

# Advantages of Bundling FRP Rebar

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## Abstract:

Steel reinforcement of concrete has been used for just over two centuries. Iron, the primary element in steel, is the most commonly used metal and one of the least expensive. It has fairly high tensile strength, is relatively stiff, and is isotropic. Its primary shortcomings are its weight and that it is easily corroded, and corrosion of reinforcing steel often results in structural failure. Recently, there has been a significant amount of interest in using non-corroding FRP rebar to overcome the issues of corrosion and weight. Because of its differing mechanical properties from steel, design and construction methods have been developed. ACI 440 contains design guidance for the use of FRP in reinforced concrete design.

Both FRP rebar and steel rebar may be bundled in accordance with ACI guidelines. This paper looks at the advantages of bundling FRP rebar, particularly basalt FRP (BFRP) rebar (GatorBar®) as manufactured by Neuvokas Corp., as a further way of reducing weight, reducing installation labor, overcoming the lower guaranteed tensile strength ( $f_{tu}^*$ ) of larger bar sizes, and providing other advantages. This paper presents the potential advantages of bundling BFRP rebar and concludes that this may be a preferred method of design and construction in many instances.

*Keywords:* Reinforced concrete, bundling, modulus of elasticity, FRP, BFRP, basalt, tensile reinforcement.

## OVERVIEW

The use of FRP rebar is becoming more common and many in the concrete industry believe it is the wave of the future because of its superior chemical and mechanical properties. A harbinger of this belief is the recent purchase by Owens-Corning of the Aslan brand of FRP rebar from Hughes Brothers, indicating their desire to play a major role in this trend.

A further factor in FRP rebar gaining attention in the construction industry is that its environmental footprint is much less than steel, with up to 50% less emissions in precast panels.<sup>i</sup> Consideration of LEED and Institute for Sustainable Infrastructure standards in project design and planning will create even further interest in FRP rebar.

For decades, FRP rebar has been almost exclusively used in specialized situations, such as where:

- extreme chloride corrosion protection (exposure to deicing chemicals or marine environments) is required, such as bridge decks and seawalls,
- other corrosive environments (chemical or wastewater containment) are encountered,
- interference with electromagnetic fields or radio frequency is problematic, such as MRI rooms, toll plazas, and radio transmission facilities,
- high voltages or stray currents are a problem, such as substations, duct banks, and dairy barns
- rust staining is an aesthetic concern, such as architectural panels,

- future penetration of cast in place concrete must occur as in tunneling to create “soft eyes”, and
- rock bolting must occur in corrosive environments

For corrosion protection, epoxy coated steel (ECR) has been most commonly used, since it is lower cost than FRP rebar or other corrosion resistant reinforcements. However, it has been found to not provide the degree of corrosion protection needed in many applications, leaving stainless steel, corrosion resistant steels, and FRP as the preferred alternatives to epoxy coated steel<sup>iiiii</sup>. And in some jurisdictions, epoxy coated steel is not allowed, forcing the use of these alternative reinforcements.<sup>iv</sup> All of these alternatives can be more expensive than epoxy coated steel. Although on a life-cycle cost basis, they can be lower in cost where corrosion is a concern.<sup>v</sup>

For applications requiring electromagnetic or radio frequency transparency, FRP has been almost exclusively used.

Recent technological advances, however, have reduced the cost of FRP rebar, and one manufacturer, Neuvokas Corp., is using a patented high-speed process to produce basalt FRP (BFRP) at a cost competitive with black steel. This “sea change” potentially takes FRP out of the niche markets that it has inhabited and makes it a worthy competitor in nearly all reinforced concrete construction.

With FRP rebar use likely to become more common-place, this paper looks at its unique properties and suggests that bundling, as a design consideration, will result in superior structures. With FRP approaching a cost competitive with steel and with less labor, the

intrinsic advantages of FRP rebar can be realized. For general reinforced concrete structures these advantages are that FRP rebar is much lighter than steel creating advantages in lightening completed structure weight, reducing labor and machinery costs, and because of its corrosion resistant properties the potential of reducing concrete cover and increasing structure life.

## BUNDLING DESIGN

Bundling of steel rebar has long been permitted by the major code agencies, but has not been commonly used. Primarily, this is because of the additional labor required to field tie and handle bundles, without any significant improvement in structural properties. Bundling, however, is sometimes used in heavily reinforced structures where uniform spacing would present difficulties in getting concrete thoroughly consolidated and distributed.

It has been found that bundling up to four bars results in them functioning as an equivalent area single bar, with certain differences.<sup>vi</sup> The ACI Code allows bundling of rebars in up to four-bar bundles, but does increase the development length based on the number of bars in a bundle<sup>vii</sup>. This is true whether the reinforcement is steel or FRP (ACI 318 and ACI 440). Further, ACI 318 7.6 allows bundling bars no larger than #11 bars, and requires enclosing stirrups or ties.

