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Guide to Design with Fiber-Reinforced Concrete

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New developments in materials technology and the addition of field experience to the engineering knowledge base have expanded the applications of fiber-reinforced concrete (FRC). Fibers are made with different materials and can provide different levels of tensile/flexural capacity for a concrete section, depending on the type, dosage, and geometry. This guide provides practicing engineers with simple, yet appropriate, design guidelines for FRC in structural and nonstructural applications. Standard tests are used for characterizing the performance of FRC and the results are used for design purposes, including flexure, shear, and crack-width control. Specific applications of fiber reinforcement have been discussed in this document, including slabs-on-ground, composite slabs-on-metal decks, pile-supported ground slabs, precast units, shotcrete, and hybrid reinforcement (reinforcing bar plus fibers).

Keywords: crack control; fiber-reinforced concrete; flexural toughness; macrofiber; moment capacity; precast; residual strength; shear capacity; shotcrete; slabs-on-ground; steel fibers; synthetic fibers; tensile strength; toughness.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

The aim of this guide is to provide practicing engineers with design guidelines and recommendations for fiber reinforcement. Several approaches for designing fiber-reinforced concrete (FRC) have been developed over the years that are based on conventional design methods modified by special procedures to account for contributions of the fibers. These methods generally modify the internal forces in the member to account for the additional tensile capacity provided by the fibers. When compared with full-scale test data, these methods have provided satisfactory designs for FRC members (Parra-Montesinos 2006; Moccichino et al. 2006; Altoubat et al. 2009).

Concrete is a brittle material that is strong in compression but weak in tension. Steel bars are traditionally used to carry the tensile forces after concrete has cracked in structural applications. In reinforced concrete, the tensile strain of the concrete at cracking is much lower than the yield strain of the steel bars, which results in cracking of concrete before any significant load is transferred to the steel. Steel reinforcement is also used to limit the crack widths under specified levels for serviceability requirements. Unlike reinforcing bars, fibers are uniformly distributed in the volume of concrete; hence, the distance between fibers is much smaller than the spacing between bars. Fibers can provide post-crack tensile and flexural capacity and crack-width control in concrete elements.

Natural sources of reinforcement were used for brittle construction materials more than 3000 years ago, such as straw reinforcement in mud bricks. The first scientific studies on the use of steel fibers in concrete date back to the 1960s (Romualdi and Batson 1963; Naaman and Shah 1976). Since then, thousands of projects have been successfully completed using fiber reinforcement, including slabs-on-ground, composite steel decks, slabs-on-pile, precast, and shotcrete.

The major differences in the proposed methods are in the determination of the increase in tensile capacity of concrete provided by the fibers and the manner in which the total force is calculated. A conservative but justifiable approach in structural members such as beams, columns, walls, or elevated suspended slabs is that reinforcing bars should be used to support the total tensile loads. ACI 544.6R, however, describes the design for elevated suspended slabs where steel fibers are used as the primary reinforcement along with a minimum of continuous bars from columns to columns. Fibers can be used, in general, to supplement and reduce the reinforcing bars in various structural members. In applications where the presence of continuous reinforcement is not essential to the safety and integrity of the structure such as slabs-on-ground, pavements, overlays, shotcrete linings, slabs-on-piles (ACI 544.6R), and some precast units, fibers may be used as the sole means of reinforcement.

Fibers reliably control cracking and improve material resistance to deterioration as a result of fatigue, impact, and shrinkage, or thermal stresses. Fibers can contribute to the improved performance of concrete members in two ways: 1) by resisting the tensile stresses and, therefore, playing a structural role; or 2) by controlling crack development and, therefore, improving the durability of concrete. When fibers are intended to contribute to the structural performance of an element or structure, the FRC should be designed accordingly and the fiber contribution to the load-bearing capacity should be properly assessed and justified.

The commercial momentum for using steel fibers occurred during the 1970s for industrial floors as a major application. Other applications for steel fibers include composite metal