion protection measures taken to protect black steel.

Compared to traditional materials, GFRP is corrosion resistant, high strength, light weight, and provides increased longevity, durability and reliability.

100+ Years Sustainability
Structures last up to 4 times longer eliminating expensive capital expenditures over time.

Codes are published and design tools are ready to use.
Questions?

info@tufbarcanada.com 1-888-99-REBAR