



# Glass Fiber Reinforced Polymer (GFRP) **REBAR**

## Aslan **100**



*by* Hughes Brothers

# CONCRETE IN Corrosive Applications



- **Concrete Exposed to De-Icing Salts** Bridge decks, Median barriers, Approach slabs, Parking structures, Railroad crossings, Salt storage facilities



- **Concrete Exposed to Marine Salts** Seawalls, Buildings & structures near waterfronts, Aquaculture operations, Artificial reefs and water breaks, Floating marine docks



- **Tunneling and Mining Applications**  
Soft-eye openings for tunnel boring machine (TBM's) and temporary works, Rock nails, Electrolytic and ore extraction tanks

## Other Corrosive Applications

- Concrete used in chemical plants and containers
- Pipeline and chemical distribution facilities
- Any polymer concrete requiring reinforcement
- Architectural precast and cast stone elements
- Thin concrete sections where adequate cover is not available
- Swimming Pools • Architectural Cladding • Brine Tanks

## Benefits of GFRP Rebar

- Impervious to chloride ion and low pH chemical attack
- Tensile strength greater than steel
- 1/4<sup>th</sup> weight of steel reinforcement
- Transparent to magnetic fields and radio frequencies
- Non-conductive
- Thermally non-conductive

## Where should GFRP Rebar be considered?

- Any concrete member susceptible to corrosion of steel reinforcement by chloride ion or chemical corrosion
- Any concrete member requiring non-ferrous reinforcement due to electro-magnetic considerations
- As an alternative to epoxy, galvanized or stainless steel rebar
- Only in secondary load bearing members
- Strengthening existing unreinforced masonry walls for seismic, wind or blast loads
- Rehabilitate existing masonry

## Potential of GFRP Rebar

- Significantly improve the longevity of civil engineering structures
- Strengthen and rehabilitate masonry structures

## CONCRETE IN Electromagnetic Applications

- MRI rooms in hospitals
- Airport radio & compass calibration pads
- Electrical high voltage transformer vaults and support pads
- Concrete near high voltage cables and substations



## Masonry Strengthening

- Flexural and shear strengthening of existing unreinforced masonry for seismic, wind or blast loading events.
- Rehabilitate existing masonry with step cracks and other bed joint issues.

# Physical Properties - Aslan 100, 101 GFRP Rebar

**Aslan 100** Vinylester Matrix GFRP Rebar

**Aslan 101** Polyester Matrix GFRP Rebar for non-portland cement and temporary use applications.

## I. Tensile Stress, Nominal Diameter & Cross Sectional Area

Size	Diameter		Area		Guaranteed Tensile Strength		Ultimate Tensile Load		Tensile Modulus of Elasticity	
	(mm)	(in)	(mm <sup>2</sup> )	(in <sup>2</sup> )	(MPa)	(ksi)	kN	kips	(GPa)	(psi 10 <sup>6</sup> )
2	6	1/4	31.67	0.049	825	120	26.2	5.89	40.8	5.92
3	10	3/8	71.26	0.110	760	110	54.0	12.1	40.8	5.92
4	13	1/2	126.7	0.196	690	100	87.3	19.6	40.8	5.92
5	16	5/8	197.9	0.307	655	95	130	29.1	40.8	5.92
6	19	3/4	285.0	0.442	620	90	177	39.8	40.8	5.92
7	22	7/8	387.9	0.601	586	85	227	51.1	40.8	5.92
8	25	1	506.7	0.785	550	80	279	62.8	40.8	5.92
9	29	1-1/8	641.3	0.994	517	75	332	74.6	40.8	5.92
10	32	1-1/4	791.7	1.227	480	70	382	85.9	40.8	5.92

Hughes Brothers reserves the right to make improvements in the product and/or process which may result in benefits or changes to some physical-mechanical characteristics. The data contained herein is considered representative of current production and is believed to be reliable and to represent the best available characterization of the product as of May 2007. Tensile tests per ASTM D7205.

### Cross Sectional Area

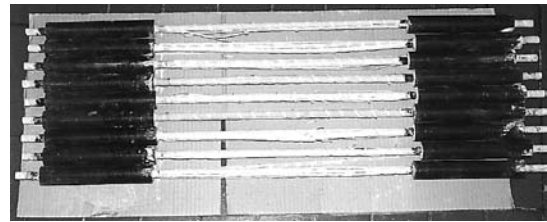
The cross sectional area of the rebar may be determined by immersing a sample in water and measuring the volume displacement of the piece. When calculating the cross sectional area, the cross section is assumed to be a circle. Per ASTM D7205.

