Lecture Notes in Mechanical Engineering

Lecture Notes in Mechanical Engineering (LNME) publishes the latest developments in Mechanical Engineering—quickly, informally and with high quality. Original research reported in proceedings and post-proceedings represents the core of LNME. Volumes published in LNME embrace all aspects, subfields and new challenges of mechanical engineering. Topics in the series include:

- Engineering Design
- Machinery and Machine Elements
- Mechanical Structures and Stress Analysis
- Automotive Engineering
- Engine Technology
- Aerospace Technology and Astronautics
- Nanotechnology and Microengineering
- Control, Robotics, Mechatronics
- MEMS
- Theoretical and Applied Mechanics
- Dynamical Systems, Control
- Fluid Mechanics
- Engineering Thermodynamics, Heat and Mass Transfer
- Manufacturing
- Precision Engineering, Instrumentation, Measurement
- Materials Engineering
- Tribology and Surface Technology

To submit a proposal or request further information, please contact the Springer Editor of your location:

China: Ms. Ella Zhang at ella.zhang@springer.com
India: Priya Vyas at priya.vyas@springer.com
Rest of Asia, Australia, New Zealand: Swati Meherishi at swati.meherishi@springer.com
All other countries: Dr. Leontina Di Cecco at Leontina.dicecco@springer.com

To submit a proposal for a monograph, please check our Springer Tracts in Mechanical Engineering at https://link.springer.com/bookseries/11693 or contact Leontina.dicecco@springer.com

Indexed by SCOPUS. All books published in the series are submitted for consideration in Web of Science.

More information about this series at https://link.springer.com/bookseries/11236

Amaresh Chakrabarti · Satyam Suwas ·
Manish Arora
Editors

Industry 4.0 and Advanced Manufacturing

Proceedings of I-4AM 2022

Springer

Editors
Amaresh Chakrabarti
Centre for Product Design
and Manufacturing
Indian Institute of Science Bangalore
Bengaluru, India

Manish Arora
Centre for Product Design
and Manufacturing
Indian Institute of Science Bangalore
Bengaluru, India

Satyam Suwas
Department of Materials Engineering
Indian Institute of Science Bangalore
Bengaluru, India

ISSN 2195-4356 ISSN 2195-4364 (electronic)
Lecture Notes in Mechanical Engineering
ISBN 978-981-19-0560-5 ISBN 978-981-19-0561-2 (eBook)
https://doi.org/10.1007/978-981-19-0561-2

Preface

Industry 4.0 is about using connected intelligence to usher in greater productivity, quality, flexibility, safety and resource utilisation across manufacturing enterprises, in which advanced manufacturing such as Robotics or Additive Manufacturing plays a critical role.

The collection of papers in this book volume constitutes the Proceedings of the Second International Conference on Industry 4.0 and Advanced Manufacturing (I-4AM 22) held online at the Indian Institute of Science, Bangalore, India, during 10–11 January 2022. I-4AM 22 is the second in a series of biennial conferences held in India to bring together all stakeholders in manufacturing and Industry 4.0, in particular, those in academia and industry in both India and abroad, for them to deliberate on the nature, needs, challenges, opportunities, problems and solutions in this transformational area of endeavour.

I-4AM 22 was hosted online in Bangalore, the "silicon plateau" of the world, with the second fastest-growing community of start-ups, many of which are exploring emerging technologies such as IoT, IIoT, digital twins, sensor networks, I4.0 and so on to design new products, systems and services. The theme for I-4AM 22 was aligned with this ambiance. A specific focus of this conference is to provide a platform for exploring avenues for creating a vision of, and enablers for sustainable, affordable and human-centric Industry 4.0 and to showcase cutting-edge practice, research and educational innovation in this crucial and rapidly evolving area.

