

# Nondestructive Testing of Materials and Structures

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Editors

# Nondestructive Testing of Materials and Structures

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# Preface

This two-part proceedings book comprises keynote, invited, and contributed papers presented at the International Symposium on Nondestructive Testing of Materials and Structures (NDTMS-2011), held at Istanbul Technical University (ITU), Istanbul, Turkey, on May 15–18, 2011. The concern about the deteriorating nature of the World's infrastructures, and the need for the assessment of structural materials and systems make the development and implementation of nondestructive testing (NDT) and evaluation (NDE) methodologies a necessity. Although research on NDT in engineering may have a history of more than 60 years, early developments primarily referred to metals and metal components. With the technological advances in the areas related to NDT and increasing number of engineering structures, NDT methods have also been required for the quality control and condition assessment of building structures and materials as a basis for repair, retrofit and strengthening.

Several NDT techniques which are known in metallurgy, medical diagnostics, aviation and aerospace, and geophysical applications have been adopted and further developed for use in the condition assessment of structures and construction materials. Recent advances in NDT methodologies for materials and structures combined with the increased speed and memory of computers and efficient imaging algorithms have led to the processing of measured responses from NDT to better characterize materials and determine the spatial extent of the anomalies in two or three dimensions as well as the nature of such anomalies.

Pursuant to these developments and considering the need to foster ideas and identify efficient application techniques, NDTMS-2011 at ITU has been organized. The Symposium has provided a forum of engineers, scientists, and professionals for the exchange of ideas and knowledge on NDT with applications in civil and other engineering fields. This symposium was originally conceptualized as a scientific collaboration by researchers from Massachusetts Institute of Technology, University of Stuttgart, University of Edinburgh, Technical University of Munich, German Federal Laboratory for Material Research and Testing (BAM), and Istanbul Technical University. We thank Christian U. Grosse, Hans W. Reinhardt, Michael C. Forde and Herbert Wiggenhauser for their encouragement and intellectual contributions. We also express our gratitude to Urs Meier, Dionisio Bernal, Luigia

Binda, Steven D. Glaser, and Tribikram Kundu for their support and contributions. The symposium was sponsored by a number of academic/research institutions, and technical and industrial/professional organizations. Their supports are thankfully acknowledged.

NDT/NDE is a highly multi-disciplinary field involving various scientific disciplines, innovative theoretical and experimental techniques, and advanced computational modeling and imaging. Therefore, there is a need to bridge the gaps between these various aspects, as well as the gap between the developers and the practicing engineers. It is hoped that the proceedings of this symposium will represent a unifying theme contributing to the closing of these gaps to some extent. The organizers are pleased with the overwhelming interest shown from researchers, developers and engineers in contributing to this publication. The large number of abstracts and papers received for consideration to be included in NDTMS-2011 proceedings attests to the continuing importance of the subject and the need for further developments. The proceedings included in this two-part volume comprise 175 papers contributed by 473 authors from 36 countries around the world. It is only fitting that this symposium with such multi-national representation is held in a world city, Istanbul, with its profound history and rich culture as well as unique location between two continents, Europe and Asia.

The topics of the proceedings are organized as follows: NDT methods for the characterization of materials and structures; NDT for material and property characterization; early age NDT of concrete and other materials; NDT for metallic material characterization; NDT of metals and composites; theoretical modeling and simulation studies as a basis for NDT; NDT of civil infrastructures; geotechnical and geophysical applications of NDT; health monitoring of structures; NDT and evaluation of historic buildings and monuments; NDT planning, practice, reliability, codes and standards.

A distinguishing quality of this proceedings book is that it not only captures the state of the art in NDT of materials and structures through papers by leading experts, but also provides informative descriptions of ongoing NDT research and development in diverse areas as well as field experiences by practicing engineers. Achieving this objective took much effort by all parties involved; numerous papers went through several cycles of review and revisions in the limited time available for the preparation of this book. The editors hope that the readers will benefit from this effort and will tolerate any imperfections that may remain in the book.

We would like to thank the members of the international organizing committee, local organizing committee, and the international scientific committee, for their contribution and substantial effort in the rigorous review process for the 210 submitted papers ensuring the quality of the accepted papers. We also would like to thank our students Arda Kiremitçi and Adile Aslı Özbora (ITU), Halil Ibrahim Andiç (Atılım University, Ankara), and Denvi Lau (MIT) for their assistance, positive attitude and willingness to help whenever needed. We express our appreciation to Tolga Orhon for his invaluable work in designing and managing the conference website. He volunteered his professional expertise and accommodated our needs at most critical times.