FRP rebar while it has higher tensile strength than steel its guaranteed tensile strength,  $f_{tu}^*$ , decreases with size. One manufacturer publishes a decline from 120 ksi for a #3 bar to 80 ksi for a #10 bar. Using smaller bundled FRP bars will increase the tensile strength of a given reinforcement ratio when compared to a larger single bar, decreasing the amount of bar required. This is the primary reason for considering bundling of FRP rebar.

Also, bundling of rebar has advantages in terms of reducing bond stress, potentially increasing rebar spacing in congested members, or allowing narrower, more aesthetically pleasing structural members.<sup>viii</sup> The bond dependent coefficient describes the bond created between tension reinforcement and concrete relative to a crack width in a prescribed flexural beam. It is calculated based on the following formula.

$$k_b = \frac{w}{2\varepsilon_f\beta\sqrt{d_c^2 + \left(\frac{s}{2}\right)^2}}$$

where:

$k_b$ : bond dependent coefficient

$w$ : maximum crack width (mm).

$\varepsilon_f$ : average measured strain in the longitudinal bars

$\beta$ : ratio of distance from neutral axis to extreme tension fiber to distance from neutral axis to center of tensile reinforcement (calculated using strain compatibility)

$d_c$ : thickness of concrete cover measured from extreme tension fiber to center of bar (mm)

$s$ : longitudinal bar spacing (mm)

From this equation it may be seen that for a given allowable crack width in a particular beam, the tension reinforcement will experience a certain average strain. It also may be seen that the lower the bond dependent coefficient the higher the average strain to achieve a given crack width and that they are inversely proportional.

Recent testing of Neuvokas basalt fiber rebar with two different coatings (#3 size) by the University of Nebraska has shown the  $k_b$  to be 0.67 for a sand coating and 0.8 for uncoated bar.<sup>ix</sup> For steel bar  $k_b$  is approximately 1.0. The conclusion being that BFRP in this size, used as tensile reinforcement in a flexural beam, can be

subjected to 1.25 to 1.5 times the average strain as steel at the same crack width. This is consistent with previous testing that has shown that the bond of FRP rebar to concrete is superior to steel, measured using direct pullout tests and flexural beam tests<sup>x</sup> to measure bond strength.

Surface area for purposes of calculating bond strength is relatively easily determined for a single bar, but for bundled bars the entire surface area of each bar, with some of the surface area being interior to the bundle, cannot be bonded to the concrete to the same extent as the exterior. A Texas DOT study<sup>xi</sup> found that the surface on the exterior of the bundle could be used to calculate bond strength of a bundle, if the bond strength of a single bar is known.

ACI 318 R 12.4.2 states that, “Development length of bundled bars increased by 20% for three bar bundles and 33% for four bar bundles. The cover and spacing criteria are derived from the equivalent bar diameter of a single bar.”

So for reasons of gaining higher tensile strength and greater bond, bundling of FRP rebar is a recommended design consideration.

### **BUNDLING CAN REDUCE INVENTORY**

With just #3, #4 and #5 bars all bar sizes between #3 and #10 can be replicated with very little excess cross sectional area, using bundling. In many cases, this can be done with very little excess material as shown in Table 1 following:

**Table 1 - Bundled Bars for Equivalent Single Bar**

<b>Bar Size</b>	<b>Area, in<sup>2</sup></b>	<b>Bundled Bars</b>	<b>Area, in<sup>2</sup></b>	<b>Bundled Area/Single Bar Area</b>
#3	0.110	1 - #3	0.110	1.00
#4	0.196	1 - #4	0.196	1.00
#5	0.307	1 - #5	0.307	1.00
#6	0.442	4 - #3	0.442	1.00
#7	0.601	2 - #5	0.614	1.02
#8	0.785	4 - #4	0.785	1.00
#9	0.994	3 - #5 & 1 - #3	1.031	1.04
#10	1.227	4 - #5	1.227	1.00

### **OTHER BENEFITS**

FRP rebar also has a longitudinal coefficient of thermal expansion that is similar to concrete. The higher coefficient of thermal expansion of steel than concrete has resulted in concrete pops and spalling in pavements exposed to higher temperature differentials. FRP rebar has a coefficient of thermal expansion nearly identical to concrete and thus little or no differential in expansion can occur. In pavements where either high ambient temperatures or large differential ambient temperatures are experienced, this is an important consideration in reducing maintenance costs and poor ride quality.

## SUMMARY

- FRP rebar is likely to become more commonly used as its cost decreases and the industry becomes more familiar with design of reinforced concrete structures using FRP rebar.
- FRP rebar is environmentally less impactful than steel and can assist in meeting higher LEED and ISI Envision ratings.
- FRP rebar has some unique properties that make bundling more attractive as a design consideration than for steel rebar.

- Because of declining FRP rebar tensile strength with bar diameter, bundling can lead to higher overall reinforcement tensile strength.
- Bundling results in greater surface area for bonding.
- Bundling can reduce inventory requirements.

For these reasons, it is recommended that bundling be considered during the design of reinforced concrete structures using FRP rebar.

## ENDNOTES

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