Seventy-Seven full papers were submitted, which were reviewed by experts from the I-4AM 2022 International Programme Committee comprising 75 members from 13 countries spanning 5 continents. Finally, 41 full papers, authored by 119 researchers from 4 countries spanning 2 continents were selected for presentation at the conference and for publication as chapters in this book. I-4AM has grown, starting from a humble beginning in 2019 with 28 papers to the current 41 papers with over 140 people who attended the conference.

I-4AM 22 had 41 papers presentations followed by discussion. It had eight academic keynotes from prominent researchers and practitioners from around the world such as Diane J Mynors from Brunel University London, UK, Paulo Bartolo from Nanyang Technological University (NTU), Singapore, S N Omkar from Indian

Institute of Science, Bangalore, India, Soundar Kumara from Pennsylvania State University, USA, Satyandra K. Gupta from University of Southern California, USA, Seeram Ramakrishna from National University of Singapore, Singapore, Ashutosh Tiwari from The University of Sheffield, UK, and Manoj Kumar Tiwari from NITIE Mumbai.

It had two Industrial keynotes from prominent industry and organisations around India, such as Giridhar M Prabhakar from Siemens Technology and Services Limited, India, and Ms. Nidhi Chhibber from DHI GoI, India. It had three panel discussions: "Industry needs for I-4.0 & AM"; "Manufacturing Needs of the strategic sector"; and "Industry needs for training and education in manufacturing". Over thirty thought leaders from industry, academia and policy sectors participated in the panel discussions.

Bengaluru, India

Amaresh Chakrabarti
Satyam Suwas
Manish Arora

Major Sponsors

Springer
Indian Institute of Science

Conference Organisation

Advisory Committee

B. Gurumoorthy, Indian Institute of Science, Bangalore, India (Chair)
Bharadwaj Amrutur, Indian Institute of Science, Bangalore, India
Debashish Bhattacharjee, Tata Steel, India
U. Chandrasekhar, Wipro 3D, India
Das, Debabrata, International Institute of Information Technology (IIIT), Bangalore, India
R. Gnanamoorthy, Indian Institutes of Technology Madras, India
PS. Goel, National Institute of Advanced Studies (NIAS), Bangalore, India
Kris. Gopalakrishnan, Axilor Ventures, India
Mike Gregory, University of Cambridge, UK
Vikram Jayaram, Indian Institute of Science, Bangalore, India
Kishore Jayaraman, Rolls Royce, India
Suhas S. Joshi, Indian Institutes of Technology, Bombay, India
Pramod Khargaonkar, University of California, Irvine, USA
Banshidhar Majhi, Indian Institute of Information Technology, Design and Manufacturing, Kancheepuram, India
KM. Mandanna, Ashok Leyland, India
Nagahanumaiah, Central Manufacturing Technology Institute (CMTI), Bangalore, India
Y. Narahari, Indian Institute of Science, Bangalore, India
Suresh Palanisamy, Swinburne University, Australia

Rudra Pratap, Indian Institute of Science, Bangalore, India
P. Radhakrishnan, PSG Institute of Technology, Coimbatore, India
Seeram Ramakrishna, National University of Singapore, Singapore
V. Bhujanga Rao, National Institute of Advanced Studies (NIAS), Bangalore, India
Satheesh Reddy, Defence Research and Development Organisation (DRDO), India
Subra Suresh, Nanyang Technological University, Singapore
Manoj Kumar Tiwari, National Institute of Industrial Engineering (NITIE), India
Prasad Yarlagadda, Queensland University of Technology, Australia

Conference and Programme Chair

Amaresh Chakrabarti, Indian Institute of Science, Bangalore, India
Satyam Suwas, Indian Institute of Science, Bangalore, India