Finally, we express our most heartfelt gratitude to Oğuz Güneş for his creative ideas, his invaluable contributions and timeless efforts from the conception of the symposium to the completion of this publication. Without his efforts, initiatives, and meticulous attention to practically every detail, this book would not have been a reality.

We trust that the efforts of all those who have contributed to the International Symposium on Materials and Structures, NDTMS-2011, will be fruitful, and that, as a basic reference, this publication will contribute to the science, engineering, and practice of NDT for many years to come.

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January 2011

# Dedication



**Professor M. Cengiz Dökmeci**  
**Dipl.-Ing., Dr.-Ing. (ITU), Ph.D. (Cornell)**

*This proceedings book is dedicated to M. Cengiz Dökmeci, a research pioneer, educator, leader, and mentor in recognition of his outstanding contributions to the science of materials, continuum mechanics, and fundamental studies underpinning the development of nondestructive evaluation methods for materials and structures.*

M. Cengiz Dökmeci, a native of Harput, Turkey, received his Dipl.-Ing.(Civil Engineering) and Dr.-Ing. degrees in June 1960 and March 1965, respectively, from Istanbul Technical University (ITU), and his Ph.D. degree in May 1972 from Cornell University (Ithaca, New York). His doctoral advisors were late Professor Mustafa Inan (ITU), and Professor Bruno A. Boley with whom he first worked at Columbia University, and later continued working at Cornell and Northwestern Universities. He was promoted to the rank of associate professor in 1974 and to full professor in 1980 at ITU. His mentors and co-workers included Professors Rifat Yazar (ITU), Raymond D. Mindlin and Warren P. Mason (Columbia), James A. Krumhansl (Cornell), and Liviu Librescu (Virginia Polytechnic and State University) all of whom had a profound influence on his academic life in many respects.

Dr. Dökmeci was a research fellow of the Organization of European Cooperation and Development (OECD) at ITU in 1963–1965, and a NATO postdoctoral fellow at the Massachusetts Institute of Technology (MIT) during the summer of 1976. He was a visiting scientist at MIT, University of California at Berkeley, and the University College of London in the summers of 1976 and 1982, 1977 and 1981, and 1979, respectively. He was the founding dean of the Faculty of Aeronautics and Astronautics (1983–1989) and director of the Bioengineering Research Center (1985–1987) at ITU. He was the editor-in-chief of the Bulletin of the Technical University of Istanbul (1985–1994), has been an international editorial board member of the Journal of Aircraft (AIAA) since 1987, and a reviewer for Zentralblatt für Mathematik since 1973. He has served as a recommender for the Japan Prize since 1984 and was a correspondent for the International Ship Structures Congress (ISSC) (1979–2000) and the International Council of Aeronautical Sciences (ICAS) (1987–2004). He was awarded the Encouragement Award in 1975 and the Science Award in 1985 by the Scientific and Technical Research Council of Turkey (TUBITAK). He is a member of the honor societies Sigma Xi and Phi Kappa Phi, and an honorary member of the Turkish Academy of Sciences (TUBA).

Professor Dökmeci's research has mainly dealt with structural optimization, variational principles of continuum physics, and mathematical modeling of materials and structural elements, including fully variational formulations and internal consistency of solutions. His research is distinguished as pioneering in materials and structures subjected to coupled mechanical, thermal, electric, magnetic, and moisture effects. His scientific contributions including those from his early years at Columbia, Cornell, University of California (Berkeley) and MIT have been recognized as unique in the coupled field problems of electromagnetic-acoustic discontinuous fields, high-frequency vibrations of porous piezoelectric plates, and higher order theories of piezoelectric, thermopiezoelectric, and hygrothermo-piezoelectric continua. Dr. Dökmeci's research has significantly contributed to the theoretical foundations of smart materials and nondestructive evaluation of materials and structures, crossing multi-disciplinary boundaries.

The Chair of this symposium has the privilege of having been associated with Dr. Dökmeci for many years, first at ITU and Cornell during his studies and later as a colleague and friend at MIT and beyond. Dr. Dökmeci's students and colleagues alike have a great sense of respect for his personal values and admiration for his scholarly contributions. As a mentor, Professor Dökmeci's positive influence on his students and junior colleagues through guidance and inspiration has been profound and everlasting.

Dr. Dökmeci is currently an Emeritus Professor at his alma mater, ITU, where he is active in research and teaches mechanics and applied mathematics.

