IN-LB	Inch-Pound Units
SI	International System of Units

Fiber-Reinforced Shotcrete—Guide

Reported by ACI Committee 506

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This guide describes the technology and applications of fiber-reinforced shotcrete (FRS) with a focus on synthetic and steel macrofibers. It serves as a bridge between information given in documents reported by ACI Committee 506 and ACI Committee 544. Proportions of typical mixtures, batching, mixing, and application procedures are described, including modification of mixture proportions and equipment needed for FRS. General performance criteria of FRS, particularly postcracking flexural strength and toughness, are described along with other typical properties and benefits, such as increased resistance to shrinkage cracking and impact resistance. Corresponding test methods are also discussed. The document presents general FRS design considerations. Applications of FRS are described, including construction and repair of tunnel and mining linings, slope stabilization, retaining structures, fire-explosive-spalling-resistant linings, and architectural structures. The report also gives guidance on the specification and quality control of FRS.

Keywords: fiber-reinforced shotcrete; fibers; linings; mining; repair; shotcrete; steel fibers; synthetic fibers; tunneling.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Fiber-reinforced shotcrete (FRS) is shotcrete containing discontinuous discrete fibers. Continuous meshes, woven fabrics, and long rods are not considered as discrete fiber-type reinforcing elements covered in this guide. FRS is used in a wide range of applications and is popular for its versatility as a construction material and placement process. FRS is primarily used in applications where its geometrical flexibility and safe application provides advantages over conventional steel bar or mesh reinforcement or where only limited structural tensile forces are expected.

FRS with steel fibers was first placed in North America early in 1971 in experimental work directed by Lankard et al. (1971). Steel FRS (SFRS) was proposed for underground support by Parker (1974). Additional trials were made by Poad et al. (1975) in an investigation of new and improved methods of using shotcrete for underground support. Subsequently, the first practical application of SFRS was made in a tunnel adit at Ririe Dam, ID, in 1973 (Kaden 1977). Since that time, SFRS has been used throughout the world. Shotcrete using micropolypropylene fibers was first placed in Europe in 1968 (Hannant 1978). Macrosynthetic fibers for use in shotcrete were developed in the mid-1990s and have since increasingly been used in mining, tunnel, and slope stabilization projects (Morgan and Heere 2000; Nitschke and Winterberg 2016).

1.2—Scope

This guide provides information and guidance on fiber-reinforced shotcrete (FRS) with a focus on synthetic and steel macrofibers. Topics covered include materials used, mixture proportions, production of FRS, performance criteria, testing procedures, design considerations, specifications, and examples of several applications. Although portions of the conventional shotcrete and fiber-reinforced concrete (FRC) practice apply to FRS, this document discusses specific aspects that are essential for FRS applications.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

C	=	equivalent compressive force on a cross section, lbf (kN)
CMOD	=	crack mouth opening displacement, in. (mm)
d	=	height of the cross section, in. (mm)
f_c	=	compressive strength of concrete, psi (MPa)
$f_{t1,2,3}$	=	residual flexural strengths of FRC, psi (MPa)
LOP	=	limit of proportionality, psi (MPa)
M	=	resulting moment, lb-in. (N-mm)
m	=	dimensionless moment
N	=	resulting normal force, lbf (kN)
n	=	dimensionless normal force
T	=	equivalent tension force on a cross section, lbf (kN)
Z_C	=	distance from the neutral axis to the equivalent compressive force, lbf (kN)
Z_T	=	distance from the neutral axis to the equivalent tension force, lbf (kN)
ε_c	=	compressive strain
ε_t	=	tensile strain
κ	=	cross section's curvature, ft^{-1} (m^{-1})
$\kappa_{max\ c}$	=	cross section's maximum curvature related to compressive failure, ft^{-1} (m^{-1})
$\kappa_{max\ t}$	=	cross section's maximum curvature related to tensile failure, ft^{-1} (m^{-1})
σ_c	=	compressive stress, psi (MPa)
σ_t	=	tensile stress, psi (MPa)

2.2—Definitions

Please refer to the latest version of ACI Concrete Terminology for a comprehensive list of definitions. Definitions provided herein complement that resource.

denier—measure of fiber linear mass density, taken as the mass in grams of 29,528 ft (9000 m) of the fiber.

fiber balling—formation of large clumps of entangled fibers that may occur before or during the mixing process.

Fig. 3.2a—Examples of steel fibers.

CHAPTER 3—MATERIALS

3.1—General

Fiber-reinforced shotcrete (FRS) is shotcrete containing dispersed, randomly oriented fibers. Materials for use in FRS should conform to the requirements of ASTM C1436, which covers the typical materials used in shotcrete, including chemical admixtures, supplementary cementitious materials, fibers, and the combined grading of aggregates for fine and coarse aggregates. Useful information about the materials for use in shotcrete is presented in ACI 506R. Requirements for the use of shotcrete can be found in ACI 318.

3.2—Fibers

Fibers used in shotcrete are generally classified by the material they are made of and by their size. They are divided into two groups by their size: microfibers and macrofibers. In this guide, focus is kept on steel and synthetic macrofibers because they are the most frequently used for structural purposes in shotcrete. Additional information regarding the use of microfibers in concrete can be found in ACI 544.1R, ACI 544.2R, ACI 544.3R, ACI 544.4R, ACI 544.5R, and ACI 544.9R. Another parameter to characterize macrofibers is the fiber aspect ratio (ACI 544.4R). Typical fiber aspect ratios of macrofibers for shotcrete range from 40 to 65 for common fiber lengths used for shotcrete. The length of fibers used in shotcrete applications is typically shorter than in cast-in-place applications and is primarily limited by the shotcrete hose diameter and shotcreting equipment used. Aspect ratio and length of fibers can affect their reinforcing performance in FRS (ACI 544.4R). Fibers for use in shotcrete should meet the requirements of ASTM C1116/C1116M. General information on the use of fibers in concrete can be found in ACI 544.1R, ACI 544.2R, ACI 544.3R, ACI 544.4R, ACI 544.5R, and ACI 544.9R. Figures 3.2a and 3.2b illustrate typical steel and synthetic macrofibers being used in shotcrete.

3.2.1 *Microfibers*—Microfibers are defined as fibers with an equivalent diameter less than 0.012 in. (0.3 mm)

Fig. 3.2b—Examples of synthetic macrofibers.

for use in shotcrete and are normally polyolefin-based. If the microfibers are used to mitigate explosive spalling in fires by melting and providing void space, then fibers should be polypropylene, with equivalent diameters less than 0.0013 in. (33 μm) and lengths equal to or less than 0.5 in. (12 mm) (Tatnall 2002) (6.4.8). Synthetic microfibers lengths vary from 0.25 to 2 in. (6 to 50 mm). Microsynthetic fibers are also added to minimize plastic shrinkage cracks (Nitschke and Winterberg 2016).

The term denier is often used to indicate the fineness of microfibers. A typical synthetic shotcrete microfiber to minimize plastic shrinkage cracks has a denier of 6, which results in an equivalent diameter of 0.0012 in. (32 μm).

3.2.2 *Macrofibers*—Macrofibers are defined as fibers with an equivalent diameter greater than or equal to 0.012 in. (0.3 mm) for use in shotcrete. The majority of macrofibers used in shotcrete are either steel or synthetic fibers.

3.2.2.1 *Steel macrofibers*—Steel macrofibers used in shotcrete are generally between 0.7 to 1.4 in. (18 to 36 mm) in length and 0.016 to 0.03 in. (0.4 to 0.8 mm) in equivalent diameter. Steel fibers should conform to ASTM A820/A820M.