Vice-chair

Manish Arora, Indian Institute of Science, Bangalore, India

Co-Chairs

Nico Adams, Swinburne University, Australia
Ramesh Babu, Indian Institute of Technology, Madras, India
Paulo JDS. Bartolo, University of Manchester, UK
Walter Frenz, RWTH Aachen, Germany
Satyandra K. Gupta, University of Southern California, USA
Sunil Jha, Indian Institutes of Technology Delhi, India
Mark Jolly, Cranfield University, UK
Satish Vasu Kailas, Indian Institute of Science, Bangalore, India
K.P. Karunakaran, Indian Institutes of Technology Bombay, India
Tim Minshall, University of Cambridge, UK
Hiroyuki Morikawa, University of Tokyo, Japan
Surja Kanta Pal, Indian Institutes of Technology Kharagpur, India
PVM Rao, Indian Institutes of Technology Delhi, India
B. Ravi, Indian Institutes of Technology Bombay, India
Rajkumar Roy, City University of London, UK
Christopher A. Schuh, MIT, USA
Rachuri Sudarsan, Department of Energy, USA
Puneet Tandon, Indian Institute of Information Technology, Design and Manufacturing, Jabalpur, India
Asim Tewari, Indian Institutes of Technology Bombay, India

International Programme Committee

V. Anbu, Indian Machine Tool Manufacturers' Association (IMTMA), India
Vivek Bajpai, Indian Institute of Technology (Indian School of Mines) Dhanbad, India
Dipankar Banerjee, Indian Institute of Science, India
Amar Behera, University of Chester, UK
Shalabh Bhatnagar, Indian Institute of Science, India
Pradipta Biswas, Indian Institute of Science, India
Abdelaziz Bouras, Qatar University, Qatar
Ratna Babu Chinnam, Wayne State University, USA
Olaf Ciszak, Poznan University of Technology, Poland
Sivasrinivasu Devadula, Indian Institute of Technology Madras, India
Rameshwar Dubey, Liverpool John Moores University, UK
Bashar El-Khasawneh, Khalifa University, United Arab Emirates
Joao Federal Ferreira, University of Santa Catarina (UFSC), Brazil
Alejandro Germán Frank, Federal University of Rio Grande do Sul, Brazil
G. R. Jayanth, Indian Institute of Science, India
Ashitava Ghosal, Indian Institute of Science, India
Gopinath Muvvala, Indian Institute of Technology Hyderabad, India
Suhasini Gururaja, Indian Institute of Science, India
Karl R. Haapala, Oregon State University, USA
Yiinlun Huang, Wayne State University, USA
Vipul Jain, Victoria University of Wellington, New Zealand
Jayakrishna Kandasamy, Vellore Institute of Technology (VIT), India
Amlan Kar, Indian Institute of Technology (Indian School of Mines) Dhanbad, India
Satyabodh Kulkarni, National Institute of Technology Karnataka, India
C. S. Kumar, Indian Institute of Technology Kharagpur, India
Kumara, Soundar, The Pennsylvania State University, USA
Senthilkumaran Kumaraguru, Indian Institute of Information Technology, Design and Manufacturing, Kancheepuram, India
Jay Lee, University of Cincinnati, USA
N. Madhusudanan, Corporate Technology, Siemens, India
Ajay Malshe, Purdue University, USA
Monto Mani, Indian Institute of Science, India
Kusum Meena, Indian Institute of Technology Delhi, India
Amiya Mohanty, Indian Institute of Technology Kharagpur, India
Diane Mynors, Brunel University, UK
S. K. Ong, National University of Singapore, Singapore
Sanjay Pande, Indian Institute of Technology Bombay, India
Fritz Prinz, Stanford University, USA
Thulasi Raman, Indian Institute of Science, India
Anton Rassõlkin, Tallinn University of Technology, Estonia
Fayyaz Rehman, Southampton Solent University, UK