### Nominal Diameter

The nominal diameter of the rebar is the average diameter and assumes the shape of the rebar is a circle. Nominal diameter should be used for design.

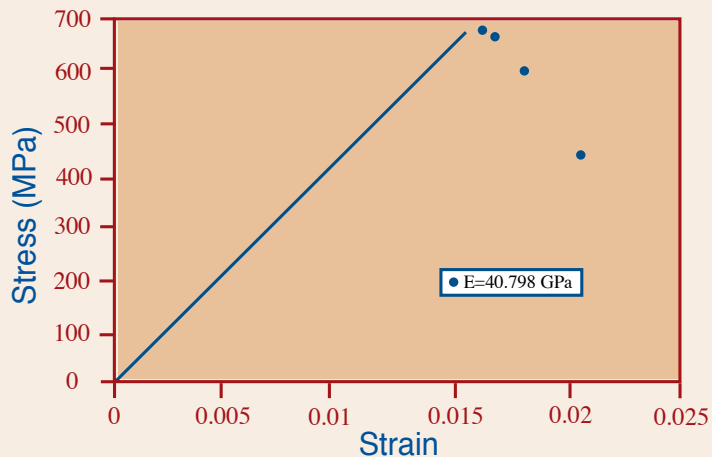
### Tensile Stress

Tensile stress values shown are determined as the average failure load divided by the cross sectional area based on nominal bar diameter, less three standard deviations. Tensile stress varies as diameter increases due to shear lag which develops between the fibers in the larger sizes. For AC1440.1R-06 design, this value is the guaranteed tensile strength,  $f_{tu}^*$ .



Results of destructive tensile testing performed at Penn State University

### Typical Stress / Strain Curve for GFRP Rebar



### Certification of Measured Mechanical Properties

Test reports from an independent lab are available on request for each production lot. Reports show the tensile strength of the sample population, average tensile modulus and the calculated ultimate strain for each tensile test based on the average modulus. Per ASTM D7205.

ASLAN 100 Fiberglass Rebar

## II. Modulus of Elasticity

The variation in the Modulus of Elasticity of different diameter bars is much smaller than that of the tensile stress.

Modulus of Elasticity ..... 40.81 G PA  
(5.92 X 10<sup>6</sup> psi)

Published values are an average modulus from a population of samples.

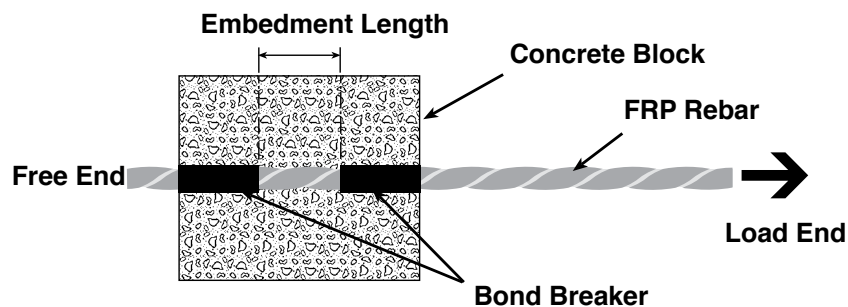


*Extensometer measuring elongation during tensile test.*

## III. Bond Stress to Concrete

The bond stress to concrete shown is based on pull out tests performed using test methods proposed in ACI 440.3R-04 Method B.3. This method is used as it is easily repeatable and gives an indication of relative performance.

Forms constructed out of plywood are used to cast a concrete block around one meter long rods as shown below.



In order to control the embedment length within the block, the rods are prepared with a bond breaker which consists of soft plastic tubing placed around the rods to prevent contact between the rod and concrete. The embedment length is 5 bar diameters.

The concrete used is a high early strength portland cement, fine aggregate (all purpose sand) and water (49.89 kg cement, 45.36 sand and, 12.5 l water). The 14 day compressive strength of cylinders is typically 45MPa.

Previous research has shown that bond strength does not vary significantly with varying concrete strength, provided the concrete block is properly sized to prevent splitting.

Loads are measured by the electronic load cell of a test frame and the slip between the rod & concrete is measured by six DC voltage LVDT's, three at each end.

