Pulwell Glass Fiber Reinforced Polymer (GFRP) Rebar--- Fiberglass Rebar

Pulwell manufactures GFRP rebars by combining the pultrusion process and an in-line winding & coating process for the outside sand surface. The GFRP rebar is made from high strength glass fibers along with an extremely durable vinyl ester or epoxy resin. The glass fibers impart strength to the rod while the vinyl ester or epoxy resin imparts excellent corrosion resistance properties in harsh chemical and alkaline environments. For improved stiffness and mechanical properties high modulus of glass fiber with epoxy resin is also available. GFRP rebar significantly improves the longevity of civil engineering structures where corrosion is a major factor.

Pulwell's GFRP rebar Features & Benefits:

High Strength-to-Weight Ratio – provides good reinforcement in weight-sensitive applications.

Non-Corrosive – will not corrode under exposure to a wide variety of corrosive elements including chloride ions.

Non-Conductive – provides excellent electrical and thermal insulation.

Excellent Fatigue Resistance – performs very well in cyclic loading situations.

Good Impact Resistance – resists sudden and severe point loading.

Magnetic Transparency – is not affected by electromagnetic fields. Excellent for use in MRI and other types of electronic testing facilities.

Lightweight – easily transported and assembled in the field without need for heavy lifting equipment.

Pulwell's GFRP Rebar Applications:

Six general categories of applications have been identified for which FRP reinforcement are suitable alternatives to steel, epoxy-coated steel, and stainless steel bars:

Reinforced Concrete Exposed to Deicing Salts-FRP bars can eliminate the corrosion problems and reduce maintenance and repair costs in northern climates where deicing salts are used every year on roads and pavements. Applications most likely to benefit include: parking structures; bridge decks; jersey barriers, parapets; curbs; retaining walls and foundations; roads and slabs on grade; and many others.

Structures Built in or Close to Seawater-Corrosion of steel reinforcement is a common problem in structures built in or close to seawater. Examples of possible applications: quays; retaining walls; piers; pilings; jetties; caissons; decks; bulkheads; floating structures; canals; roads and buildings; offshore platforms; swimming pools and aquariums.

Applications Subjected to Other Corrosive Agents-Chemical processing industries of all types, as well as wastewater of domestic or industrial origin, constitute major sources of corrosion for steel reinforcement. Typical applications include: wastewater treatment plants; petrochemical plants; pulp and paper mill and liquid gas plants; pipelines and tanks for fossil fuel; cooling towers; chimneys; mining operations of various types, nuclear power plants; and nuclear dump facilities.

Applications Requiring Low Electric Conductivity or Electro-magnetic Neutrality-Using steel bars in applications where low electric conductivity or electromagnetic neutrality is needed often result in complex construction layouts, if such use is possible at all. Potential applications are: aluminum/copper smelting plants; manholes for electrical and telephone communication equipment; structures supporting electronic equipment such as transmission towers for telecommunications; airport control towers; magnetic resonance imaging in hospitals; railroad crossing sites; and military structures needing radar invisibility.

Applications in Tunneling / Boring Requiring Reinforcement of Temporary Concrete Structures: Structures including mining walls; underground rapid transit structures and underground vertical shafts.

Applications in Weight Sensitivity or Thermally Sensitivity Structures: Concrete construction in areas of poor load bearing soil conditions, remote geographical locations, sensitive environmental areas, Apartment patio decks; thermally insulated concrete housing and basements; thermally heated floors and conditioning rooms, or active seismic sites posing special issues that the use of lightweight reinforcement will solve.

