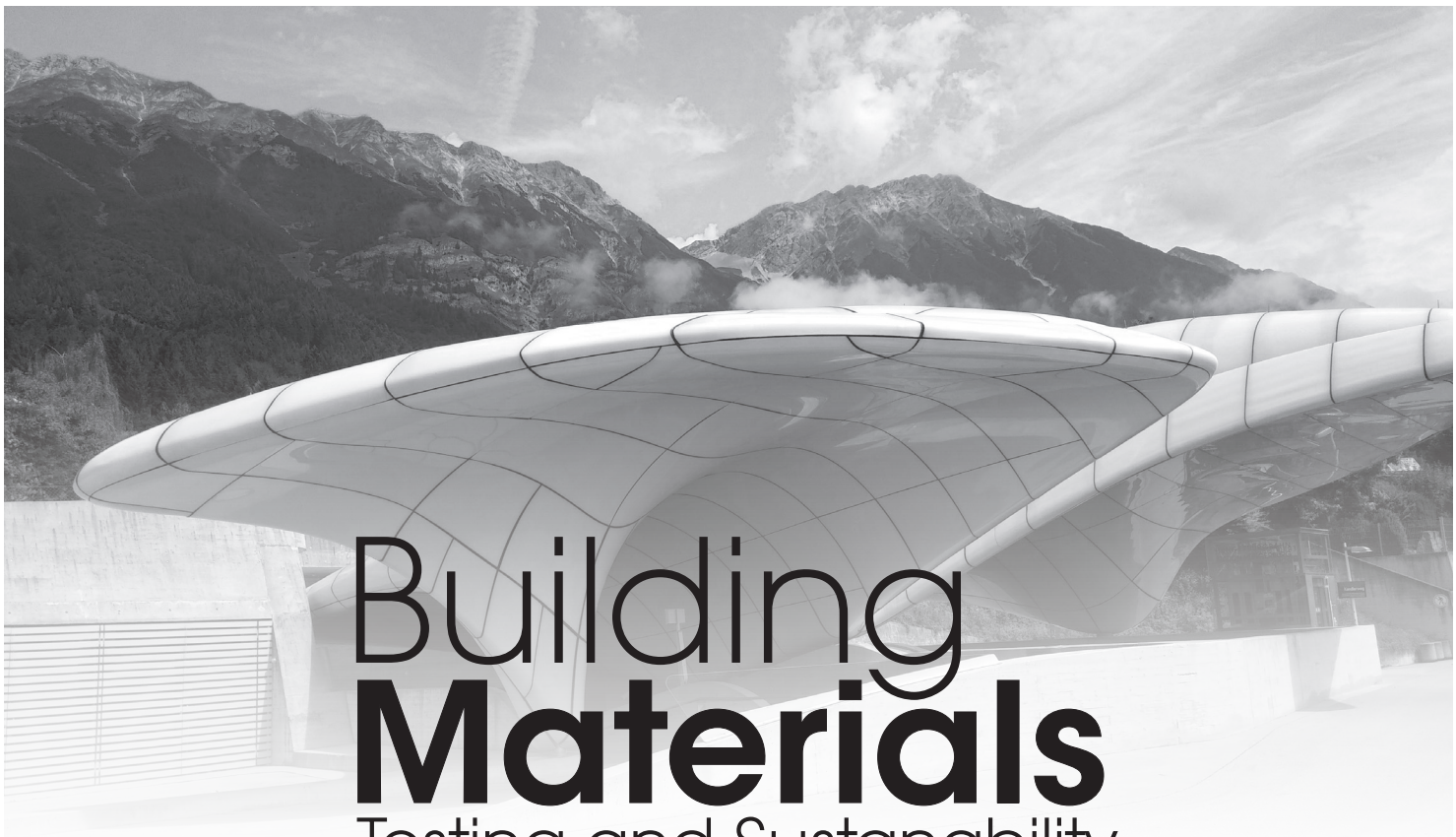

Building Materials

Testing and Sustainability

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PREFACE

Ancient civilization lived in caves. After fire and tools were discovered, they started to use natural products such as stones, bricks, and wood to build habitats, which provided protection from the natural environment. Bricks have been found in Egypt as early as 14,000 BC. By 200 BC, the Romans successfully used concrete in the majority of their construction (though the present day concrete construction is much different from theirs). In the industrial age (between the mid-1700s and 1840), several manufacturing processes to produce cement (Joseph Aspdin, 1824), concrete, macadam roads (John Loudon McAdam, c. 1815), mass production of steel from molten pig iron by the Bessemer Process (Henry Bessemer, 1856), method of converting pig iron into wrought iron (Henry Cort, 1784), etc., were invented, resulting in the extensive use of concrete and steel. Now, concrete is the most widely used substance on earth, after water. We now use a variety of materials in our buildings and constructions ranging from stones, bricks, cement, reinforced concrete, steel, stainless steel, wood and wood products, glass, fibreglass, aluminium, plastics, ceramics, gypsum, paints and varnishes, bitumen, to copper, zinc, and aluminium alloys.