While the free end LVDT's measure direct indication of free end slip, the loaded end measurements need to be adjusted for elongation of the rod between the actual loaded end of the embedment length and the attachment point of the LVDT's.

$$\text{Actual Slip} = \text{Measured Slip} - \frac{\text{Load} \cdot \text{Length}}{E \cdot A_R}$$

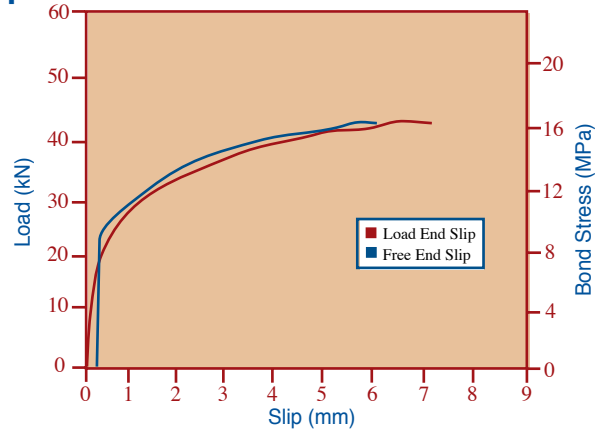
Where  $A_R$  is the effective cross sectional area of the rod.

Bond Stress is calculated as

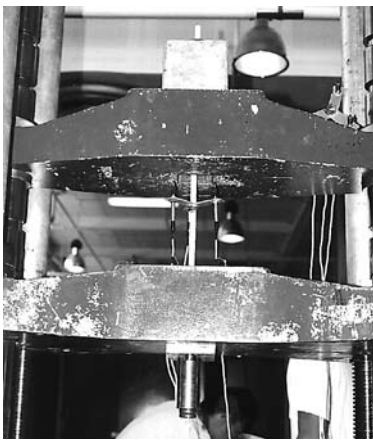
$$T_b = \frac{P}{A_b}$$

Where  $P = \text{Load}$   
 $A_b = \pi \cdot d_b \cdot L_b$   
 $d_b = \text{Effective Bar Diameter}$   
 $L_b = \text{Embedment Length}$

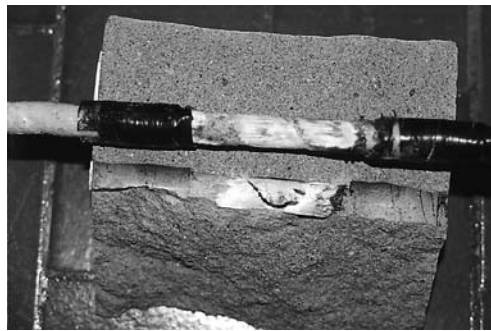
### Typical Load/Slide Curve for GFRP Rebar



Bond of GFRP to concrete is controlled by the following internal mechanisms: chemical bond, friction due to surface roughness of the GFRP rods, mechanical interlock of the GFRP rod against the concrete, hydrostatic pressure against the GFRP rods due to shrinkage of hardened concrete and swelling of GFRP rods due to moisture absorption and temperature change. Friction and mechanical interlock are considered to be the primary means of stress transfer.



Bond stress pull out test in fixture.



**Maximum Bond Stress**..... **11.6 MPa (1679 psi)**

Based on pull out tests performed using the Penn State method.

#### IV. Coefficient of Thermal Expansion:

Transverse Direction  $18.7 \times 10^{-6}/^{\circ}\text{F}$   
 $33.7 \times 10^{-6}/^{\circ}\text{C}$   
 Longitudinal Direction  $3.66 \times 10^{-6}/^{\circ}\text{F}$   
 $6.58 \times 10^{-6}/^{\circ}\text{C}$

#### V. Barcol Hardness:

50 min. per ASTM D2583

#### VI. Glass Fiber Content by Weight:

70% minimum per ASTM D2584

#### VII. Specific Gravity:

2.0 per ASTM D792

#### VIII. Shear Stress:

Shear stress ACI 440.3R-04 Method B.3; 22,000 psi (152 MPa)



Shear Strength Test Fixture

# Durability

Potential durability versus traditional steel reinforcement is one of the chief benefits of GFRP Rebar. However, being a relatively new material for use as a concrete reinforcement, decades of performance data are not available. Therefore, durability or longevity is one of the key issues concerning GFRP reinforcement.

