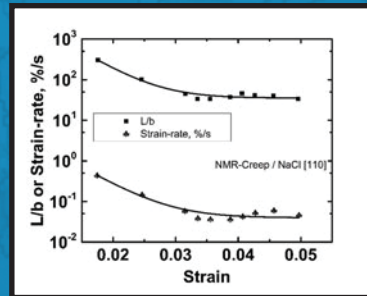
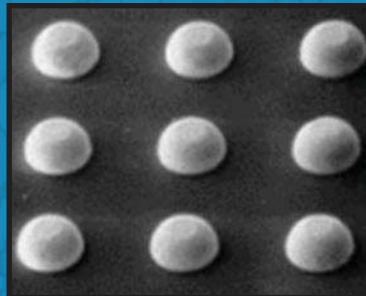
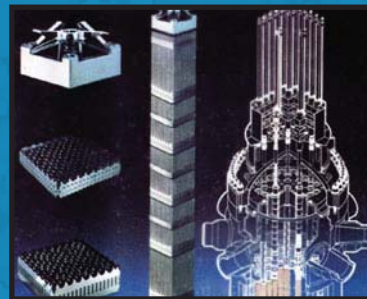
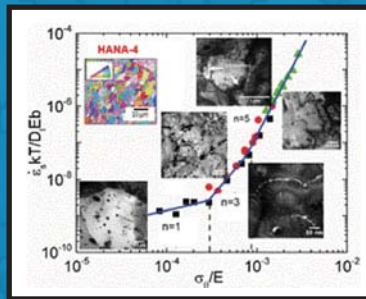


MECHANICAL AND CREEP BEHAVIOR OF ADVANCED MATERIALS

A SMD Symposium Honoring Prof. K. Linga Murty



Edited by
Indrajit Charit • Yuntian T. Zhu
Stuart A. Maloy • Peter K. Liaw

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 Springer

The Minerals, Metals & Materials Series

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ISSN 2367-1181 ISSN 2367-1696 (electronic)
The Minerals, Metals & Materials Series
ISBN 978-3-319-51096-5 ISBN 978-3-319-51097-2 (eBook)
DOI 10.1007/978-3-319-51097-2

Library of Congress Control Number: 2016960561

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Printed on acid-free paper

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The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This monograph is based on the papers that were presented in the TMS 2017 Annual Meeting & Exhibition (TMS2017) symposium, Mechanical and Creep Behavior of Advanced Materials: A SMD (Structural Materials Division) Symposium Honoring Prof. K. Linga Murty. TMS 2017 was held in San Diego during February 26 to March 2, 2017. The symposium received a total of seventy-six abstracts. Out of them, sixteen presentations were keynote talks, forty-two invited talks and eighteen contributed presentations (including eight posters). Out of these, twenty-three manuscripts were submitted and peer-reviewed for publication in the book. The symposium was jointly sponsored by two TMS Structural Materials Division (SMD) technical committees, Nuclear Materials and Mechanical Behavior of Materials. The symposium was organized to celebrate the 75th birthday and lifelong contributions of Prof. K. Linga Murty in the area of structural materials and provide a forum for discussion on the present status and recent advances in research areas in which he has made seminal contributions. Those areas included the following:

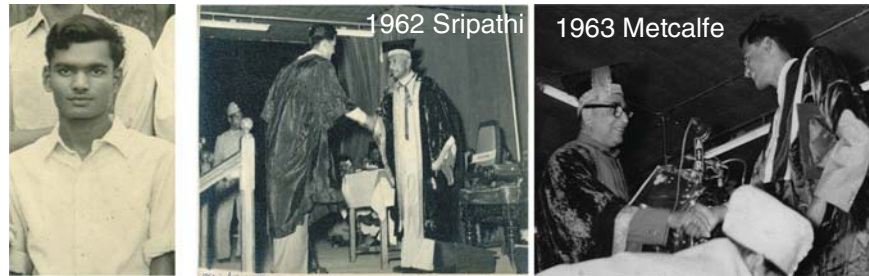
- High-temperature creep deformation of materials and micromechanistic interpretation;
- Synergistic effects of dynamic strain aging and radiation-induced defects on mechanical and fracture of ferritic steels;
- Prediction of mechanical behavior of HCP metals/alloys using crystallographic texture;
- Creep and fatigue behavior of microelectronic solders;
- Radiation tolerance of nanostructured materials;
- Development and application of ball indentation technique as a nondestructive monitoring method of structural materials;
- Characterization of dynamical behavior of point and line defects, and evaluation of strain-induced vacancy concentration using nuclear magnetic resonance techniques.