The exploding population growth (3 billion in 1960 to an estimated 7.7 billion in 2019) and the resulting urbanization has resulted in greater energy use [according to BP's Statistical Review of World Energy, world primary energy consumption reached 157 terawatt-hour (TWh) in 2017]; it has to be noted that materials such as cement and steel require large amounts of energy as their production requires them to be heated to temperatures exceeding 1300°C in kilns. This causes emission of huge quantities of greenhouse gases like CO_2 and also large amounts of industrial waste by-products like fly ash, which are harmful to the environment. In addition, indiscriminant mining of natural resources for the production of building materials has resulted in severe adverse effects on the environment, including loss of biodiversity, erosion, contamination of surface and ground water, and soil. Several (rocky) mountains are disappearing and river beds and even beaches (which took numerous years to form) are being denuded of sands. As these natural resources are limited, there is a shortage of coarse aggregates and sand in several parts of the world, necessitating the use of alternate materials or recycling of used materials and even the use of industrial wastes like fly ash. Several other materials such as plastics and lead are harmful to the environment or to the heath of human beings and have to be handled carefully. In addition, some materials like paints, varnishes, or wood impregnated with preservative chemicals may off-gas volatile organic compounds (VOC), which may affect the health of people living in air-conditioned interiors.

Almost all materials that are used in the construction have to follow the norms stipulated in the national codes (Bureau of Indian Standards has numerous codes on building materials). In addition, as buildings account for about one-third of worldwide energy consumption and are one of the largest contributors to GCG emissions, several countries including India have recently developed *Energy Conservation Building Codes*. They usually contain mandatory and voluntary provisions on insulation, thermal and solar properties of the building envelope, heating, ventilation and air conditioning, and also hot water supply systems, lighting, and electrical power.

From the above discussions, it is clear that all those engaged in the design and construction of buildings should have a sound knowledge about the manufacture, energy required in the manufacture, properties, effect on health, environmental friendliness, recyclability, sustainability, etc., of the materials they are using and also the norms prescribed for these materials. This book has been written

to fulfill these needs. This text is based on several latest Indian Standard codes on building materials. SI units have been used throughout the book.

About the Book

Building Materials, Testing, and Sustainability is a comprehensive text book designed to meet the requirements of the undergraduate students of civil engineering, based on the recent AICTE syllabus on *Materials, Testing & Evaluation*. This book will also be useful to students of architecture (who usually specify the materials), students of diploma courses in civil engineering and will serve as an invaluable reference to postgraduate students and practising engineers, as well as researchers.

Each chapter starts with an introduction about the origin and development of the material discussed in that chapter, the manufacture, properties, uses, advantages and disadvantages, and sustainability of that material. After presenting the subject, multiple-choice questions (MCQ) and review questions are provided at the end of each chapter, which will help the students assimilate the topics presented in the chapters. Answers to the MCQ are given at the end of each chapter, so that the students can check their answers. Several interesting case studies are also included as part of every chapter.

Key Features

The following features in the book make it stand out among the other books in this area:

- It covers traditional materials to the most modern materials such as plastics, gypsum, and ceramics.
- Each chapter covers a brief history, composition, classification, manufacture, properties, advantages and disadvantages, use in buildings, environmental effects, sustainability, etc., of the material discussed in that chapter.
- Several Indian codes are available which stipulate norms for these materials. Most of these codes are cited in the book and important extracts are provided. The list of several codes, which are not cited, are also included in the references of each chapter and included in the online resource centre (ORC). In addition, a bibliography is provided in the book which lists the important references, for further study and research.
- Several topics, which are normally not found in other books, such as different types of brick kilns, substitutes for bricks, green cement, industrial by-products that can be used to replace cement, green substitutes for coarse aggregates and sand, green mortars, green and special concrete, mix design of concrete, controlled permeability formwork (CPF), industrial timber products, various reinforcing bars, structural insulated panel (SIP), sustainability of various materials, green building rating systems, bamboo, nano-materials, composite materials and concrete canvas, health effects and precautions to be taken while handling certain materials, etc., are discussed.
- 30 interesting practical case studies are provided.
- Students and engineers will find the separate chapter on testing and evaluation of these materials to be useful.
- A rich pedagogy provides the required rigour for students to excel in this subject in the examinations: Over 750 review questions and 440 multiple-choice questions (with answers) to test the understanding of the students; over 300 illustrative figures and photographs and 200 tables to supplement the text; more than 1440 references, which include relevant Indian and American codes.
- Provides most updated information in this subject covering the state-of-the-art trends and developments.

