

FIBER-REINFORCED POLYMER REBAR

The bar developed at Cornell University is made from fiber reinforced polymer laminated composite panel. The panel is manufactured in three layers; a core layer with transverse ribs and two cover layers bent over the ribs. The bar is cut from the panel to the desired width, in rectangular cross-sections. Composite bars do not corrode and are easier (much lighter than steel) to install into forms. Bars made from commercially carbon prepreg have tensile strength about 2 to 3 times that of Grade 60 steel, (the US standard rebar of 60 ksi yield strength) and are about 5 times lighter, for same cross-section. Therefore, one (1) lb of carbon bar can substitute about 10 to 15 lb of steel rebar in a concrete structure. At this rate the carbon composite rebars could compete with steel bars in structures where corrosion is an issue such as bridge decks, parking structure, pavements, roads, marine structures, and building facades. The bar is a proven success and should have a positive effect, especially for reinforcing concrete bridge decks.

This bar has three main innovative features in comparison with other composite rebars:

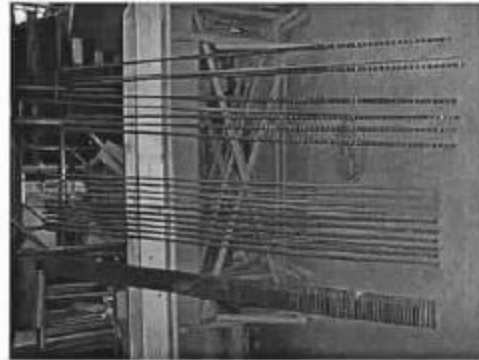
1. **Improved mechanical bond to concrete.** This bar, as a result of its construction, expands laterally under tension. (It should be noted that the diameter of steel bars or other composite bars loaded in tension decreases slightly due to Poisson's ratio.) When this bar is embedded in concrete the lateral expansion induces stresses on concrete at the bar concrete interface. The result of this behavior is a strong mechanical bond to concrete. Strong bond to concrete is the key quality of any reinforcing bar. Test results show that bars having 1.0 inch by 0.5 inch cross-section dimensions made of carbon fiber/polymer composites, embedded in normal strength concrete, developed about 2500 to 3000 psi bond strength. As a result, this laminated ribbed bar satisfies the American Concrete Institute requirements for anchorage of straight bars embedded in concrete.
2. **Ductility.** The key mechanical properties, the tensile strength, the stiffness and the ductility are determined by the proportion of the core thickness to the cover layers thickness and the rib size and spacing. Thus, the design of the bar can be tailored to meet strength, stiffness and ductility requirements.
3. **Variable cross-section.** The bar can be made with variable thickness (by varying the number of layers along the length in the core layer of the panel) offering an efficient use of the material for reinforcing beams and bridge decks in which the bending moments are variable along the length. With this bar "we can put the material where the stresses are". This quality translates into about 30% saving of bar material (cost) for reinforcing bridge decks.

Test results of concrete beams reinforced with carbon laminated bars show excellent flexural behavior, both in term of strength and ductility. We also designed and built a pedestrian bridge in Ithaca, NY, of 42-ft span with 8 ft wide and 5.5 inches thick deck. The bridge deck is reinforced with carbon laminated composite bars with variable cross section placed at a depth $d = 4.5$ inches. The strength and stiffness of the bridge satisfies the design specifications.

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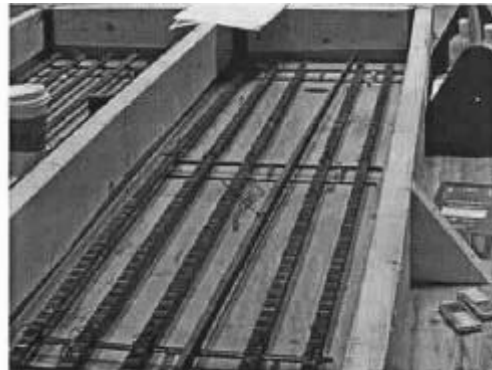
Carbon composite panels



Bars cut from panels



Beam reinforced with carbon FRP tested to failure



FRP rebar for bridge panels



Installation of Carl Sagan Pedestrian Bridge in Ithaca, New York (June 2000)