

Springer Tracts in Additive Manufacturing

Adam Khan M.
Gurpreet Singh
Sarina Sulaiman *Editors*

Challenges and Innovations in 3D Printed Bio-Organs and Their Materials

 Springer

Springer Tracts in Additive Manufacturing

Series Editor

Henrique de Amorim Almeida, Polytechnic Institute of Leiria, Leiria, Portugal

Editorial Board

Abdulsalam Abdulaziz Al-Tamimi, Riyadh, Saudi Arabia

Rodrigo Alvarenga Rezende, Uniara, Araraquara, Brazil

Helena Bártolo, Politécnico de Leiria, Leiria, Portugal

Deon de Beer, Bloemfontein, South Africa

Alain Bernard, Ecole Centrale de Nantes, IRCCyN UMR CNRS 6597, Nantes Cedex 03, France

Richard Bibb, Loughborough University, Leicestershire, UK

Andrew Boydston, University of Washington, Seattle, USA

Paulo Jorge da Silva Bártolo, Nanyang Technological University, Singapore, Singapore

Joaquim de Ciurana, University of Girona, Girona, Spain


Igor Drstvensek, University of Maribor, Maribor, Slovenia

Giorgia Franchin, Dipartimento di Ingegneria Industriale - DII, Università Degli Studi Di Padova, Padova, Italy

Ian Gibson, University of Twente, Enschede, The Netherlands

Bahattin Koc, Maltepe, Sabanci University, Istanbul, Türkiye

Tatjana Kosova Spahiu, Mother Tereza Square, Polytechnic University of Tirana, Tirana, Albania

Eujin Pei , College of Engineering, Design and Physical Sciences, Brunel University London, London, UK

David W. Rosen, Atlanta, USA

Brent Stucker, Louisville, USA

Mayra Vasques, Department of Dentistry, Faculdade Israelita de Ciências da Saúde Albert Einstein, São Paulo, Brazil

Ryan Wicker, University of Texas at El Paso, El Paso, USA

Evren Yasa, Advanced Manufacturing Research Centre, University of Sheffield, Blackburn, UK


*** Indexed in Scopus 2024 ***

The book series aims to recognise the innovative nature of additive manufacturing and all its related processes and materials and applications to present current and future developments. The book series will cover a wide scope, comprising new technologies, processes, methods, materials, hardware and software systems, and applications within the field of additive manufacturing and related topics ranging from data processing (design tools, data formats, numerical simulations), materials and multi-materials, new processes or combination of processes, new testing methods for AM parts, process monitoring, standardization, combination of digital and physical fabrication technologies and direct digital fabrication.

Adam Khan M. · Gurpreet Singh · Sarina Sulaiman
Editors

Challenges and Innovations in 3D Printed Bio-Organs and Their Materials

Editors

Adam Khan M. 
Department of Mechanical Engineering
Kalasalingam Academy of Research
and Education
Srivilliputhur, Tamil Nadu, India

Gurpreet Singh
Centre for Biomedical Engineering
Indian Institute of Technology Delhi
New Delhi, Delhi, India

Sarina Sulaiman
Department of Chemical Engineering
and Sustainability
International Islamic University Malaysia
Kuala Lumpur, Malaysia

ISSN 2730-9576 ISSN 2730-9584 (electronic)
Springer Tracts in Additive Manufacturing
ISBN 978-3-031-90806-4 ISBN 978-3-031-90807-1 (eBook)
<https://doi.org/10.1007/978-3-031-90807-1>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature
Switzerland AG 2025

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

If disposing of this product, please recycle the paper.

*Thanks to ALMIGHTY
Editors would like to dedicate this book to the
Management and Administration Team of
Our Institutes.*

*Adam Khan M.
Gurpreet Singh
Sarina Sulaiman*

Preface

The field of 3D printing and additive manufacturing has witnessed remarkable progress in recent years, particularly in biomedical applications. The ability to design, fabricate, and customize complex biological structures using advanced printing technologies has opened new frontiers in tissue engineering, regenerative medicine, and medical implants. As researchers explore innovative materials and fabrication methods, the potential for 3D printed bio-organs and biomaterials to revolutionize modern medicine has become a focal point of scientific investigation.

