# FIBER-REINFORCED CEMENT COMPOSITES

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*Dedicated to Our Parents*
*(Late) Perumalsamy Nadu*
*and Kengammal, and*
*(Late) Poonamchand Shah*
*and Maniben Shah*

# Preface

Reinforcing brittle matrices to improve their mechanical properties is an age-old concept. However, the modern development of fiber-reinforced cement composites dates back only to the 1960s. In the beginning, only straight steel fibers were used. The acceptance of fiber-reinforced concrete by the construction industry has led to a number of developments. Among these developments are new fiber types made of steel, stainless steel, polymeric and mineral materials, and naturally occurring materials. New manufacturing techniques and applications have also been developed. A large number of researchers around the world have investigated the various aspects of fiber-reinforced composites [FRC].

The primary purpose of this book is to introduce the reader to various portland cement–based fiber composites and to provide information on their constituent materials, fabrication, mechanical and long-term properties, applications, and field performance. The book is geared toward advanced undergraduate and graduate students, professional engineers, field engineers, fiber manufacturers, precast fiber-reinforced structural and nonstructural component manufacturers, and engineers involved with user agencies such as various departments of transportation. The book can be used as a reference text for fiber-reinforced composites.

The chapters in the book are conveniently arranged for readers with varied interests. For example, readers interested in glass fiber–reinforced composites can concentrate on the first few chapters, dealing with various mechanical properties, and on Chapter 13, dealing with the fabrication, properties, and applications of glass fiber–reinforced composites.

Chapter 1 provides a historical development of fiber-reinforced cement composites and the various types of composites that are currently used. This chapter also provides information on the various professional and research organizations that periodically update the state of the art.

Chapters 2, 3, and 4 cover the basic concepts and are geared toward graduate students. These chapters deal with the latest testing and modeling developments and with promising research directions. These chapters are also useful for design professionals who are interested in the basic concepts.

Chapters 5 through 11 deal with conventional fiber-reinforced concrete. The majority of applications involve the use of either steel or polymeric fibers. The chapters cover the designing of mixes and the properties of plastic (fresh) and hardened concrete. Matrix compositions and fiber contents normally used in the field are covered in these chapters. Typically, the matrix contains coarse aggregate and the fiber volume fraction is less than 2 percent. Although these chapters are written mainly for professionals involved in FRC use, students will greatly benefit by learning about real-life situations.

Chapter 12 deals with the shotcreting method of construction using FRC. A great deal of practical applications have been devised in this area for tunnel and canal linings and for the lining of waste dispoal sites. Both steel and polymeric fibers have been used. The use of the shotcreting technique, special requirements for mix proportions, additives such as silica fume and high-range water-reducing admixtures, and plastic and drying shrinkages are covered in this chapter.

Chapter 13 specifically deals with the use of glass fibers. This is a growing industry, with more than $100 million in sales per year in the United States alone. Constituent materials, construction methods, and problems with long-term durability that are unique to glass fiber–reinforced concrete (GFRC) are discussed in this chapter.

Chapter 14, which deals with other thin-sheet products, includes the composites developed primarily to replace asbestos fiber–reinforced sheets. This is also a growing field worldwide. Products included in this chapter are thin sheets reinforced with polymeric fabrics and meshes and with short fibers (pulps) including wood fiber–reinforced products. The recent developments in the area of polymeric pulp and the advances made to improve the performance of wooden fibers are also discussed in this chapter.

The chapter on slurry-infiltrated fiber concrete (SIFCON) deals with composites with high volume fractions of fibers. These composties have some unique properties and applications for blast-resisting structures.

Chapter 16, dealing with the use of FRC in structural components, provides details for designing beams, columns, and slabs. Fiber-reinforced concrete was found to provide notable improvements in the area of shear, ductility under cyclic loading, and impact and fatigue loading. It shows good potential for earthquake-resistant structures because of the ductility it provides compared to plain concrete. Reinforcement congestion can also be reduced by using FRC and less continuous reinforcement in the junctions of beams and columns and other critical locations.

The chapter on field performance and case studies provides examples of real-life applications and the performance of FRCs in the field.

The authors would like to add the following note for the readers. Selecting a system of units of measure for the text, either the metric system or the U.S. and avoirdupois systems, was a problem. After considerable thought we decided to use the units that were used in the publications from which the information was taken. This decision led to the use of both systems. Conversions are provided so that the reader can have a feel for the dimensions. We would like to mention that the conversions are not as accurate (say, to three digits) and also not as complete as we would like them to be. We had to choose between clarity (readability) and accuracy and we choose the clarity, since the readers can always obtain an accurate conversion if they need one. A complete conversion table is provided at the end of the text.

We would also like to inform the readers that the tables and figures are not exactly the same as those presented in the sources cited. They were modified to improve the clarity. Some of the illustrations were taken from the original reports rather than the references mentioned. Since the reports are difficult to obtain, the published papers are used for references.

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The authors acknowledge the dedication and support of their familes. The book is as much their accomplishment as ours.

# Contents

Chapter

# 1

# Introduction

The use of randomly oriented, short fibers to improve the physical properties of a matrix is an age-old concept. For example, fibers made of straw or horsehair have been used to improve the properties of bricks for thousands of years. In modern times, fiber-reinforced composites are being used for a large variety of applications. The composite could be a clay brick reinforced with natural fibers or a high-strength, fiber-reinforced ceramic component used in space shuttles. This book deals with the fiber-reinforced composites made with primarily portland cement–based matrices. These matrices can consist of any of the following:

1. Plain portland cement
2. Cement with additives such as fly ash or condensed silica fume
3. Cement mortar containing cement and fine aggregate
4. Concrete containing cement, fine and coarse aggregates

In certain applications, the matrix may also contain admixtures and polymers. Composites containing non-portland cement-based matrices, which are primarily used for rapid repairs, are also briefly discussed.

The fibers can be broadly classified as

1. Metallic fibers
2. Polymeric fibers
3. Mineral fibers
4. Naturally occurring fibers

Metallic fibers are made of either steel or stainless steel. The polymeric fibers in use include acrylic, aramid, carbon, nylon, polyester,