Report on Measuring Mechanical Properties of Hardened Fiber-Reinforced Concrete

Reported by ACI Committee 544

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American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

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*Members of subcommittee who contributed to this report.
†Chair of the subcommittee that developed this report.
‡Consulting members who contributed to this report.

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This report provides a synopsis of the existing testing methodologies for the determination of mechanical properties of hardened fiber-reinforced concrete (FRC). This report applies to the mechanical properties of conventionally mixed and placed FRC, including fiber-reinforced self-consolidating concrete (FRSCC), or fiber-reinforced shotcrete (FRS) using steel, glass, polymeric, and natural fibers.

The objective is to enable manufacturers to characterize the mechanical properties of hardened FRC and encourage researchers and testing laboratories to adopt common and unified test methods to build a meaningful database of mechanical properties of hardened FRC materials and products. Test results from the test procedures used in this report are not intended for the design of FRC structures, but to gain a better understanding of factors influencing the determination of their mechanical properties and of FRCs and FRC products.

Keywords: compressive strength; fiber pullout; fiber-reinforced concrete; flexural fatigue resistance; flexural strength; impact resistance; multiaxial behavior; shear and torsion; tensile strength; toughness.

CONTENTS

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

The use of fiber-reinforced concrete (FRC) has evolved from small-scale applications to routine factory and field applications that involve the global use of tens of millions of cubic yards (meters) annually. This growth of application, in conjunction with new fibers, admixtures, and mixture designs, has created an urgent need to review existing test methods and, where necessary, develop new methods for determining the fresh and hardened properties of FRC.

1.2—Scope

This report documents the determination of mechanical properties of hardened FRC. The objective is to characterize these mechanical properties and encourage common and unified test methods. This objective builds a meaningful database of mechanical properties of hardened FRC materials and products. Further, the results should not be taken out of the context presented for illustrating the tests and not for comparing fibers out of context. The results from the tests and procedures used in this document are not intended to be used for the design of FRC structures. The purpose of this document is to gain a better understanding of the many factors influencing tests for the determination of mechanical properties of FRCs and FRC products.

Although most of the test methods described in this report were developed initially for steel FRC (SFRC), they are applicable to concretes reinforced with glass, synthetic/polymeric, and natural fibers, except when noted. In Fig. 1.2, an example of different types of fibers commonly employed in FRC is provided.

This report applies to the mechanical properties of conventionally mixed and placed FRC or fiber-reinforced shotcrete (FRS) using steel, glass, synthetic/polymeric, and cellulose/natural fibers.

Some newer test methods and evaluation procedures under development are not included in this report. Examples of this are tensile creep and flexural creep of concrete where the section has cracked and the bridging fibers are carrying loads.

This report does not discuss test methods for thin glass FRC or mortar products produced by the spray-up process. The Prestressed Concrete Institute (PCI MNL 128) and the International Glassfibre Reinforced Cement Association (2016a,b) have prepared recommendations for test methods for these spray-up materials.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

a, b = dimensions, in. (mm)
b = width, in. (mm)
d = depth, in. (mm)
d_f = fiber diameter, in. (mm)
f_1 = first cracking nominal stress (as from results of flexural tests according to ASTM C1609/C1609M), psi (MPa)

