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Report on the Physical Properties and Durability of Fiber-Reinforced Concrete

Reported by ACI Committee 544

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This document addresses the physical properties and durability of fiber-reinforced concrete (FRC). The effects of fiber reinforcement are evaluated for various physical, short-term, and long-term benefits they impart to the concrete mixture. A variety of test methods, conditions, and properties are reported. The various properties listed, in addition to the wide variety of the choices available in formulating matrix systems, allow performance-based specification of concrete materials using fibers to become a viable option. This document provides a historical basis and an overview of the current knowledge of FRC materials for tailoring new, sustainable, and durable concrete mixtures.

This document is divided into three sections. The first section discusses the physical properties of FRC in terms of electrical, magnetic, and thermal properties. Rheological properties, which affect fiber dispersion and distribution, are discussed using both empirical and quantitative rheology. Mechanisms of creep and shrinkage and the role of various fiber types in affecting both plastic shrinkage cracking and restrained shrinkage cracking are also addressed. The durability of concrete as affected by the addition of fibers is documented under freezing and thawing, corrosion resistance, and scaling. The durability of FRC systems is also affected as different fibers respond differently to the highly alkaline cementitious microstructure. The durability of alkali-resistant glass and cellulose fibers are studied by an in-depth evaluation of long-term accelerated aging results. Degradation and embrittlement due to alkali attack and bundle effect are discussed. Recent advances for modeling and design of materials with aging characteristics are presented. Literature on the use of FRC materials under aggressive environments, extreme temperatures, and fire is presented. The final sections list a series of applications where the use of FRC has resulted in beneficial durability considerations.

Keywords: aging; chloride permeability; corrosion; cracking; creep; diffusion; degradation; ductility; durability; electric properties; embrittlement; fiber-reinforced cement-based materials; fiber-reinforced products; fire resistance; flexural strength; freezing-and-thawing; glass; microcracking; permeability; plastic shrinkage; polypropylene; polyvinyl alcohol; reinforcing materials; rheology; shrinkage cracking; steel; sulfate attack; thermal conductivity; toughness; water permeability; wood pulp.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

The use of fibers in concrete to improve pre- and post-cracking behavior has gained popularity. Since 1967, several different fiber types and materials have been successfully used in concrete to improve its physical properties and durability. This is supported by an extensive number of independent research results showing the ability of fibers to improve durability and physical properties of concrete. Regardless of origin, cracking, when induced by chemical, mechanical, or environmental processes, results in deteriorated and less-durable concrete. In addition, the increased permeability caused by cracking can accelerate other deterioration processes such as freezing-and-thawing damage, again resulting in less-durable concrete.

This report addresses the physical properties and durability of FRC that includes fibers in concrete. In this report, many structural systems are evaluated for various physical, short-term, and long-term benefits. These effects of using fibers have been determined using various testing methods. Many needed tests are not described by existing ASTM standards and similar standards due to the diverse nature of test methods, conditions, and properties reported. It would be a daunting task to address every project in an effort to develop correlations across the various test results. This report presents a limited collection of the published research results in relevant area. With the exception of a few characteristic responses such as creep, plastic shrinkage cracking, and long-term aging, this report does not address the mechanical properties in detail. The justification for this treatment is that topics such as mechanical properties and testing methods are addressed by subcommittees. The broader category of physical properties is in context to specific chapters.

There are several fiber types on the market intended to address various design requirements and constraints. Table 1.1

Table 1.1—A compilation of mechanical properties of commonly used fibers in concrete materials*

Type of fiber	Equivalent diameter, mm	Specific gravity, kg/m^3	Tensile strength, MPa	Young's modulus, GPa	Ultimate elongation, %
Acrylic	0.02 to 0.35	1100	200 to 400	2	1.1
Asbestos	0.0015 to 0.02	3200	600 to 1000	83 to 138	1.0 to 2.0
Cotton	0.2 to 0.6	1500	400 to 700	4.8	3.0 to 10.0
Glass	0.005 to 0.15	2500	1000 to 2600	70 to 80	1.5 to 3.5
Graphite	0.008 to 0.009	1900	1000 to 2600	230 to 415	0.5 to 1.0
Aramid	0.010	1450	3500 to 3600	65 to 133	2.1 to 4.0
Nylon	0.02 to 0.40	1100	760 to 820	4.1	16 to 20
Polyester	0.02 to 0.40	1400	720 to 860	8.3	11 to 13
Polypropylene (PP)	0.02 to 1.00	900 to 950	200 to 760	3.5 to 15	5.0 to 25.0
Polyvinyl alcohol (PVA)	0.027 to 0.66	1300	900 to 1600	23 to 40	7 to 8
Carbon (standard)	—	1400	4000	230 to 240	1.4 to 1.8
Rayon	0.02 to 0.38	1500	400 to 600	6.9	10 to 25
Basalt	0.0106	2593	990	7.6	2.56
Polyethylene	0.025 to 1.0	960	200 to 300	5.0	3.0
Sisal	0.08 to 0.3	760 to 1100	228 to 800	11 to 27	2.1 to 4.2
Coconut	0.11 to 0.53	680 to 1020	108 to 250	2.5 to 4.5	14 to 41
Jute	0.1 to 0.2	1030	250 to 350	26 to 32	1.5 to 1.9
Steel	0.15 to 1.00	7840	345 to 3000	200	4 to 10

*Data from Nawy (1996), Kuraray (2007), Saechtling (1987), Sim et al. (2005), Toledo et al. (2000), and Balaguru and Shah (1992).
Notes: 1 mm = 0.039 in.; 1 kg/m^3 = 0.06 lb/ft^3; 1 MPa = 145 psi; 1 GPa = 1,450,000 psi.