Online Resources

The following resources are available to support the faculty and students using this text:

For faculty

- Lecture PPTs

For students

- List of references

Using the Book

The text is divided into 25 chapters and completely covers the undergraduate (UG) curriculum of most of the universities. The teacher adopting this book is requested to exercise discretion to select portions of the text to be presented for a particular course. It is suggested that portions of Chapters 2–8, 11–13, 15–18, and 25 may be taught and Chapters 1, 9–10, 14, and 19–24 may be left for self-study.

Although relevant information from some important codes of practice has been included in the text, readers are advised to buy and refer to the latest codes published by the Bureau of Indian Standards, New Delhi. It is recommended that readers should use the book along with the latest codes/publications released by the Bureau of Indian Standards, for better clarity.

Contents and Coverage

The text is divided into 25 chapters.

Chapter 1 deals with the general information on physical, mechanical, thermal, and other properties of materials. It also gives some indications on sustainable (healthy and ecological) materials. Introduction to various green building systems is given and a comparison of structural steel, reinforced and prestressed concrete, and wood, which are the major materials used in construction, is provided. A discussion on Alternative Building Materials and building codes is also included.

Various aspects of stone including durability, deterioration, preservation, selection and uses of stones are discussed in ***Chapter 2***. It also has brief introduction to stone masonry and a comparison of stone and brick masonry.

Bricks, which are usually used for constructing the walls of buildings, are the subject of ***Chapter 3***. In India, the current brick manufacturing is through the use of highly polluting, energy inefficient, and uneconomical kilns. Hence various types of kilns are discussed and the vertical shaft brick kiln/tunnel kiln is suggested. Qualities of good bricks, properties, characteristics, etc., of bricks are provided. Several substitutes for bricks are also suggested.

Chapter 4 deals with lime, which is a green material, and was used in olden days; this chapter discusses its manufacture, types, classifications, uses, and precautions while handling it. The manufacture, chemical composition, properties, and hydration of various types of cement, which is an important ingredient of concrete, are explained in ***Chapter 5*** along with the various pozzolana/green cement replacement materials. ***Chapter 6*** deals with the characteristics and properties of coarse and fine aggregates, which are mainly used in concrete, and include topics on grading of aggregates, alkali–aggregate reaction, and green substitutes for coarse aggregates and sand. ***Chapter 7*** is concerned with mortars and plasters, which are used in building masonry and providing protective coating on walls and ceilings, respectively.

Various aspects of concrete and RCC, which is used extensively in India in buildings, bridges, dams, etc., are covered in ***Chapter 8***. Various special concretes such as ready mixed concrete, high-strength/high-performance concrete, self-compacting concrete (which is the material of the future), structural light weight concrete, foamed concrete, fibre reinforced concrete, ultra-high performance concrete, polymer concrete, geoploymer concrete, prestressed concrete, precast concrete, decorative concrete, etc., are discussed in ***Chapter 9***. As concrete contributes to about 5–6% of global emissions of greenhouse gases,

the methods to reduce these emissions by the use of industrial by-products such as fly ash, GGBS, etc., (which also improve the properties of concrete) are also described in Chapter 9.

Chapter 10 describes gypsum, a fire retardant and sustainable material, requiring low energy in its production, and mostly used in wall panels. The technology developed at IITM, using glass fibre reinforced gypsum panels, could reduce the cost and time required to build houses.

Wood is the most sustainable and renewable building material having a low level of embodied energy, and wood products can be carbon negative. In order to use it we should maintain sustainable forestry. ***Chapter 11*** explains the classifications, defects, conservation, seasoning and preservation, properties, selection and testing of timber. Several wood products such as layered timber composites, parallel laminates, particle composites, fibre composites, and timber-concrete composites are now available; their use and properties are briefly explained along with cork and linoleum.

Chapter 12 deals with the various forms of iron (pig, wrought, cast) and ***Chapter 13*** describes steel, which is the second most used structural material. Steel could be alloyed with other elements (mainly with carbon) to improve the properties. It has equal strength in tension and compression, but its main drawback is its corrosion. Steel is used in various forms from structural sections to bolts, nuts, and nails. Hot rolled and cold-formed steel sections are available. Rebars used in concrete and prestressed concrete are usually made of high strength steel. Several techniques have been developed to mitigate the corrosion problem including the development of stainless steel and weathering steel. The production of steel is also energy intensive and requires high temperatures (up to 1650°C), but is considered sustainable due to its 100% recyclability. ***Chapter 14*** is concerned with non-ferrous materials such as aluminium, copper, zinc, lead, etc., and its alloys like brass and bronze. Steel is galvanized using zinc.