Pulwell's GFRP rebar Properties:

1. Tensile Stress, Nominal Diameter & Cross Sectional Area, Modulus of Elasticity:

In Imperial Units

Bar Sizes	Nominal Dia. (in)	Cross Sectional Area(in2)	Guaranteed Tensile Strength (ksi)	Average Tensile strength (ksi)	Average Tensile Load (klbf)	Tensile Modulus of Elasticity (psi X106)
#2	1/4"	0.049	131	152	7.45	6.53
#3	3/8"	0.11	123	152	16.72	6.53
#4	1/2"	0.196	116	145	28.42	6.53
#5	5/8"	0.307	109	131	40.22	6.53
#6	3/4"	0.442	102	123	54.37	6.53
#7	7/8"	0.601	99	116	69.72	6.53
#8	1"	0.785	94	113	88.71	6.53
#9	1-1/8"	0.994	91	112	111.33	6.53
#10	1-1/4"	1.227	90	110	134.97	6.53
#11	1-3/8"	1.484	87	109	161.76	6.53
#12	1-1/2"	1.766	87	109	192.49	6.53
#13	1-5/8"	2.073	87	109	225.96	6.53

In Metric Units

Item	Nominal Dia. (mm)	Cross Sectional Area (mm2)	Guaranteed Tensile Strength (Mpa)	Average Tensile strength (Mpa)	Average Tensile Load (KN)	Tensile Modulus of Elasticity (Gpa)
1	6mm	28.26	900	1050	29.67	45
2	8mm	50.24	850	1050	52.75	45
3	10mm	78.50	850	1000	78.50	45
4	12mm	113.04	800	1000	113.04	45
5	14mm	153.86	800	950	146.17	45
6	16mm	200.96	750	900	180.86	45
7	18mm	254.34	720	850	216.19	45
8	20mm	314.00	690	850	266.90	45
9	22mm	379.94	680	800	303.95	45
10	25mm	490.63	650	780	382.69	45
11	28mm	615.44	630	770	473.89	45
12	30mm	706.50	620	760	536.94	45
13	32mm	803.84	620	750	602.88	45
14	36mm	1017.36	600	750	763.02	45
15	40mm	1256.00	600	750	942.00	45

Note:

* Tensile and Modulus Properties are measured per ASTM D7205 - 06 <Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars> . The tensile modulus is measured at approximately 10% to 50% of the ultimate load.

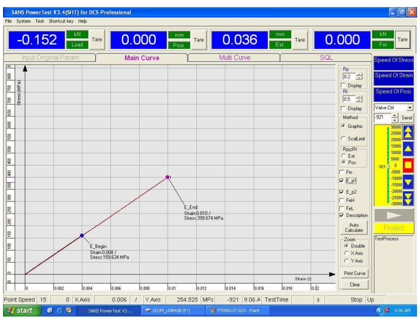
** The area used in calculating the tensile strength is the nominal cross sectional area.

*** The "Guaranteed Tensile Strength", is as defined by ACI 440.1R as the average tensile strength of a given production lot, minus three times of the standard deviation.

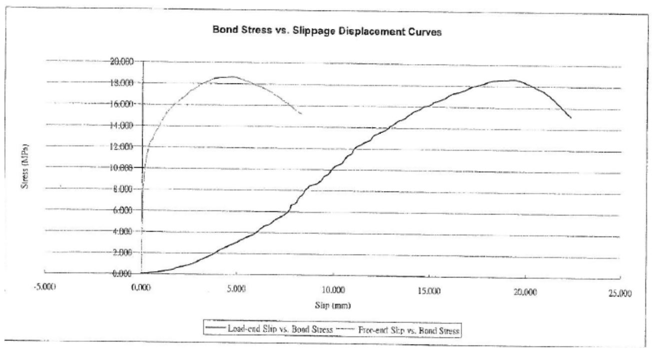
**** The "Tensile Modulus of Elasticity" is as defined by ACI 440.1R as the average modulus of a production lot.

***** The data contained herein is considered representative of current production and is believed to be reliable, and Pulwell reserves the right to make improvements in the product and/or process which may result in benefits or changes to some physical -mechanical characteristics.

