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Emerging Technology Series

Prestressing Concrete Structures with FRP Tendons

Reported by ACI Committee 440

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Prestressing Concrete Structures with FRP Tendons

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Fiber-reinforced polymers (FRPs) have been proposed for use instead of steel prestressing tendons in concrete structures. The promise of FRP materials lies in their high-strength, lightweight, noncorrosive, nonconducting, and nonmagnetic properties. This document offers general information on the history and use of FRP for prestressing applications and a description of the material properties of FRP. The document focuses on the current state of design, development, and research needed to characterize and ensure the performance of FRP as prestressing reinforcement in concrete structures. The proposed guidelines are based on the knowledge gained from worldwide experimental research, analytical work, and field applications of FRPs used as prestressed reinforcement. The current development includes a basic understanding of flexure and axial prestressed members, FRP shear reinforcement, bond of FRP tendons, and unbonded or external FRP tendons for prestressing applications. The document concludes with a description of research needs.

Keywords: anchorage; bond length; crack; deflection; deformation; development length; ductility; fatigue; jacking stresses; post-tensioning; prestressed concrete; pretensioning; reinforcement ratio; shear; tendon.

CONTENTS

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CHAPTER 1—INTRODUCTION

Fiber-reinforced polymer (FRP) composites have been proposed for use as prestressing tendons in concrete structures. The promise of FRP materials lies in their high-strength, lightweight, noncorrosive, nonconducting, and nonmagnetic properties. In addition, FRP manufacturing, using various cross-sectional shapes and material combinations, offers unique opportunities for the development of shapes and forms that would be difficult or impossible with conventional steel materials. Lighter-weight materials and preassembly of complex shapes can boost constructibility and efficiency of construction. At present, the higher cost of FRP materials suggests that FRP use will be confined to applications where the unique characteristics of the material are most appropriate. Efficiencies in construction and reduction in fabrication costs will expand their potential market. FRP reinforcement is available in the form of bars, grids, plates, and tendons. This document examines both internal and external prestressed reinforcement in the form of tendons.

One of the principal advantages of FRP tendons for prestressing is the ability to configure the reinforcement to meet specific performance and design objectives. FRP tendons may be configured as rods, bars, and strands as shown in Fig. 1.1. The surface texture of FRP tendons may vary, resulting in bond with the surrounding concrete that varies from one tendon configuration to another. Unlike conventional steel reinforcement, there are no standardized shapes, surface configurations, fiber orientation, constituent materials, and proportions for the final products. Similarly, there is no standardization of the methods of production, such as pultrusion, braiding, filament winding, or FRP preparation for a specific application. Thus, FRP materials require considerable engineering effort to use properly. Bakis (1993) has outlined manufacturing processes.

FRP tendons are typically made from one of three basic fibers. These fibers are aramid, carbon, and glass. Aramid fibers consist of a semicrystalline polymer known as aromatic polyamide. Carbon fibers are based on the layered graphene (hexagonal) networks present in graphite, while glass generally uses either E-glass or S-glass fibers. E-glass is a low-cost calcium-aluminoborosilicate glass used where strength, low conductivity, and acid resistance are important. S-glass is a magnesium-aluminosilicate glass that has higher strength, stiffness, and ultimate strain than E-glass. S-glass costs more than E-glass, and both are susceptible to degradation in alkaline environments. Table 1.1 gives properties of typical fibers.

The selection of the fiber is primarily based on consideration of cost, strength, stiffness, and long-term stability. Within these fiber groups, different performance and material characteristics may be achieved. For example, aramids may come in low, high, and very high modulus configurations. Carbon fibers are also available with moduli ranging from below that of steel to several multiples of that of steel. Of the several fiber types, glass-based FRP reinforcement is least expensive and generally uses either E-glass or S-glass fibers.