This book, *Challenges and Innovations in 3D Printed Bio-Organs and Their Materials*, aims to provide a comprehensive exploration of recent advancements, challenges, and future perspectives in the field of 3D printed bio-organs and biomedical materials. It brings together contributions from leading experts in academia and industry, covering a broad spectrum of topics that address fundamental principles, material developments, biofabrication techniques, and real-world applications of 3D printed organs and implants. The book comprised 16 chapters, each offering an in-depth discussion on various aspects of 3D printing in biomedical science. These chapters highlight the fundamental mechanisms, key challenges, recent innovations, and future directions in the field. It covers a range of critical topics, including biomaterials, antibacterial bioinks, additive manufacturing techniques, tribological and mechanical behavior of biomedical implants, and applications in diabetic care and skin disorders.

This book serves as a valuable resource for researchers, biomedical engineers, clinicians, and students interested in bioprinting, medical implants, and tissue engineering. It offers:

- Fundamentals of 3D Printed Bio-Organs and Tissue Engineering, including the latest materials, methods, and antibacterial bioinks for organ fabrication.
- Advancements in Additive Manufacturing, covering innovations in medical solutions for diabetic patients, 3D printing in diabetes care, and bio-compatible metal implants.

- Tribological and Wear Analysis of Biomedical Materials, focusing on titanium alloys, polymeric materials for skin disorders, and the role of Ti6Al4V alloys in implant development.
- Future Perspectives, addressing the biocompatibility of additive manufacturing processes and the latest trends in soft materials and soft gel applications for artificial organ development.

Chapters 1–5 of the book introduces fundamental concepts of 3D printed organ and tissue engineering, including an overview of the latest biofabrication methods and the role of biomaterials and bioinks in creating functional tissues and organs. The initial chapters explore the potential of 3D printed organ models, their clinical relevance, and the latest innovations in biofabrication. Subsequent Chaps. 6–11 focus on advancements in additive manufacturing for biomedical applications, detailing novel biomaterials, metal implants, and polymer-based solutions for tissue repair and organ regeneration. These chapters also discuss the role of metallic and polymeric materials in the development of bio-compatible implants, emphasizing the importance of biomechanical properties and long-term durability. Chapters 12 and 13 explore the latest developments in 3D printing for diabetic care, including customized insoles, wound healing techniques, and pressure offloading solutions for patients with diabetic foot ulcers. The final chapters (Chaps. 14–16) address emerging trends in the field, including 3D printing of textured Ti6Al4V alloy for enhanced implants, biocompatibility studies, and advances in soft materials and soft gels for artificial organ fabrication. These topics provide valuable insights into the next generation of biomedical devices and implantable structures, emphasizing their clinical implications and translational potential.

We hope that this book inspires further research and innovation in 3D printed bio-organs and biomaterials. We extend our heartfelt gratitude to all the contributors, reviewers, and editorial team members who have played a crucial role in making this book possible. Their expertise and dedication have significantly enriched the content, making this volume a valuable reference for the scientific community.

Srivilliputhur, India
New Delhi, India
Kuala Lumpur, Malaysia

Adam Khan M.
Gurpreet Singh
Sarina Sulaiman

Contents

1	Current Approaches in 3D Printed Organ and Tissues Engineering	1
	Balaji Govindaswamy, Israel John, Rithika Thangaraju, Murugappan Kumarappan, and Sanjay B. Vasam	
2	Challenges and Innovations in 3D Printed Biomaterials and Biomedical Applications	45
	Cem Alparslan and Şenol Bayraktar	
3	3D Printing of Bio-organs: Materials, Methods and Future Prospects	67
	Kota Sobha, K. Lakshmi Chaitanya, Ratnakumari Anantha, and Sneha H. Dhorja	
4	The Integration of Innovative Antibacterial Bioinks in 3D Printing of Human Organs	111
	D. Priyadharshini, C. Logeshwaran, V. Aruna Janani, U. Lakshmana Bharathi, B. Muthu Rajesh, Umar Faarukh, and K. S. Devika	
5	Challenges and Innovations in 3D Printed Bio-organs and Their Materials	149
	M. Indira, K. Abraham Peele, Pooja Angolkar, and T. Ram Prabhu	
6	Advances in Additive Manufacturing for Biomedical Applications	177
	T. Arunnellaiappan, Arun Raphel, S. Arun, Joby Joseph, and Tomson Anjilavellil	
7	Tribological Behaviour and Wear Mechanisms of Titanium Alloys in Bio-medical Applications	209
	K. Thavasilingam, D. Sakthimurugan, S. Prasanna Raj Yadav, R. Selva Bharathi, and A. Perumal	