G. L. Samuel, Indian Institute of Technology Madras, India
Vivek Sangwan, Indian Institute of Technology Bombay, India
S. P. Sarmah, Indian Institute of Technology Kharagpur, India
Dibakar Sen, Indian Institute of Science, India
Mahmoud Shafik, University of Derby, UK
Himanshu Shee, Victoria University, Australia
Vijay Srinivasan, National Institute of Standards and Technology, USA
Nachiappan Subramanian, University of Sussex, UK
John W. Sutherland, Purdue University, USA
Tetsuo Tomiyama, International Professional University of Technology in Tokyo, Japan
Arun Dayal Udai, Indian Institute of Technology (Indian School of Mines) Dhanbad, India
S. Vinodh, National Institute of Technology Trichy, India
Koushik Viswanathan, Indian Institute of Science, India
Chandrika Prakash Vyasarayani, Indian Institute of Technology Hyderabad, India
Paul-William Witherell, National Institute of Standards and Technology, USA
Lang Yuan, University of South Carolina, USA

Local Organising Committee

Mr. Ansuman Sahu, Indian Institute of Science, Bangalore, India
Mr. Anubhab Majumder, Indian Institute of Science, Bangalore, India
Mr. Apoorv Naresh Bhatt, Indian Institute of Science, Bangalore, India
Mr. Arun S. Kumar, Indian Institute of Science, Bangalore, India
Ms. Charu Tripathi, Indian Institute of Science, Bangalore, India
Mr. Govind Kumar, Indian Institute of Science, Bangalore, India
Mr. Ishaan Kaushal, Indian Institute of Science, Bangalore, India
Mr. Kaushik Bhattacharya, Indian Institute of Science, Bangalore, India
Mr. Kiran Ghadge, Indian Institute of Science, Bangalore, India
Ms. Naz Yaldiz, Indian Institute of Science, Bangalore, India
Ms. Nishath Salma, Indian Institute of Science, Bangalore, India
Mr. Prasanth Soundappan, Indian Institute of Science, Bangalore, India
Mr. Priti Panda, Indian Institute of Science, Bangalore, India
Mr. Puneeth K. S., Indian Institute of Science, Bangalore, India
Ms. Sanika Paranjape, Indian Institute of Science, Bangalore, India
Mr. Sanjay Singh, Indian Institute of Science, Bangalore, India
Mr. Subin Raj, Indian Institute of Science, Bangalore, India
Mr. Vivek Upadhyay, Indian Institute of Science, Bangalore, India
Mr. B. Karthick, Indian Institute of Science, Bangalore, India
Mr. Surenderan Krishnan, Indian Institute of Science, Bangalore, India
Mr. Venu Allam, Indian Institute of Science, Bangalore, India

About This Book

This book, Industry 4.0 and Advanced Manufacturing—Proceedings of I-4AM 2022, focuses on the following topics:

- Controls, Autonomous Systems, Robotic
- Digital Manufacturing
- Industry 4.0
- Materials Processing and Joining
- Policy and Entrepreneurship
- Supply Chains
- Sustainable Manufacturing

On behalf of the Steering Committee, Advisory Committee, Organising Committee and Co-chairs, we thank all the authors, delegates, institutions and organisations that participated in the conference. We also thank the members of the International Programme Committee for their support in reviewing the papers for I-4AM 22, which is essential for maintaining the quality of the conference, and for their support in helping us put this book together.

We are thankful to the major sponsors (Indian Institute of Science and Springer); other industry partners (Ashok Leyland, Tata Consultancy Services (TCS), Yaskawa, Toyota Kirloskar and Faurecia) and partnering departments (Centre for Product design and Manufacturing, Robert Bosch Centre for Cyber Physical Systems, Department of Aerospace Engineering, Department of Electronic Systems Engineering, Department of Electrical Communications Engineering, Centre for Sustainable Technology, Department of Instrumentation and Applied Physics, Department of Civil Engineering, Department of Materials Engineering, Department of Mechanical Engineering and Department of Management Studies) for their kind endorsement of I-4AM 22. We thank the Indian Institute of Science (IISc), Bangalore, and its Centre for Product Design and Manufacturing, for their support of this event by allowing their employees and students to be involved for the various functions at the conference. We also wish to place on record and acknowledge the enormous support provided by Mr. Venu Allam, Mr. Karthick B., Ms. Nishath Salma, Dr. Shakuntala Acharya, Mr. Kiran Ghadge, Mr. Puneeth K. S., Mr. Ishaan Kaushal, Mr. Apoorv Bhatt, and Mr.