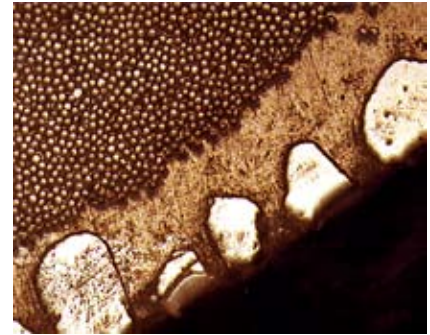
In environments that would degrade steel reinforcement, there is little concern that these same agents (low pH solutions) will degrade the quality of GFRP rebar. High pH or alkaline solutions will, however, degrade glass fibers. Research has focused on encapsulating the glass fibers in a resin matrix that protects them from potential alkaline degradation. Aslan 100 is produced using a vinylester resin matrix.

Typical portland concrete pour water is very alkaline with a pH of approximately 13. It is presumed that any water that hydrates through the concrete also creates a high pH solution that could potentially degrade the rebar.

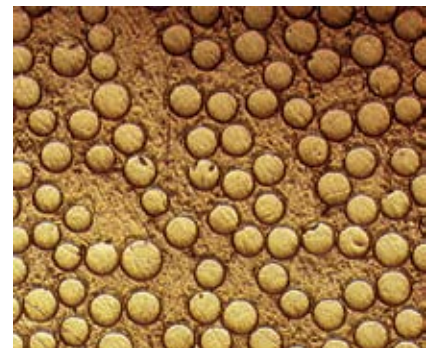
Most durability studies have focused on subjecting GFRP Rebars to alkaline solutions of 13pH at elevated temperatures to simulate service lives on the order of 50 years.

Fortunately, research from the ISIS network in Canada which involved extracting GFRP bars from several bridges and structures across Canada that have been in service from between 5 and 8 years reveals NO DEGRADATION of the GFRP bars. (Durability of GFRP Reinforced Concrete from Field Demonstration Structures – M. Onofrei University of Manitoba May 2005). This performance matches that of GFRP dowel bars that had been extracted from service in Ohio after 20 years.

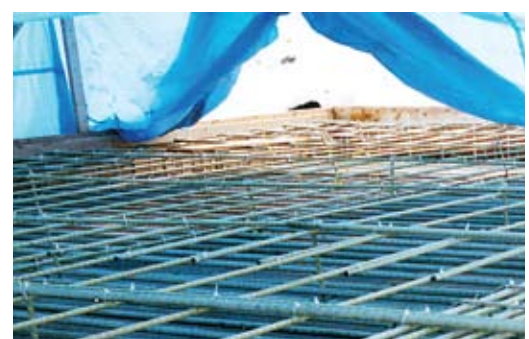
If used in polymer concrete, a plastic matrix, or as temporary reinforcing in portland concrete, a separate GFRP rebar formulation, Aslan 101, is available.



*Microscopy photo of Hughes Brothers Rebar - 60 X*



*Microscopy photo of Hughes Brothers Rebar - 240 X*



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# 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 conducted in Germany by Bundelmann & Rostasy in 1993, indicate that if sustained stresses are limited to less than 60% of short term strength, creep rupture does not occur in GFRP rods. For this reason, GFRP rebars are not suitable for use as prestressing tendons. In addition, other environmental factors such as moisture can affect creep rupture performance.

**Based on ACI 440 design guidelines, sustained stress may not exceed 20% of minimum ultimate tensile stress.**

For a summary of the recommended design guidelines, refer to AC440.1R-06 or your controlling national guide.



*Sierrita de la Cruz Creek Bridge, RM1061 Amarillo Texas.*

# Stirrups, Shapes and Bends

Bends in Hughes Brothers GFRP Rebar are fabricated by shaping over a set of molds or mandrels prior to thermoset of the resin matrix. Field bends are not allowed.

- **All bends must be made at the factory.**

Research has shown that bends typically maintain 38% of ultimate tensile strength through the radius. (Eshani, Rizkalla)

- **Bent portions of GFRP rebars have a lower tensile strength than straight portions.**
- **Studies indicate that the maximum load carrying capacity of the bent portion of GFRP rebar is 38% of the straight bar.**

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. For example, a J-Hook at the end of a 10 meter length of rebar would be achieved by lap splicing a J-hook piece to the 10 meter rebar.