8	Recent Trends and Future Prospects in Metallic Implants for Biomedical Applications	223
	Jayakrishna Kandasamy, S. Arulvel, P. Jeyapandiarajan, Mohanram Murugan, and R. Prayer Riju	
9	Role of Polymers for Skin Disorders	255
	Balaji Govindaswamy and Pulakhandam Sai Kirti	
10	Biocompatibility of Additively Manufactured Metal Implants	281
	K. Arunprasath, S. Kavitha, S. Ramasamy, R. Nalaeram Sivaram, and M. Armstrong	
11	Development of Biocompatible Medical Implants Using Metal Additive Manufacturing	319
	P. Vijaya Kumar and C. Velmurugan	
12	Additive Manufacturing of Medical Solutions for Diabetic Patients	365
	Vaishnavi Babu, Lakshmanan Muthulakshmi, and Nellaiah Hariharan	
13	3D Printing in Diabetes Care: Innovations in Treatment, Monitoring, and Wound Healing	391
	Himanshu Taneja, Malkeet Singh, Avanish S. Parmar, and Shilpi Chaudhary	
14	Materials and Challenges in the Development of 3D Printed Bio-Organs	403
	Vijay Tambrallimath, Manish Amin, Adarsh Patil, and Priyanka Paul	
15	Advances in 3D Printing Textured Ti6Al4V Alloy for Enhanced Implants: A Review	421
	R. Ganapathy Srinivasan, M. Selvam, K. A. Harish, and S. Palani	
16	Additive Manufacturing of Soft Materials and Soft Gel for Bio-organs	443
	Angshuman Chattopadhyay, S. Suresh Kumar, Temel Varol, and A. Perumal	

Editors and Contributors

About the Editors

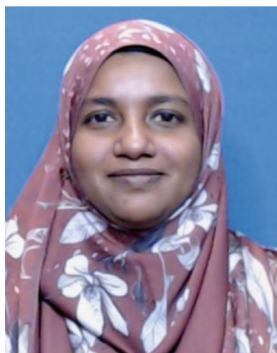


Dr. Adam Khan M. is working as a Professor and Head—Department of Mechanical Engineering, and heading the Centre for Surface Engineering at Kalasalingam Academy of Research and Education, Virudhunagar, India. He completed his Post Doctoral Research from the University of Johannesburg, Doornfontein Campus, Johannesburg, South Africa. He received his Doctoral Degree from the National Institute of Technology, Tiruchirappalli, India, and his Undergraduate and Postgraduate Degrees from Anna University, Chennai, India. His research focus is on material development for different engineering applications. He has developed nickel-based superalloys through a direct laser sintering process for high temperatures. Current his research interest has focused on metal for bio medical engineering and surface sciences. He is working in the invitro analysis on 3D printed and commercial titanium implants; before and after material processing. The research has been placed in track to report the surface quality and cell viability. In addition, the biocompatibility of the same processed materials is studied using simulated body fluids. Recently the research has been more focused to develop the titanium implant material through direct laser sintering process (DMLS) additive-built material and its post processing. Further, the material has been investigated for different property studies, including mechanical strength, surface qualities, corrosion, and oxidation behavior. Beyond his

research, he is serving as a reviewer for more than 30 journals. He also had a chance to serve as Guest Lead Editor for the Journals and Books hosted by SpringerNature, Elsevier, Hindawi and Taylor & Francis publishers. He has published more than one hundred and thirty research articles in the journal of international repute. He has good knowledge of teaching-learning process (outcome-based education) evaluation. Under his supervision, two research scholars have been awarded doctoral degree.



Gurpreet Singh is a Ph.D. scholar at the Centre for Biomedical Engineering, Indian Institute of Technology Delhi, India. He is a recipient of the most prestigious Ph.D. fellowship in India, the Prime Minister's Research Fellowship (PMRF), in the May 2021 cycle. His research interests are soft tissue mechanics, artificial tissues, biomimetics, and computational biomechanics. He is working on the computational modeling of the diabetic foot and its ulceration progression. He is also working on developing artificial human tissue surrogates for injury and disease modeling. Previously, much of his work has been on improving the surface characteristics and bioactivity of metallic biomaterials, with research interests including surface engineering, materials science, biomaterials, and non-conventional machining processes. He worked on the surface modification of metallic biomaterials using electro-discharge machining, where he studied the bioactivity of modified surfaces in terms of wear resistance, corrosion resistance, and other biological responses. He has authored/edited 3 books and contributed 50+ research papers and book chapters to leading international journals and conferences. He is the recipient of the Top Cited Paper Award 2023 for his review article on *Mechanical Properties of Whole-body Soft Human Tissues: A Review* by IOP Publishing and the Research Excellence Travel Award by the Indian Institute of Technology Delhi for this significant research contribution. He also serves as a reviewer for prominent international journals of repute.