Anubhab Majumdar of IISc in managing the review process, in the preparation of the conference programme and booklet, and for their help in preparing this book and the conference as a whole. We also thank the large and dedicated group of student volunteers of IISc Bangalore for the organisation of the conference. Finally, we thank Springer and its editorial support team, especially its Editorial Director Ms. Swati Meherishi, for their wonderful support.

Bengaluru, India

Amaresh Chakrabarti
Satyam Suwas
Manish Arora

Contents

About the Editors

Prof. Amaresh Chakrabarti is a Senior Professor and current Chairman of the Centre for Product Design & Manufacturing, Indian Institute of Science (IISc), Bangalore. He has B.E. in Mechanical Engineering from Indian Institute of Engineering Science and Technology, Shibpur, M.E. in Design of Mechanical Systems from Indian Institute of Science, Bengaluru, and Ph.D. in Engineering Design from the University of Cambridge, UK. He led the Design Synthesis group at the EPSRC funded Engineering Design Centre at the University of Cambridge before joining IISc as an Associate Professor in 2001. His interests are in synthesis, creativity, sustainability, and informatics. He has published 16 books, over 300 peer-reviewed articles, and has 11 patents granted/pending. He has been on the Advisory Board and the Board of Management of the Design Society, UK; member of the CII National Committee on Design India; member of the Jury of India Design Mark; and member of the CII Smart Manufacturing Council India. He founded IDeASLab—India's first Design Observatory. He is the Founding Programme chair for International Conference Series on Research into Design (ICoRD), Conference Chair for the 22nd CIRP Design Conference 2012 and the 3rd International Conference on Design Creativity 2015 (3rd ICDC) and vice-Chair for AI in Design and Design Computing & Cognition Conferences. In 2014, he co-initiated India's first Smart Factory R&D platform.

Prof. Satyam Suwas is a Professor and current chair of the Department of Materials Engineering, Indian Institute of Science (IISc). He received his Ph.D. from Indian Institute of Technology (IIT), Kanpur, India, M.Tech. from Indian Institute of Technology (IIT), Kanpur, India, and M.Sc. from Banaras Hindu University (BHU), India, all in the area of materials engineering. His current interests include processing texture relationship in structural and functional materials, deformation and thermomechanical processing, nano-structured materials by severe plastic deformation, high temperature structural materials for aerospace and other applications. Some of his professional experiences include Alexander von Humboldt re-visiting fellow,

at Institut für Metallkunde und Metallphysik, RWTH, Germany, IUSSTF fellow, Carnegie Mellon University, USA, Maître dé conférences 'invité' (Invited Assistant Professor) at Université Paul Verlaine de Metz, France, among others. He is also a Fellow of the Indian National Academy of Engineering (INAE).

Dr. Manish Arora is an Assistant Professor in the Centre for Product Design and Manufacturing, Indian Institute of Science (IISc), Bengaluru. He obtained Ph.D. in applied Physics from the University of Twente, The Netherlands (2006) and B.Tech. in Chemical Engineering from Indian Institute of Technology (IIT), Delhi (2002). He has 70+ patents and research publications both in national and international level to his credit. His areas of interest include biomedical devices, co-design, collaboration, opensource in design and quality manufacturing of medical devices. He is the Principal Investigator in UTSAAH Lab, which aims at developing affordable and accessible medical technology solutions for promoting universal healthcare. He also teaches courses at IISc on Mechatronics and Design of Biomedical Devices and Systems. His research group has won numerous awards for innovative and affordable designs, including Gandhian Young Technology Innovation (GYTI) Award, James Dyson Award, etc.