Glass, which is obtained from silica sand, lime, soda, and alumina, and mainly used in windows and curtain walls of multi-storey buildings, is discussed in ***Chapter 15***. Common types (sheet, plate, float, and extra clear) and special types of glass (safety, translucent, etched, tinted, reflective/coated, insulated, double-glazed, glass blocks) are described. Clay roofing tiles of various types and ceramic products are discussed in ***Chapter 16***. ***Chapter 17*** discusses plastics, which were invented in the 1800s and have revolutionized the construction industry and being used in a variety of applications. This chapter describes its classification, methods of production, properties, and uses. Most of the plastics are not recyclable and are not bio-degradable and hence have to be used with caution.

Details about paints and varnishes are provided in ***Chapter 18*** and asphalt, bitumen, and tar in ***Chapter 19***. ***Chapters 20–22*** deal with thermal and sound insulating materials and waterproofing materials, respectively. Miscellaneous and recent materials are discussed in ***Chapter 23***. A brief description of deformation and fracture of materials is provided in ***Chapter 24***. ***Chapter 25*** describes the various tests that are performed on some of the important materials, in order to evaluate them.

Though care has been taken to present error-free material, some errors might have crept in inadvertently. I would highly appreciate if these errors are brought to the attention of publishers. Any suggestions for improvement are also welcome.

Acknowledgements

I was greatly influenced during the preparation of this book by several books, papers, and websites on building materials, sustainability and testing. Although sufficient effort was taken to acknowledge the source of images, tables, etc., I wish to apologize for the use of any phrase, image, or illustrations used in this book inadvertently without acknowledgement.

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N. Subramanian

BRIEF CONTENTS

DETAILED CONTENTS

ABOUT THE AUTHOR

Dr N. Subramanian is an award winning author, consulting engineer, researcher, and mentor now living in Maryland, USA, and former Chief Executive of *Computer Design Consultants* (CDC), Chennai. He had a brilliant academic career and earned his Ph D from the *Indian Institute of Technology, Madras.* He also worked as a Post Doctoral Fellow for 2 years at IITM and then worked in the then West Germany as the prestigious *Alexander von Humboldt Fellow* with Prof. J. Lindner and Prof. Ch. Peterson. After his return from West Germany, he worked for a brief period in Anna University and then started his own company, CDC, during 1982.

He has more than 45 years of professional experience which include research, teaching, and consultancy. He has served as a consultant to several leading organizations in India and designed several noteworthy structures involving RCC, structural steel, and cold-formed steel in India and abroad. More than 600 microwave/transmission towers, ranging in height from 20 m to 120 m have been designed by him. One Defense project earned the certificate of merit from the Consultancy Development Centre, DSIR, Govt of India in 1992.

Dr N. Subramanian also developed several special-purpose software packages for the analysis and design of different types of structures. Being a member/fellow of several professional bodies, he took very active part in these organizations, and is the past All India Vice president of the Association of Consulting Engineers (India) and also the Indian Concrete Institute. He organized several conferences/seminars for ACCE(I) and ICI.

Dr Subramanian has authored more than 25 wide selling books and more than 260 technical papers, published in national and international journals/conferences. He is the author of *Design of Steel Structures – Limit States Method*, 2nd Edition (OUP), *Steel Structures: Design and Practice* (OUP), *Design of Reinforced Concrete Structures* (OUP), 8 books in the series *Access to Computer Education* (OUP), and *Space Structures: Principles and Practice* (Multi-Science, UK). Three of these books earned the coveted *ACCE-Nagadi Award* and are prescribed as text books in several universities.

Dr Subramanian is in the editorial/review boards of prestigious International journals such as International Journal of Space Structures, Structural Journal of the American Concrete Institute, Journal of Indian Concrete Institute and the Indian Concrete Journal. He is also honored with several awards, which include the *Tamilnadu Scientist Award, Lifetime Achievement Award* given jointly by the Indian Concrete Institute and L & T, Life member of the American Society of Civil Engineers, and Distinguished Alumnus Award of College of Engineering, Guindy (Anna University).

He is active as mentor to young engineers through several online forums such as the *Structural Engineering Forum of India (*has more than 23,400 members), Quora, and LinkedIn. He also served as the President of the Rotary Club of Madras Metro.