Dr. Sarina Sulaiman graduated from University Putra Malaysia (UPM) with a Bachelor of Engineering (Chemical) in 2004 and Master of Science (M.Sc.) in Chemical Engineering. Her M.Sc. research focused on composites and development of brake pad from carbon fiber reinforced phenolic resin. Then, she pursued her Ph.D. and graduated from UM in 2012. Her Ph.D. research was on biodiesel production using reactive extraction. Currently she is an Associate Professor at the Department of Chemical Engineering and Sustainability. Dr. Sarina's research interests include biofuel production, renewable energy technologies, green technology, heterogeneous catalysis, and chemical reaction engineering. She has published over 50 research articles. Her research grants, both as a principal investigator and co-researcher, are valued at over RM 320,000.

Contributors

K. Abraham Peele Department of Biotechnology, Vignan's Foundation for Science Technology and Research, Vadlamudi, Andhra Pradesh, India

Cem Alparslan Faculty of Engineering and Architecture, Department of Mechanical Engineering, Recep Tayyip Erdoğan University, Rize, Turkey

Manish Amin Avay Biosciences—IKP-EDEN, Bangalore, India

Ratnakumari Anantha Department of Clinical Research, Sibar Institute of Dental Sciences, Guntur, Andhra Pradesh, India

Pooja Angolkar Department of Robotics and Automation Engineering, Angadi Institute of Technology and Management, Belagavi, Karnataka, India

Tomson Anjilavellil Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

M. Armstrong Department of Mechanical Engineering, PSN College of Engineering and Technology, Tirunelveli, Tamil Nadu, India

S. Arulvel Department of Manufacturing Engineering, School of Mechanical Engineering, VIT University, Vellore Campus, Vellore, Tamil Nadu, India

S. Arun National Institute of Technology Calicut, Kozhikode, India

V. Aruna Janani Department of Chemical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, India

T. Arunnellaiappan SRM TRP Engineering College, Tiruchirappalli, Tamil Nadu, India

K. Arunprasath Department of Mechanical Engineering, PSN College of Engineering and Technology, Tirunelveli, Tamil Nadu, India

Vaishnavi Babu Biomaterials and Product Development Laboratory, Department of Biotechnology, School of Bio, Chemical and Processing Engineering, Kalasalingam Academy of Research and Education, Krishnankovil, Tamil Nadu, India

Şenol Bayraktar Faculty of Engineering and Architecture, Department of Mechanical Engineering, Recep Tayyip Erdoğan University, Rize, Turkey

Angshuman Chattopadhyay Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, Virudhunagar, Tamil Nadu, India

Shilpi Chaudhary Physics Department, Punjab Engineering College (Deemed to Be University), Chandigarh, India

K. S. Devika Department of Chemical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, India

Sneha H. Dhoria Department of Mechanical Engineering, RVR&JC College of Engineering (A), Guntur, Andhra Pradesh, India

Umar Faarukh Department of Chemical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, India

R. Ganapathy Srinivasan Department of Mechanical Engineering, Vel Tech Multi Tech Dr. Rangarajan Dr. Sakunthala Engineering College, Chennai, Tamil Nadu, India

Balaji Govindaswamy Department of Biotechnology, Bhupat and Jyoti Mehta School of Biosciences, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India;
Department of Biotechnology, School of Biotechnology and Genetic Engineering, Bharathidasan University, Tiruchirappalli, Tamil Nadu, India

Nellaiah Hariharan Shelcel Biozeen Technologies Pvt. Ltd., Bangalore, Karnataka, India

K. A. Harish Department of Mechanical Engineering, Vel Tech Multi Tech Dr. Rangarajan Dr. Sakunthala Engineering College, Chennai, Tamil Nadu, India

M. Indira Department of Biotechnology, Vignan's Foundation for Science Technology and Research, Vadlamudi, Andhra Pradesh, India

P. Jeyapandiarajan Department of Manufacturing Engineering, School of Mechanical Engineering, VIT University, Vellore Campus, Vellore, Tamil Nadu, India

Israel John Department of Molecular Microbiology, School of Biotechnology, Madurai Kamaraj University, Madurai, Tamil Nadu, India

