

3d metal printing technology

3D Metal Printing Technology: A Comprehensive Overview

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Introduction:

3D metal printing technology, also known as additive manufacturing (AM) of metals, is revolutionizing various industries. This innovative technology enables the creation of complex metal parts directly from a digital 3D model, offering unparalleled design freedom and efficiency compared to traditional subtractive manufacturing methods. This article delves into the intricacies of 3D metal printing technology, exploring diverse methodologies, applications, and future prospects.

1. Core Methodologies of 3D Metal Printing Technology:

Several distinct methodologies constitute the foundation of 3D metal printing technology. Each approach employs unique principles to fabricate metal parts layer by layer. The most prominent techniques include:

1.1 Powder Bed Fusion (PBF):

This prominent category within 3D metal printing technology uses a high-powered energy source to selectively melt and fuse powdered metal. Two prevalent variations exist:

Selective Laser Melting (SLM) / Selective Laser Sintering (SLS): A laser scans a powder bed, melting the metal powder layer by layer according to the 3D model. SLM focuses on melting the powder

completely, while SLS uses a lower energy input to sinter (fuse) the powder particles. This 3D metal printing technology is known for its high precision and excellent surface finish.

Electron Beam Melting (EBM): Instead of a laser, EBM utilizes an electron beam to melt and fuse the metal powder. EBM excels in processing high-reactivity metals like titanium, offering superior mechanical properties and density compared to SLM in certain applications. This 3D metal printing technology operates in a vacuum environment to prevent oxidation.

1.2 Directed Energy Deposition (DED):

Unlike PBF, DED techniques deposit molten metal directly onto a substrate. This 3D metal printing technology offers advantages in terms of part size and scalability. Common DED methods include:

Laser Engineered Net Shaping (LENS): A high-powered laser melts and deposits a stream of metal powder onto the build platform, layer by layer.

Electron Beam Additive Manufacturing (EBAM): Similar to LENS but employing an electron beam as the energy source, EBAM is particularly suited for large-scale metal part production.

1.3 Binder Jetting:

This method uses a liquid binder to selectively bind metal powder particles, forming a three-dimensional structure. The unbound powder is then removed, and the structure is sintered in a furnace to achieve the final metal part. Binder jetting 3D metal printing technology offers high throughput and is cost-effective for large-volume production.

1. Materials Used in 3D Metal Printing Technology:

The range of printable metals is continually expanding, with common materials including:

Titanium alloys: Primarily used in aerospace and medical applications due to their high strength-to-weight ratio and biocompatibility.

Stainless steel: A versatile choice for various industrial applications, offering good corrosion resistance and mechanical properties.

Aluminum alloys: Light and strong, ideal for automotive and aerospace industries.

Nickel-based superalloys: Used in high-temperature applications, such as gas turbine blades.

Cobalt-chromium alloys: Often chosen for biomedical implants due to their biocompatibility and high strength.

1. Applications of 3D Metal Printing Technology:

The versatility of 3D metal printing technology has opened doors for a wide array of applications:

Aerospace: Creating lightweight and high-strength components for aircraft and spacecraft.

Automotive: Producing complex engine parts, tooling, and customized components.
Medical: Manufacturing personalized implants, surgical tools, and dental prosthetics.
Energy: Developing efficient components for turbines, fuel cells, and other energy systems.
Tooling and Manufacturing: Creating customized tooling, jigs, and fixtures, leading to faster prototyping and production cycles.

1. Challenges and Future Directions of 3D Metal Printing Technology:

Despite its remarkable progress, 3D metal printing technology still faces challenges:

Cost: The initial investment in equipment and materials can be substantial.
Scalability: Scaling up production to meet high-volume demands remains a challenge for certain techniques.
Post-processing: Debinding, sintering, and finishing operations can add complexity and cost.
Material properties: Achieving consistent and reliable material properties across different parts requires further research.

Future developments will likely focus on:

Improved material selection and properties.
Increased speed and scalability of the printing process.
Enhanced process control and monitoring.
Development of new alloys and materials tailored to AM.
Integration of AI and machine learning for process optimization.

Conclusion:

3D metal printing technology is transforming manufacturing across diverse industries. While challenges remain, ongoing advancements in materials, processes, and software are rapidly expanding the capabilities and applications of this revolutionary technology. The future of 3D metal printing looks bright, promising even more efficient, customized, and sustainable manufacturing processes.

FAQs:

1. What is the difference between SLM and EBM? SLM uses a laser, while EBM uses an electron beam as the energy source. EBM is better suited for high-reactivity metals and operates in a vacuum.
1. What are the main advantages of 3D metal printing? Design freedom, reduced lead times, lightweighting possibilities, and the ability to create complex geometries.