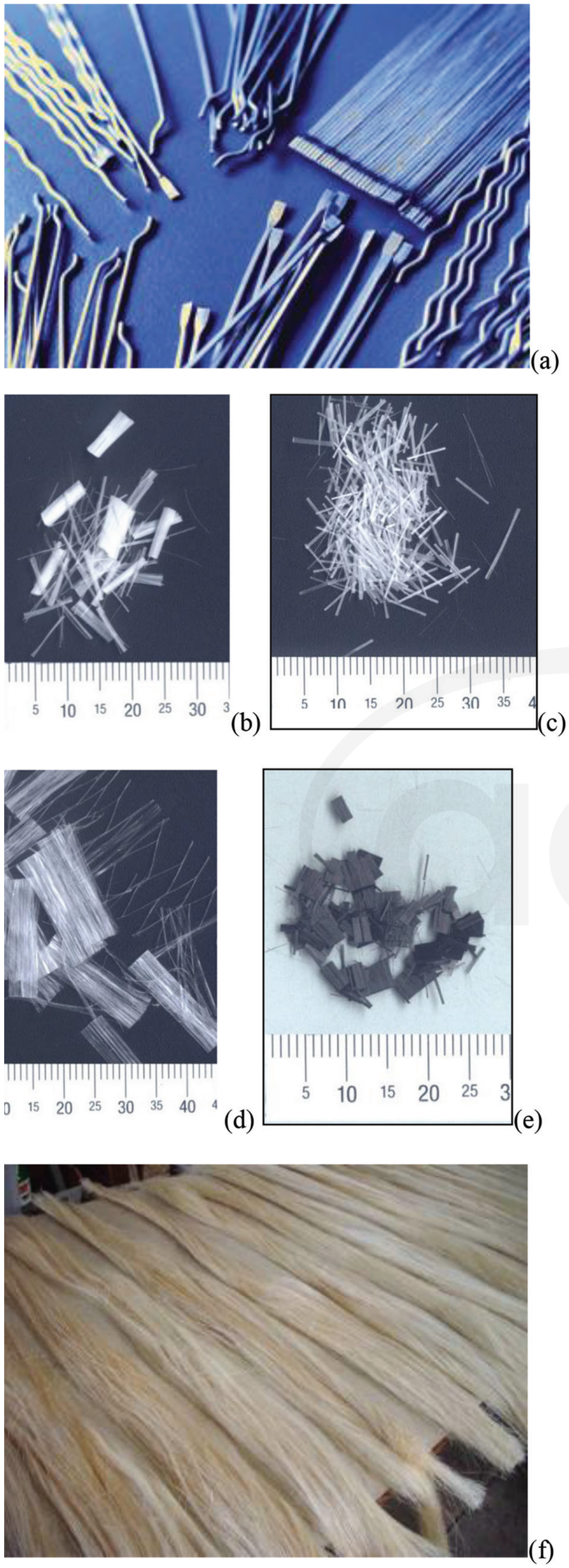

Fig. 1.2—Examples of different types of fibers used in FRC: (a) steel (with hooked ends, flattened ends, corrugated/undulated); (b) through (c) synthetic/polymeric microfibers; (d) glass; (e) carbon; and (f) natural; dimension scale where provided is in mm. (Note: 1 in. = 25.4 mm.)

f_{150} = residual nominal bending strength corresponding to P_{150}, psi (MPa)

f_{600} = residual nominal bending strength corresponding to P_{600}, psi (MPa)

f_{eq} = equivalent nominal flexural strength, calculated with reference to predefined crack opening range, from nominal flexural stress versus crack opening curves obtained from flexural tests, psi (MPa)

f_p = peak nominal stress (as from results of flexural tests according to ASTM C1609/C1609M); may coincide with or be higher than f_1, psi (MPa)

f_R, f_{Rj} = residual nominal flexural strength, at a specified value of the crack mouth opening displacement, as from results of flexural tests on notched specimens as per EN 14651, psi (MPa)

f_{R1} = residual nominal flexural strength, at CMOD = 0.02 in. (0.5 mm), as from results of flexural tests on notched specimens as per EN 14651, psi (MPa)

f_{R1k} = characteristic value of f_{R1}

f_{R2} = residual nominal flexural strength, at CMOD = 0.06 in. (1.5 mm), as from results of flexural tests on notched specimens as per EN 14651, psi (MPa)

f_{R3} = residual nominal flexural strength, at CMOD = 0.10 in. (2.5 mm), as from results of flexural tests on notched specimens as per EN 14651, psi (MPa)

f_{R3k} = characteristic value of f_{R3}

f_{R4} = residual nominal flexural strength, at CMOD = 0.14 in. (3.5 mm), as from results of flexural tests on notched specimens as per EN 14651, psi (MPa)

h = specimen height, in. (mm)

L = length, span, in.-ft. (mm); also gauge length, in. (mm)

l_f = fiber length, in. (mm)

P = load, lbf (N)

P_1 = first cracking load (as from results of flexural tests according to ASTM C1609/C1609M), lbf (N)

P_{150} = residual load measured in flexural tests as per ASTM C1609/C1609M in correspondence of a midspan net deflection equal to 1/150 of the specimen length, lbf (N)

P_{600} = residual load measured in flexural tests as per ASTM C1609/C1609M in correspondence of a midspan net deflection equal to 1/600 of the specimen length, lbf (N)

P_p = peak load (as from results of flexural tests according to ASTM C1609/C1609M); may coincide with or be higher than P_1, kip (kN)

T_{150} = area under the load deflection curve obtained from flexural tests as per ASTM C1609/C1609M up to a value of the net deflection equal to 1/150 of the specimen length, in.-lb (J)

V_f = fiber volume fraction (generally expressed in percent)

δ = deflection, in. (mm)

θ = angle, deg

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology", http://