

SpringerBriefs in Applied Sciences and Technology

Manufacturing and Surface Engineering

Series Editor

Joao Paulo Davim , Department of Mechanical Engineering, University of Aveiro,
Aveiro, Portugal

This series fosters information exchange and discussion on all aspects of manufacturing and surface engineering for modern industry. This series focuses on manufacturing with emphasis in machining and forming technologies, including traditional machining (turning, milling, drilling, etc.), non-traditional machining (EDM, USM, LAM, etc.), abrasive machining, hard part machining, high speed machining, high efficiency machining, micromachining, internet-based machining, metal casting, joining, powder metallurgy, extrusion, forging, rolling, drawing, sheet metal forming, microforming, hydroforming, thermoforming, incremental forming, plastics/composites processing, ceramic processing, hybrid processes (thermal, plasma, chemical and electrical energy assisted methods), etc. The manufacturability of all materials will be considered, including metals, polymers, ceramics, composites, biomaterials, nanomaterials, etc. The series covers the full range of surface engineering aspects such as surface metrology, surface integrity, contact mechanics, friction and wear, lubrication and lubricants, coatings and surface treatments, multiscale tribology including biomedical systems and manufacturing processes. Moreover, the series covers the computational methods and optimization techniques applied in manufacturing and surface engineering. Contributions to this book series are welcome on all subjects of manufacturing and surface engineering. Especially welcome are books that pioneer new research directions, raise new questions and new possibilities, or examine old problems from a new angle. To submit a proposal or request further information, please contact Dr. Mayra Castro, Publishing Editor Applied Sciences, via mayra.castro@springer.com or Professor J. Paulo Davim, Book Series Editor, via pdavim@ua.pt

More information about this subseries at <http://www.springer.com/series/10623>

Fredrick Madaraka Mwema ·
Esther Titilayo Akinlabi

Fused Deposition Modeling

Strategies for Quality Enhancement

 Springer

Fredrick Madaraka Mwema 
Department of Mechanical Engineering
Dedan Kimathi University of Technology
Nyeri, Kenya

Esther Titilayo Akinlabi 
Department of Mechanical
Engineering Science
University of Johannesburg
Auckland Park, Johannesburg, South Africa

ISSN 2191-530X ISSN 2191-5318 (electronic)
SpringerBriefs in Applied Sciences and Technology
ISSN 2365-8223 ISSN 2365-8231 (electronic)
Manufacturing and Surface Engineering
ISBN 978-3-030-48258-9 ISBN 978-3-030-48259-6 (eBook)
<https://doi.org/10.1007/978-3-030-48259-6>

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2020

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, express 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

Preface

Fused deposition modelling (FDM) is one of the most progressive and advanced Additive Manufacturing (AM) methods for the modern industry. The method has proven its suitability as a rapid prototyping technique and for the production of intricate functional components. However, the process faces two major limitations; poor surface quality and limited range of materials as it is mostly applicable to polymer-based raw materials. There are therefore extensive efforts by the AM researchers to enhance the quality of FDM parts and expand its application in different fields.

This book contributes to these continued efforts by presenting different strategies for quality enhancement of the technology. In the book, the terms FDM and 3D printing have been used interchangeably and they have the same meaning. The book is presented in four chapters. In Chap. 1, a general introduction to the fused deposition modelling is presented. A glimpse into different methods of AM technology, science of FDM and its applications, process parameters and quality aspects of FDM technology are presented in this chapter. Most importantly, the role of 3D printing in the fight against Coronavirus disease of 2019 is discussed in Chap. 1. In Chap. 2, a full factorial approach for the design of experiment (DOE) based on different levels of print orientation and layer resolution during FDM of PLA simple samples is presented as a strategy for enhancing both surface finish and micro-hardness properties. In Chap. 3, a multi-objective optimization approach is presented as another strategy for quality enhancement of FDM parts using case studies both from the literature and the experimental work by the authors. Finally, surface engineering technology is presented as a strategy for enhancing the surface and functional quality of the FDM parts in Chap. 4.

All the borrowed information such as methods, data and figures have been acknowledged accordingly inside the text. It is the hope of the authors that the book will, holistically, contribute towards expanding applications of fused deposition modelling parts. The book is suitable for engineers, researchers, academics and industrialists in the 3D printing field.

We acknowledge Springer for accepting to publish this work and the professional support they have accorded to us in the course of developing the idea and writing of the manuscript.