2.Typical Stress/Strain Curve for GFRP Rebar:



3.Typical Load/Slide Curve for GFRP Rebar:



4. Bond Stress: >9.7 Mpa. Actual bond strength of Pulwell GFRP rebars is more than 12.8Mpa per ACI440.3R B3. The Kb bond dependent coefficient for Pulwell GFRP rebars is … K b= 0.90

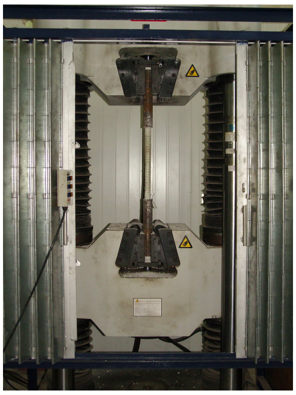
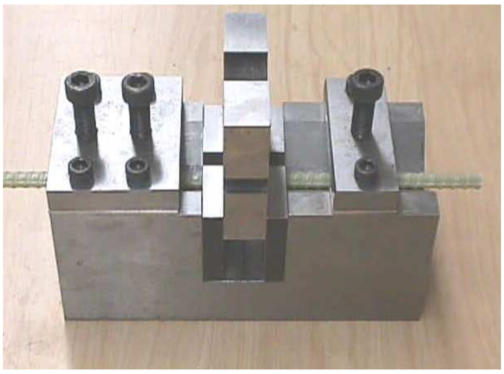
5. Coefficient of Thermal Expansion: Transverse Direction 21 - 23 x 10-6 /deg C ,Longitudinal Direction 9.07 x 10-6 /deg C

6. Barcol Hardness: 55 per ASTM D2583

7. Glass Fiber Content by Weight: 70% minimum per ASTM D2584

8. Specific Gravity: 1.95--2.05 per ASTM D792

9.Shear Stress: >125Mpa. Actual shear stress measured on 5/8" diameter bars using a double shear test fixture: 152 Mpa, per ACI 440.3R B4.

10. **Void Content:** Each production run of Pulwell GFRP rebar is sampled to screen for longitudinal thermal or mechanical cracks as well as continuous hollow fibers. No continuous voids are permitted after 15 minutes of capillary action. Testing performed per ASTM D5117.

11. **Moisture Absorption:** Susceptibility to moisture absorption is a key indicator of successful long-term durability. Testing per ASTM D570.

24 hour absorption at 122°F (50°C) ≤ 0.25%
At saturation ≤ 0.75%

12. Tensile Strength at Cold Temperature

As compared to properties at ambient conditions, temperatures at low as -50°F (-60°C) have less than 5% effect on the tensile strength of the bar.

13. Durability

Potential durability versus traditional steel reinforcement is one of the chief benefits of GFRP Rebar. In environments that would traditionally degrade steel reinforcement, there is little concern in the international research area that these same agents (low pH solutions) will degrade the quality of GFRP rebar. Typical portland concrete pour water is very alkaline with a pH of approximately 13. In addition, it is presumed that any water that hydrates through the concrete also creates a high pH solution that could potentially degrade the rebar.

A great deal of research has been performed on this subject with the conclusion being that a properly designed and manufactured composite system of resin and glass can adequately protect the glass fibers from degradation. **Pulwell rebar is made from vinyl ester or epoxy resin matrix using ECR glass fibers, with very good bond between the fiber and the resin, so that the long term performance of Pulwell GFRP rebars can be guaranteed.**

The retained tensile strength of Pulwell GFRP rebars can be more than 80% per ACI 440.3R B6 <Accelerated test method for alkali resistance of FRP bars>, when exposed to 12.8pH solution for 90 days at 140°F (60°C), and the tensile modulus properties are typically not affected by the alkaline bath at elevated temperatures. This means that Pulwell GFRP rebars have reached to "D1" durability according to CSA Standard S- 807.

14.Creep

When subjected to a constant load, all structural materials, including steel, may fail suddenly after a period of time, a phenomenon known as creep rupture. Creep tests indicate that if sustained stresses are limited to less than 60% of short term strength, creep rupture does not occur in GFRP rods.

The endurance time is greatly affected by the environmental conditions such as high temperature, alkalinity, wet and dry cycles, freezing and thawing cycles. As the percentage of sustained tensile stress to short- term strength of the bar increases, the endurance time decreases. For this reason, the design limits on GFRP bars in consensus standards limit sustained loads on GFRP rebars to very low levels of utilization.