Professor K. Linga Murty (fondly called just KL by his colleagues) is currently Progress Energy Distinguished Professor in the Department of Nuclear Engineering and a professor in the Department of Materials Science and Engineering at the North Carolina State University (NCSU), Raleigh, North Carolina, USA. He is also the Director of Graduate Programs of Nuclear Engineering at NC State. He has published approximately 330 publications, including a sole-author *Nature* paper in 1984. He is also the lead author of a popular textbook on nuclear materials published in 2013 by Wiley-VCH. Over his career of more than three decades, he has mentored 51 graduate students as their major professor and served as external examiner of Ph.D. committees of 14 students abroad. His students are distinguished in their fields, including Retired U.S. Army Chief Gen. Ray Odierno and Dr. Youn H. Jung, the former president of KAERI (Korea Atomic Energy Research Institute). Prior to starting his academic career at NC State in 1981, he had a total of 7 years of industrial experience as a senior research engineer at the Lynchburg Research Center of the Babcock Wilcox Company (1974–1979) and as a senior engineer at the Westinghouse R&D Center (1979–1981). Prior to that, he was a research metallurgist at the Lawrence Berkeley Laboratory (1970–1972) and an AINSE Fellow at the University of New Castle (Australia) working under the supervision of Prof. J.E. Dorn and Prof. E.O. Hall, respectively. He has also held many other positions of repute, such as his service as the Director of the NSF-DMR Metals Program during 2001–2003.

While Prof. Murty is very well known in the communities of nuclear materials and mechanical behavior of materials, it is instructive in the context of this book to provide all the readers with some of his inspiring biographical details of his early years. At the same time, we share with you some of the tremendous success that he has achieved along the way. Dr. Murty was born in a well-to-do philanthropic family, Dr. Korukonda Subbaraju and Mrs. Subhadramma of Anakapalle in the State of Andhra Pradesh in erstwhile British India in 1941. After receiving his early education in M.H. School and A.M.A.L.¹ College, Anakapalle, he moved to the Andhra University, Vishakhapatnam, where he completed his B.Sc.(Hons) and M.S. degrees in physics. All along, he was an exceptionally talented student and he always stood first in all his classes! In recognition, he was awarded many prizes for academic achievements: Lingamurty Memorial Prize (1956, 1957, 1958), G.N. Murthy Memorial Medal (1958), Sripathi Medal (1962), Metcalfe Medal (1963), etc. It is to be noted that the Sripathi Medal received in 1962 following his B.Sc.(Hons) was in recognition of his being the best among all sciences and technology departments in Andhra University. Along with his academics, he was actively involved with other extracurricular activities and represented his high school in badminton and received prizes for debates in English and Telugu during his high school studies. He served as the joint secretary of the Andhra University student union during his AMAL college studies and as the secretary of the Physical Society at Andhra University in 1960–1961. After completing his education in

¹L for his grandfather, Lingamurty.

India, he moved to Cornell University in the USA in 1964, where he did his M.S. in applied physics with thesis on “High-Temperature Creep of α -Iron,” in 1967 and Ph.D. in materials science on “High-Pressure High-Temperature Study of Spin Relaxation of Li in LiBr Doped with Ca—Intrinsic and Extrinsic Diffusivities,” in 1970, both under the supervision of Prof. Arthur Ruoff.



Photos of Dr. Murty: 1957 (*left*), 1962 (*middle*) and 1963 (*right*)

Dr. Murty’s experience and interests include failure analysis, corrosion and stress corrosion cracking, structure-properties correlations, effects of aggressive environment and neutron exposure on mechanical properties and fracture characteristics of metals, including radiation embrittlement of nuclear pressure vessel steels. His expertise also involves issues pertaining to formability of metals, superplasticity, and development of crystallographic texture and resulting anisotropy. The materials he studied ranged a wide spectrum including aluminum alloys (Al-Mg, Al-Zn), pressure vessel steels, zirconium alloys, stainless steels, nickel-based superalloys, lead alloys (such as Pb-Sn solder), lead-free solder alloys, Cu-Au alloys, alkali halides, high purity iron and molybdenum, HCP metals (Zr, Ti, Mg, Zn, and their alloys), WC-Co tool materials, ultrafine grained and nanocrystalline materials. He has also left an indelible mark in the nondestructive evaluation area for life assessment and condition monitoring of structural materials in nuclear reactors using automated ball indentation (ABI) technique. He led pioneering work in the use of in situ nuclear magnetic resonance (NMR) technique to understand the dynamical behavior of point and line defects as well as in the evaluation of strain-induced vacancies. He also contributed heavily in characterizing the reliability of solders in electronic packaging.