Nairobi, Kenya
Johannesburg, South Africa

Fredrick Madaraka Mwema
Esther Titilayo Akinlabi

Contents

| | | |
|----------|---|-----------|
| 1 | Basics of Fused Deposition Modelling (FDM) | 1 |
| 1.1 | Additive Manufacturing | 1 |
| 1.2 | Science of FDM and Applications | 3 |
| 1.3 | 3D Printing and the Novel Coronavirus (Covid-19) Pandemic | 6 |
| 1.4 | Process Parameters in FDM | 8 |
| 1.5 | Quality Issues in FDM | 10 |
| 1.6 | Summary | 13 |
| | References | 13 |
| 2 | Print Resolution and Orientation Strategy | 17 |
| 2.1 | Introduction | 17 |
| 2.2 | Materials and Methods | 19 |
| 2.3 | Results and Discussions | 22 |
| 2.4 | Summary | 30 |
| | References | 31 |
| 3 | Multi-objective Optimization Strategies | 33 |
| 3.1 | Introduction | 33 |
| 3.2 | Theory of Multi-optimization Techniques | 34 |
| 3.2.1 | Pareto Methods | 35 |
| 3.2.2 | Scalarization Method | 36 |
| 3.3 | Case Studies in Optimization of FDM | 36 |
| 3.3.1 | Case 1: Non-dominated Sorting Genetic Algorithm-II (NSGA-II) | 37 |
| 3.3.2 | Case 2: Signal-to-Noise and Grey Correlation Degree Multi-objective Optimization | 38 |
| 3.3.3 | Case 3: Particle Swarm Optimization Method for Fused Deposition Modelling Process | 40 |
| 3.3.4 | Case 4: Full Factorial and Grey Relational Degree Optimization of FDM Printed PLA | 42 |

- 3.4 Summary 48
- References 48
- 4 Surface Engineering Strategy 51**
- 4.1 Introduction 51
- 4.2 Traditional Surface Engineering Methods for FDM Products 55
 - 4.2.1 Sanding and Polishing 55
 - 4.2.2 Painting and Priming 58
 - 4.2.3 Gap Filling 60
 - 4.2.4 Dipping 60
- 4.3 Advanced Surface Engineering Methods for FDM Products 63
 - 4.3.1 Chemical and Physical Vapour Depositions 63
 - 4.3.2 Vapour Smoothing 65
- 4.4 Summary 66
- References 67

About the Authors

Fredrick Madaraka Mwema Dr. F. M. Mwema is a postdoctoral researcher and a lecturer at the University of Johannesburg, South Africa and Dedan Kimathi University of Technology, Kenya, respectively. He is currently the Head of Department of Mechanical Engineering Department at Dedan Kimathi University, Kenya. He obtained BSc and MSc degrees in Mechanical Engineering from Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya, in 2011 and 2015, respectively. He has a PhD in Mechanical Engineering from the University of Johannesburg, which he obtained in 2019. His PhD research work involved thin film coatings for surface protection and functional components. He has interests in advanced manufacturing, severe plastic deformation processes, additive manufacturing, thin film depositions, surface engineering, and materials characterizations. In thin films, Dr. Mwema has interest in fractal theory of coatings for enhanced depositions and behaviour in advanced applications. He has published more than 50 articles in peer-reviewed journals, conferences, and book chapters. He supervises and mentors several students, currently with 4 masters and 3 PhD students. He has over 6 years of university teaching and training experience in mechanical engineering undergraduate subjects.

Esther Titilayo Akinlabi Professor Esther Titilayo Akinlabi is a Full Professor at the Department of Mechanical Engineering Science, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa. She has had the privilege to serve as a Head of the Department of Mechanical Engineering Science and as the Vice Dean for Teaching and Learning at the University of Johannesburg. Her research interest is in the field of modern and advanced manufacturing processes—friction stir welding and additive manufacturing. Her research in the field of laser-based additive manufacturing includes laser material processing and surface engineering. She also conducts research in the field of renewable energy, and biogas production from waste. She is a rated National Research Foundation (NRF) researcher and has demonstrated excellence in all fields of endeavours. Her leadership, mentorship, and research experience are enviable as she guides her team of postgraduate students through the research journey. She is a recipient of several

research grants and has received many awards of recognition to her credit. She is a member of the prestigious South African Young Academy of Science and is registered with the Engineering Council of South Africa. Professor Akinlabi has filed two patents, edited two books, published five books, and authored/co-authored over 400 peer-reviewed publications.