- **The narrowest inside stirrup width is 10", (15 inches for #7 & #8 bar).**
- **Bends are limited to shapes that continue in the same circular direction. Otherwise lap splices are required.**

Due to the low E Modulus of GFRP bars, it is possible to field bend large radius shapes. Care must be taken to avoid bending stresses that exceed the ACI440 recommendation of 20% of ultimate sustained stress in the bar. For this reason, the minimum allowable radius for field curved GFRP bars is shown.

Available ACI Bends	
Dia.	Inside Bend Dia.
#2	3"
#3	4.25"
#4	4.25"
#5	4.5"
#6	4.5"
#7	6"
#8	6"



*Some bent shapes are made using appropriate lap splicing.*

## Large Radius Curves

Bar Diameter	Minimum Allowable Radius
#2 6mm	34" 864mm
#3 9mm	51" 1295mm
#4 13mm	67" 1702mm
#5 16mm	84" 2134mm
#6 19mm	101" 2565mm
#7 22mm	118" 2997mm
#8 25mm	135" 3429mm
#9 29mm	152" 3861mm
#10 32mm	186" 4267mm

# Design Considerations



In 2006, ACI committee 440 published ACI440.1R-06 "Guide for the Design and Construction of Concrete Reinforced with FRP Bars". To date, this represents the most authoritative guide on the subject of FRP reinforced concrete design. Other authoritative design guidance can be found in the Canadian CSA S806 Building Code and the Canadian Highway Bridge Design Code Section 16.

The designer should understand that a direct substitution between GFRP and steel rebar is not possible due to various differences in the mechanical properties of the two materials.

One difference is that all FRP's are linear elastic up to failure and exhibit no ductility or yielding. In traditional steel reinforced concrete design, a maximum amount of steel is specified so that the steel will yield and give warning of pending failure of the concrete member. ACI440.1R-06 gives the option of two failure modes to the designer, an over reinforced section where compression failure of the concrete is the preferred mode of failure. Or, failure by rupture of the FRP reinforcing in which case serviceability requirements, deflection and crack widths, must be satisfied in order to give a warning of pending failure. In either case, the suggested margin of safety against failure is higher than that used in traditional steel-reinforced concrete design.

Another major difference is that serviceability will be more of a design limitation in GFRP reinforced members than with steel. Due to its lower modulus of elasticity, deflection and crack widths will affect the design.

Outside of North America, the ASCE Journal of Composites has published design guidelines for GFRP Reinforced Concrete for Construction (Aug 1997 Vol.1 No 3 ISSN 1090-0268 Code: JCCOF2) based on the extensive work performed in Japan for the Japanese Ministry of Construction. Additional design guidelines have been published by the Canadian Highway Bridge Design Code; Section 16 "Fibre Reinforced Structures" and "Commentary for Section 16" and the Canadian CSA S806 Code for Buildings. Modifications to Norwegian Standard NS3473 when using fiber reinforced plastic (FRP) reinforcement, April 29, 1998. From the United Kingdom, the Institution of Structural Engineers, "Interim Guidance on the Design of Reinforced Concrete Structures Using Fibre Composite Reinforcement", August 1999. Active efforts are also underway for a European Eurocode 2 under the efforts of FIB Task Group 9.3 "FRP (Fibre Reinforced Polymer) Reinforcement for Concrete Structures. Links to many of these activities can be found via the Hughes Brothers web site.



*Test beam at Purdue University.*



*Concrete strain gauge for long term monitoring.*

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Hughes Brothers 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.

**Subjects covered in the ACI440.1R-06 design guide include:**

- Flexure
- Shear
- Temperature and Shrinkage Reinforcement
- Development Length and Splices

**Current knowledge restricts the use of FRP bars for:**

- Compression Reinforcement in both beams and columns
- Seismic Zones
- Moment Frames
- Zones where moment redistribution is required
- Structures subject to high temperature

**Lap Splice - Tension**

- As determined by 440.1R-06.



**Design Assistance**

To aid the designer unfamiliar with the new ACI440.1R-06 guide, Hughes Brothers engineering staff are available to assist you.