Dr. Murty has also been very active with other fields with several synergistic service activities including serving as the editor of book volumes, organizer of international symposia, and reviewer of proposals for various funding agencies and journals. He has served on the editorial boards of *Metallurgical and Materials Transactions A*, *Research Letters in Materials Science*, *Advances in Materials Science*, and *Journal of Nuclear Energy Science & Power Generation Technology*.

Dr. Murty is a member of ASM International (Fellow), TMS, American Physics Society (APS) and American Nuclear Society (ANS) (Fellow) in addition to being a life fellow and honorary member of the Indian Institute of Metals (IIM). In his professional career, he has won multiple laurels for his pioneering work in research, service, and teaching. Some are listed below:

- 1987—DAAD Fellow, Physics Department, Universitat Dortmund, FRG
- 1988—Alcoa Foundation Research Achievement Award
- 1992—Gledden Senior Visiting Fellow (UWA)
- 1993—ANS Mishima Award for outstanding research in nuclear materials and fuels (1st recipient of this award)
- 1996—Fellow of ASM International
- 1996—Life Fellow of Indian Institute of Metal
- 1996—Best Paper Award (ICNDT)
- 2002—Fellow of ANS
- 2006—ASM-IIM Lectureship
- 2008—Best Poster Paper Award, 5th Intl Conference on Creep-Fatigue (CF5)
- 2015—Honorary Membership in Indian Institute of Metals
- 2016—Mini-symposium organized in his honor during Plasticity 2016 Conference in Big Island, Hawaii
- 2016—Progress Energy Distinguished Professorship
- 2017—Honorary Symposium during TMS annual meeting in San Diego, CA

It should also be mentioned that two of his recent doctoral students received the ANS Mark Mills Award for an outstanding journal article based on their doctoral theses: Dr. Ahmad Alsabbagh in 2014 (Ph.D., NE) and Dr. Boopathy Kombaiah in 2015 (Ph.D., MSE).

Dr. Murty (*center*) accepting ANS Mishima Award in 1993





Photo of Dr. Murty in 2006 receiving ASM-IIM Lectureship Award (*left*); Photo of Dr. Murty receiving IIM Honorary Membership in 2016 (*right*)

Apart from his trail of success in research, teaching, and service, Dr. Murty has been a great philanthropist. He instituted the Linga Murty Gold Medal which is awarded to the best outgoing student of the BE Metallurgical Engineering of Andhra University in India. He also started a scholarship program for the best student in the third year of the Metallurgical Engineering Department at the Andhra University since 2000 in the memory of his father, Kalaprapoorna Dr. Korukonda Subba Raju. Dr. Murty and his wife, Ratnaveni, also instituted a scholarship program at NCSU in 2012 for outstanding undergraduate student applicants in Nuclear Engineering and/or Materials Science and Engineering. However, what has not been always known is that he has changed lives of many by serving as their mentors. The lead editor (Prof. I. Charit) of this book was a postdoctoral researcher in his research group during 2005–2007. Dr. Murty’s mentorship and advice have been extremely valuable in IC’s career, and notably, the collaboration fostered continued long after leaving his group ultimately culminating into writing of a nuclear materials textbook published in 2013. When Prof. Y.T. Zhu (a co-editor of this proceedings volume) joined NCSU in 2007 after working in Los Alamos National Laboratory, Dr. Murty gave him excellent advice on academic life in a university. They have also often discussed scientific issues and helped each other in research facilities and experiments. Another co-editor (Dr. S. Maloy) has enjoyed many discussions with Dr. Murty over several years on radiation effects in materials and co-authored a paper on strain aging in ferritic/martensitic steel. The other co-editor, Prof. P. Liaw, and Prof. Murty were colleagues at the Westinghouse R&D Center. They have been co-organizers and co-editors of proceedings of several ASM/TMS symposia including *Microstructures and Mechanical Properties of Aging Materials—I* (TMS, 1993); *Microstructures and Mechanical Properties of Aging Materials—II* (TMS, 1995); and *Non-Destructive Evaluation and Material Properties—IV* (TMS, 1999).

Dr. Murty and his wife with
2016 Murty Scholarship
Recipient Mr. Travis Willis



It has truly been an honor and privilege for us to be able to organize the symposium honoring Professor Murty's numerous contributions and his 75th birthday, and publish this book with a significant number of papers. Dr. Murty has been a role model and inspiration to many of us and his colleagues. He will always be held in high esteem among his fellow researchers and scholars, and future researchers for many years to come. Finally, we would like to thank all the authors of this book and all the participants of the symposium for their contributions. Without their valuable support, this day would not have come.

Indrajit Charit
Yuntian T. Zhu
Stuart A. Maloy
Peter K. Liaw