Stirrups, Shapes and Bends

Bends in Pulwell GFRP Rebar are fabricated by shaping over a set of molds or mandrels prior to curing of the resin matrix. Field bends are not allowed. All bends must be made at the factory. All GFRP rebars exhibit a strength reduction through the bent portion of the rebar, which is recognized by all the consensus design guidelines. Research has shown that bends typically maintain 38% to 50% of ultimate tensile strength through the radius.

While most standard steel rebar shapes are available, there are a handful of limitations that influence the economics of the detailing. Bends are limited to shapes that continue in the same circular direction. Otherwise lap splices are required.



Generally, pairs of U or C or L - shaped bars are more economical. Z - shapes or gull- wing type configurations are not very economical. A 90- degree bend with 12db bar diameter, pigtail used to shorten development length is just as effective as a J- shape as per ACI 440.1R.

The maximum leg length on any bend can be 10ft (2.5 m), but we suggest it to be less than 5ft (1.5m) if possible.


According to ACI 440.6-08 "Specification for Carbon and Glass Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement", the Min. Bend Radius can be 3 times of the rebar diameter, but we suggest the following radius to reach better performance at the bent portion.

Bar Size	Inside Bend Radius
#2	2" (50mm)
#3	2" (50mm)
#4	2" (50mm)
#5	3" (76mm)
#6	3" (76mm)
#7	4" (100mm)
#8	4" (100mm)
#9	4" (100mm)
#10	4" (100mm)

It is recommended that you work with the factory in the early stages of design, as not all standard bends and shapes are readily available.

Package in Coils and Field Forming of Large Radius Curves :

Due to the low modulus of the Pulwell GFRP bar, it is possible to pack the rebars especially small sizes (below 12.7mm) into coils with several hundred meters per roll , or field form the bar into large radius curves.

The GFRP rebars will naturally straighten when the coil is unrolled.

When the rebar is formed into big radius curves, a bending stress is resulted in the rebar. A radius smaller than those in the following table would exceed the long term sustained stresses allowable. The table gives the minimum allowable radius for induced bending stresses without any consideration for additional sustained structural loads.

Rebar Diameter			Interior Use, Ce=0.8, Min. Radius		Exterior Use, Ce=0.7, Min. Radius	
Size	mm	in	mm	in	mm	in
#2	6	1/4"	1,150	45	1,270	50
#3	10	3/8"	1,780	70	2,040	80
#4	13	1/2"	2,540	100	2,930	115
#5	16	5/8"	3,310	130	3,810	150
#6	19	3/4"	4,070	160	4,700	185
#7	22	7/8"	5,080	200	5,720	225
#8	25	1"	6,100	240	6,860	270
#9	29	1-1/8"	7,110	280	8,130	320
#10	32	1-1/4"	8,890	350	10,040	395
#11	35	1-3/8"	10,670	420	12,070	475
#12	38	1-1/2"	12,450	490	14,230	560
#13	41	1-5/8"	14,740	580	16,770	660

Summary of FRP Rebar Codes and Guidelines:

The designer should follow the recommendations in the appropriate consensus design guideline.

USA---ACI 440.1R "Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars"

The American Concrete Institute 440 guide is a mature and living document that has undergone a number of revisions since its first publication in 2001.

Companion documents to the **440.1R design guide** include the **ACI 440.3R** "Guide Test Methods for FRP's for

Reinforcing or Strengthening Concrete Structures" which is intended as an interim document superseded by new ASTM test methods as they become available.

The **ACI 440.5** "Specification for Construction with Fiber Reinforced Polymer Reinforcing Bars" and **ACI 440.6** "Specification for FRP Bar Materials for Concrete Reinforcement" give guidance in mandatory language for the use and specification of FRP bars.

ACI also offers a number of professional educational materials and special publications and proceedings specifically addressing internal FRP reinforcing bars.

AASHTO LRFD Bridge Design Guide Specifications for GFRP Reinforced Concrete Bridge Decks and Traffic Railings . Published in November 2009, this document offers authoritative design guidance to the bridge design community in safely adopting FRP bars in bridge decks and railings.