Joby Joseph Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

Jayakrishna Kandasamy Department of Manufacturing Engineering, School of Mechanical Engineering, VIT University, Vellore Campus, Vellore, Tamil Nadu, India

S. Kavitha Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Virudhunagar, Tamil Nadu, India

Pulakhandam Sai Kirti Department of Chemical Engineering, Indian Institute of Technology Bombay, Mumbai, MH, India

P. Vijaya Kumar Department of Mechanical Engineering, Indian Institute of Information Technology, Tiruchirappalli, Tamil Nadu, India

Murugappan Kumarappan Department of Biotechnology, School of Biotechnology and Genetic Engineering, Bharathidasan University, Tiruchirappalli, Tamil Nadu, India

U. Lakshmana Bharathi Department of Biotechnology, Kalasalingam Academy of Research and Education, Krishnankoil, India

K. Lakshmi Chaitanya Department of Mechanical Engineering, RVR&JC College of Engineering (A), Guntur, Andhra Pradesh, India

C. Logeshwaran Department of Chemical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, India

Mohanram Murugan Department of Manufacturing Engineering, School of Mechanical Engineering, VIT University, Vellore Campus, Vellore, Tamil Nadu, India

Lakshmanan Muthulakshmi Biomaterials and Product Development Laboratory, Department of Biotechnology, School of Bio, Chemical and Processing Engineering, Kalasalingam Academy of Research and Education, Krishnankovil, Tamil Nadu, India

B. Muthu Rajesh Department of Chemical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, India

S. Palani Department of Mechanical Engineering, Sri Venkateswara College of Engineering and Technology, Thirupachur, Tamil Nadu, India

Avanish S. Parmar Department of Physics, Indian Institute of Technology (BHU), Uttar Pradesh, Varanasi, India

Adarsh Patil School of Mechanical Engineering, KLE Technological University, Hubballi, India

Priyanka Paul Avay Biosciences—IKP-EDEN, Bangalore, India

A. Perumal Department of Mechanical Engineering, Sethu Institute of Technology, Karipatti, Virudhunagar, Tamil Nadu, India

S. Prasanna Raj Yadav Department of Mechanical Engineering, Easwari Engineering College, Chennai, India

R. Prayer Riju Department of Manufacturing Engineering, School of Mechanical Engineering, VIT University, Vellore Campus, Vellore, Tamil Nadu, India

D. Priyadharshini Department of Chemical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, India

S. Ramasamy Department of Mechanical Engineering, Annamalai University, Cuddalore, Tamil Nadu, India

T. Ram Prabhu Defence Research and Development Organization (DRDO), Bangalore, Karnataka, India

Arun Raphael SRM Institute of Science and Technology, Chennai, India

D. Sakthimurugan Department of Mechanical Engineering, Easwari Engineering College, Chennai, India

R. Selva Bharathi Department of Mechanical Engineering, AAA College of Engineering and Technology, Sivakasi, Tamil Nadu, India

M. Selvam Department of Mechanical Engineering, Vel Tech Multi Tech Dr. Rangarajan Dr. Sakunthala Engineering College, Chennai, Tamil Nadu, India

Malkeet Singh School of Engineering, Swinburne University of Technology, Hawthorn, VIC, Australia

R. Nalaeram Sivaram Department of Aeronautical Engineering, PSN College of Engineering and Technology, Tirunelveli, Tamil Nadu, India

Kota Sobha RVR&JCCE STP Foundation, RVR&JC College of Engineering (A), Guntur, Andhra Pradesh, India

S. Suresh Kumar Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, Virudhunagar, Tamil Nadu, India

Vijay Tambrallimath Department of Mechanical Engineering, Global Academy of Technology, Bangalore, India

Himanshu Taneja Department of Mechanical Engineering, Punjab Engineering College (Deemed to Be University), Chandigarh, India

Rithika Thangaraju Institute of Bioinformatics and Biotechnology, Savitribai Phule Pune University, Pune, MH, India

K. Thavasilingam Department of Mechanical Engineering, Easwari Engineering College, Chennai, India

Temel Varol Metallurgical and Materials Engineering, Karadeniz Technical University, Trabzon, Turkey

Sanjay B. Vasan CarMeN Laboratory, INSERM, INRAE, Universite Claude Bernard Lyon 1, Pierre-Benite, France

C. Velmurugan Department of Mechanical Engineering, Indian Institute of Information Technology, Tiruchirappalli, Tamil Nadu, India