

Fourth Edition

CONCRETE

MICROSTRUCTURE, PROPERTIES, AND MATERIALS



P. KUMAR MEHTA / PAULO J. M. MONTEIRO

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Concrete

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Paulo J. M. Monteiro

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Foreword

The authors of this outstanding textbook, Professors Mehta and Monteiro, are leading researchers who have made lasting and seminal contributions in the field of nano- and microstructure of concrete, cement chemistry, concrete technology and mechanics. Apart from their distinguished academic career, they have also served as consultants for challenging real-world projects. The perceptive case studies described in the textbook will inspire engineers to find creative and sustainable solutions for concrete materials and structures. The text material has been presented in a remarkably clear and intuitive manner; it is greatly appreciated by students and professional engineers. The quality of the textbook has been recognized worldwide; previous editions have been translated into Japanese, Chinese, Greek, Spanish, Portuguese, and Persian.

For this fourth edition, every chapter has been carefully revised or rewritten to incorporate new developments in the field, including recent construction projects worldwide, shrinkage-reducing admixtures, self-consolidating concrete, shotcrete, pervious concrete, internal curing, electrical tomography of concrete, and other cutting-edge innovations. A strong feature of the textbook is the synergy between concrete materials, concrete technology, and concrete mechanics. For the new edition, the chapter on concrete mechanics includes the ground-breaking poromechanics formulation to model concrete exposed to freezing temperatures, analysis of the length scale in nanomechanics and an insightful review of the modeling of the alkali-aggregate reaction in concrete.

The authors made a profound analysis of the environmental impacts caused by the global concrete industry. They estimated that in 2010, 33 billion tonnes of concrete were produced globally, consuming nearly 3.7 billion tonnes of portland cement clinker and 27 billion tonnes of aggregate, in addition to 2.7 billion tonnes of mixing water and a small amount of chemical admixtures. The mining, processing, and transport of such huge quantities of materials for making concrete require considerable energy, and adversely affect the ecology of virgin lands. Also, the world's yearly cement production of mostly portland cement is responsible for nearly 7 percent of the global anthropogenic CO₂ emissions. Professors Mehta and Monteiro provided solid guidelines for the development of green concrete by using large amounts of supplementary cementing materials, particularly coal fly ash or blast-furnace slag. Chemical and mineral admixtures are fully described in Chapter 8 and their applications to the development of

high-performance green concrete are given in Chapter 12. Professors Mehta and Monteiro rounded off the textbook with a discussion of concrete in the era of global warming and sustainability. This should be required reading for everyone committed to sustainable concrete construction.

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Preface

There is a direct relationship between population and urbanization. During the last 100 years, the world population has grown from 1.5 to 7 billion and nearly 3 billion people now live in and around the cities. Seventeen of the 20 megacities, each with a population of 10 million or more, happen to be situated in developing countries where enormous quantities of materials are required for the construction of housing, factories, commercial buildings, drinking water and sanitation facilities, dams and canals, roads, bridges, tunnels, and other parts of the infrastructure. And the principal material of construction is portland cement concrete. *By volume, the largest manufactured product in the world today is concrete.* Naturally, design and construction engineers need to know more about concrete than about other materials of construction.

Written primarily for the use of students in civil engineering, it covers a wide *spectrum of topics in modern concrete technology* that should be of considerable interest to practicing engineers. For instance, to reduce the environmental impact of concrete, roles of pozzolanic and cementitious by-products as well as superplasticizing admixtures in producing highly durable products are thoroughly covered.

One of the objectives of this book is to present the *art and science of concrete in a simple, clear, and scientific manner*. Properties of engineering materials are governed by their microstructure. Therefore, it is highly desirable that structural designers and engineers interested in properties of concrete become familiar with microstructure of the material. In spite of apparent simplicity of the technology of producing concrete, the *microstructure of the product is highly complex*. Concrete contains a heterogeneous distribution of many solid compounds as well as voids of varying shapes and sizes that may be completely or partially filled with alkaline solution.

Compared to other engineering materials like steel, plastics, and ceramics, the microstructure of concrete is not a static property of the material. This is because two of the three components of the microstructure, namely, the bulk cement paste and the interfacial transition zone between aggregate and cement paste change with time. In fact, the word *concrete* comes from the Latin term *concretus*, which means to grow together. The strength of concrete depends on the volume of the cement hydration products that continue to form for several years, resulting in a gradual enhancement of strength. Depending on the exposure to environment, solutions penetrating from the surface into the interior of concrete sometimes dissolve the cement hydration products causing an increase in porosity which reduces the strength and durability of concrete; conversely, when the products of interaction recrystallize in the voids and microcracks, it may enhance the strength and durability of the material. This explains why analytical

methods of material science that work well in modeling and predicting the behavior of microstructurally stable and homogeneous materials do not seem to be satisfactory in the case of concrete.

In regard to organization of the subject matter, the *first part* of this three-part book is devoted to hardened concrete microstructure and properties, such as strength, modulus of elasticity, drying shrinkage, thermal shrinkage, creep, tensile strain capacity, permeability, and durability to various processes of degradation. Definition of each property, its significance and origin, and factors controlling it are set forth in a clear manner. The *second part* of the book deals with concrete-making materials and concrete processing. Separate chapters contain state-of-the-art reviews on composition and properties of cements, aggregates, and admixtures. There are also separate chapters on proportioning of concrete mixtures, properties of concrete at early ages, and nondestructive test methods. The *third part* covers special topics in concrete technology. One chapter is devoted to composition, properties, and applications of special types of concrete, such as lightweight concrete, high-strength concrete, high-performance concrete, self-consolidating concrete, shrinkage-compensating concrete, fiber-reinforced concrete, pervious concrete, shotcrete, concretes containing polymers, and mass concrete. A separate chapter deals with advances of concrete mechanics covering composite models, creep and shrinkage, thermal stresses, fracture of concrete, and durability of concrete. The final chapter contains some reflections on current challenges to concrete as the most widely used building material, with special emphasis on ecological considerations.

A special feature of the book is the inclusion of numerous unique diagrams, photographs, and summary tables intended to serve as teaching aids. New terms are indicated in italics and are clearly defined. Each chapter begins with a preview of the contents, and ends with a self-test and a guide for further reading.

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