*Traditional construction methods are used.*



*Light weight of GFRP rebar aids installation.*



*Plastic coated wire ties are recommended. Nylon zip-ties may be used for completely non-magnetic applications.*

## Masonry Strengthening

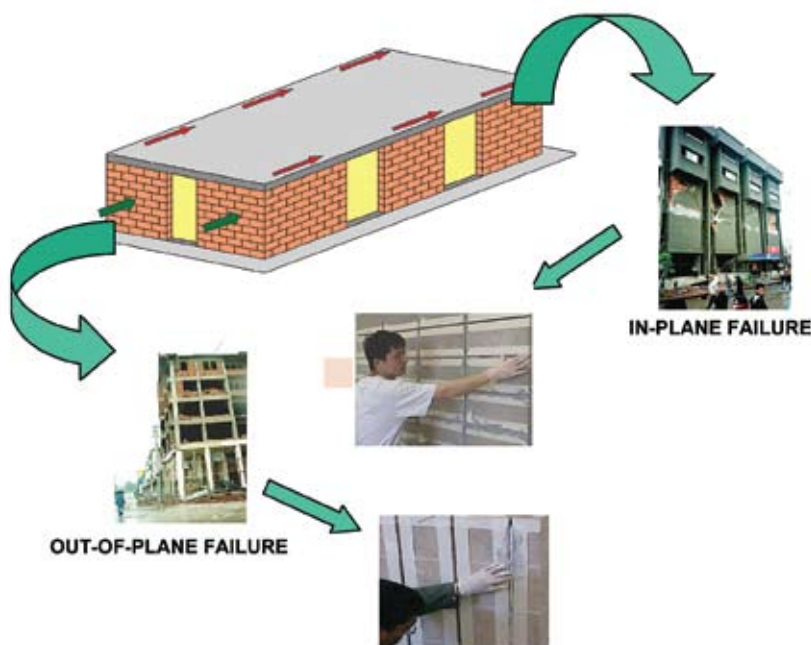
Aslan 100 GFRP bars can be used to increase the strength of existing unreinforced masonry walls in flexure (out-of-plane) and shear (in-plane).

This has important implications in areas that are subject to new seismic codes, hurricane wind loading or even blast mitigation schemes. In addition, Aslan 100 GFRP bars can be used to restore or increase the structural strength of existing masonry walls that have already cracked.

In many instances the strengthening procedure can maintain the visual appearance of the existing masonry, particularly in the case of shear reinforcing.

The technique used is known as “Near Surface Mount” or NSM strengthening. The procedure consists of:

- 1) grooving of slots having a width and depth of approximately 1.5 times the bar diameter,
- 2) cleaning the groove,
- 3) applying a structural epoxy or cementitious based paste into the groove,
- 4) insertion of the GFRP bar in the groove,
- 5) finishing for appearance.



If hollow Concrete Masonry Units (CMU) are being strengthened, the groove depth should not exceed the thickness of the masonry unit shell to avoid local fracture of the masonry. It is also recommended to mask off the groove to avoid staining the surrounding masonry during the application of epoxy or cementitious pastes.

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## Handling and Placement

- When necessary, cutting of GFRP rebars should be done with a masonry or diamond blade, grinder or fine blade saw. A dust mask is suggested when cutting the bars. It is recommended that work gloves be worn when handling and placing GFRP rebars.
- Sealing of cut ends is not necessary since any possible wicking will not ingress more than a small amount into the end of a rod.
- GFRP rebar has a very low specific gravity and may “float” in concrete during vibration. Care should be exercised to adequately secure GFRP in formwork using chairs, plastic coated wire ties or nylon zip ties.



*Traditional rebar chairs are used but with greater frequency. i.e. 2/3<sup>rd</sup>s spacing used with steel.*

## Quality Assurance

- To provide for lot or production run traceability, each lot is color coded.
- Individual rebars are tensile tested based on a random statistical sampling, with a minimum of 5 samples tested per production lot.
- Certifications of conformance are available for any given production lot.
- In addition, quality assurance tests are routinely performed to determine:
  - Glass content - i.e. impregnation ASTM D2584
  - Die wicking - checking for voids ASTM D5117
  - Barcol hardness ASTM D2583
  - Cross sectional area ASTM D7205
  - Mass uptake in water ASTM D570
  - Inter-laminar shear or shear in flexure ASTM D4475
  - Shear strength by double shear method. ACI 440.3R Method B.4
  - Tensile, modulus and strain per ASTM D7205



*Cutting should be done with fine blade saw, masonry, diamond blade or grinder. Shearing is NOT permitted.*



*Moisture uptake testing in lab.*

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