Canada---CSA S-806 The Canadian designer has the luxury of utilizing the S806 document **"Design and Construction of Building Components with Fibre-Reinforced Polymers".**

CSA S-6 Canadian Highway Bridge Design Code Widespread adoption of GFRP bars in Canadian bridge structures is being made possible by this important document.

CSA S-807 Specification for Fibre-Reinforced Polymers.

This specification offers guidance in terms of limits of constituent materials for FRP bars, criteria for qualification of FRP bar systems, manufacturers quality control reporting and owners acceptance criteria. The specification provides a framework for owners to use to pre-qualify FRP bar suppliers for bidding on major public works projects and for the manufacturers reporting of specific, traceable production lot properties and acceptance limits.

Europe---FIB Task Group 9.3 – bulletin 40 "FRP Reinforcement in RC Structures"

In Europe, the Federation Internationale du Beton FIB Task Group 9.3 has published a technical report "Bulletin 40", which is a "state of the art" of FRP reinforcement in RC structures. Work is under way on provisions for FRP bars in EuroCode 2 format. Norway and Italy have published internal design codes for the use of FRP rebars.

Design Considerations

FRP composite reinforcement has desirable performance advantages over other concrete reinforcing products. However, since the properties of the reinforcing products are different from those of steel reinforcement, the design of concrete reinforced with FRP products will be also different in many cases. Design engineers should consider the appropriateness of reinforcing concrete with FRP bars, keeping in mind the following basic points in their designs:

- **Direct substitution of FRP bars in a concrete member designed with steel bars is not possible in most cases.**
- **Lower modulus of elasticity of composite rebars will limit the applications**

○ Important Design Differences- FRP vs Steel

Physical Properties

Tensile strength

Bond Strength to Concrete

Stress Strain Curve

GFRP is linear elastic to failure , Steel has ductility

GFRP v.s. Steel - Physical Properties

Tensile strength of GFRP significantly greater than steel

Modulus of Elasticity for GFRP much lower than steel

Bond Strength to Concrete shall be higher

Design differences for GFRP RC members :

Deflection and crack widths may control design

Failure mode should be compression failure of the concrete

Strength reduction factor or safety factors different

Rebar spacing and cover may different

Lap splice length different

Tension Lap Splice Length Approximately 40 bar diameters for GFRP v.s. 30 bar diameters for steel .

There are a number of authoritative consensus design guidelines for the designer to follow. Generally the design methodology for FRP reinforced concrete members follows that of steel reinforcing but taking into account the linear elastic or non-ductile nature of the material with different safety factors. Care is taken to avoid the possibility of a balance failure mode where concrete crushing and rupture of the rebar could occur simultaneously.

The designer must choose between compression failure of concrete, which is the preferred mode, and rupture of the FRP rebar with a higher factor of safety.

Due to the low modulus of elasticity of FRP bars, serviceability issues such as deflections and crack widths generally control design.

The compressive strength of FRP bars is disregarded in design calculations.

Although the FRP bars themselves are not ductile, an FRP reinforced concrete section is characterized by large deformability i.e. significant deflections and crack widths are a warning of pending failure of the section.

Pulwell only guarantees the performance of its material to meet minimum ultimate requirements as listed. The use of competent experienced engineering personnel should always be employed in the design and construction of concrete reinforced structures.

Handling and Placement

Follow guidelines in ACI440.5-08 “Specification for Construction with FRP Bars”.

In general, field handling and placement is the same as for epoxy or galvanized steel bars.

Do NOT shear FRP bars. When field cutting of FRP bars is necessary, use a fine blade saw, grinder, carborundum or diamond blade.

Sealing the ends of FRP bars is not necessary.

Support chairs are required at two-thirds the spacing of steel rebar.

Plastic coated tie wire is the preferred option for most projects. When completely non-ferrous reinforcing, i.e., no steel is required in the concrete, nylon zip ties (available from local building materials centers) or plastic bar clips are recommended.

Care should be exercised to adequately secure GFRP in the formwork. GFRP rebars shall “float” during vibrating because of low weight, especially in precast applications

Storage

Keep out of direct sunlight

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