1. What are the limitations of 3D metal printing? Higher initial investment costs, potential for surface imperfections, and limitations in material selection.
1. What types of metals can be 3D printed? Titanium alloys, stainless steel, aluminum alloys, nickel-based superalloys, and cobalt-chromium alloys are commonly used.
1. What are the typical applications of 3D printed metal parts? Aerospace components, medical implants, automotive parts, and tooling.
1. How does powder bed fusion work? A high-powered energy source melts and fuses metal powder layer by layer according to a 3D model.
1. What is directed energy deposition? Molten metal is deposited directly onto a substrate, layer by layer, creating the part.
1. What is the role of post-processing in 3D metal printing? Post-processing steps like heat treatment and surface finishing are crucial to achieve the desired mechanical properties and surface finish.
1. What is the future of 3D metal printing technology? Continued advancements in materials, processes, and software, leading to wider adoption and more diverse applications.

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3d metal printing technology: 3D Printing of Metals Manoj Gupta, 2019-08-13 3D printing is rapidly emerging as a key manufacturing technique that is capable of serving a wide spectrum of applications, ranging from engineering to biomedical sectors. Its ability to form both simple and intricate shapes through computer-controlled graphics enables it to create a niche in the manufacturing sector. Key challenges remain, and a great deal of research is required to develop 3D printing technology for all classes of materials including polymers, metals, ceramics, and composites. In view of the growing importance of 3D manufacturing worldwide, this Special Issue aims to seek original articles to further assist in the development of this promising technology from both scientific and technological perspectives. Targeted reviews, including mini-reviews, are also welcome, as they play a crucial role in educating students and young researchers.

3d metal printing technology: Manufacturing Process Selection Handbook K. G. Swift, J. D. Booker, 2013-02-15 Manufacturing Process Selection Handbook provides engineers and designers with process knowledge and the essential technological and cost data to guide the selection of manufacturing processes early in the product development cycle. Building on content from the authors' earlier introductory Process Selection guide, this expanded handbook begins with the challenges and benefits of identifying manufacturing processes in the design phase and appropriate strategies for process selection. The bulk of the book is then dedicated to concise coverage of different manufacturing processes, providing a quick reference guide for easy comparison and informed decision making. For each process examined, the book considers key factors driving selection decisions, including: - Basic process descriptions with simple diagrams to illustrate - Notes on material suitability - Notes on available process variations - Economic considerations such as costs and production rates - Typical applications and product examples - Notes on design aspects and quality issues Providing a quick and effective reference for the informed selection of manufacturing processes with suitable characteristics and capabilities, Manufacturing Process Selection Handbook is intended to quickly develop or refresh your experience of selecting optimal processes and costing design alternatives in the context of concurrent engineering. It is an ideal reference for those working in mechanical design across a variety of industries and a valuable learning resource for advanced students undertaking design modules and projects as part of broader engineering programs. - Provides manufacturing process information maps (PRIMAs) provide detailed information on the characteristics and capabilities of 65 processes in a standard format - Includes process capability charts detailing the processing tolerance ranges for key material types - Offers detailed methods for estimating costs, both at the component and assembly level

3d metal printing technology: Handbook of Metal Injection Molding Donald F Heaney, 2018-11-01 Metal injection molding combines the most useful characteristics of powder metallurgy and plastic injection molding to facilitate the production of small, complex-shaped metal components with outstanding mechanical properties. Handbook of Metal Injection Molding, Second Edition provides an authoritative guide to this important technology and its applications. Building upon the success of the first edition, this new edition includes the latest developments in the field and expands upon specific processing technologies. Part one discusses the fundamentals of the metal injection molding process with chapters on topics such as component design, important powder characteristics, compound manufacture, tooling design, molding optimization, debinding, and sintering. Part two provides a detailed review of quality issues, including feedstock characterisation, modeling and simulation, methods to qualify a MIM process, common defects and carbon content control. Special metal injection molding processes are the focus of part three, which provides comprehensive coverage of micro components, two material/two color structures, and porous metal techniques, as well as automation of the MIM process and metal injection molding of large components. Finally, part four explores metal injection molding of particular materials, and has been expanded to include super alloys, carbon steels, precious metals, and aluminum. With its distinguished editor and expert team of international contributors, the Handbook of Metal Injection Molding is an essential guide for all those involved in the high-volume manufacture of small precision parts, across a wide range of high-tech industries such as microelectronics, biomedical and

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3d metal printing technology: 3D Printing Technology and Its Diverse Applications H. B. Muralidhara, Soumitra Banerjee, 2021-12-22 This new volume explores the exciting and diverse applications of three-dimensional printing in a variety of industries, including food processing, environmental sciences, biotechnology, medical devices, energy storage, civil engineering, the textile and fashion industry, and more. It describes the various 3D printing methods, the commonly used materials, and the pros and cons. It also presents an overview of the historical development and modern-day trends in additive manufacturing, as well as an exploration of the prospects of 3D printing technology in promoting academic education.

3d metal printing technology: Additive Manufacturing of Metals John O. Milewski, 2017-06-28 This engaging volume presents the exciting new technology of additive manufacturing (AM) of metal objects for a broad audience of academic and industry researchers, manufacturing professionals, undergraduate and graduate students, hobbyists, and artists. Innovative applications ranging from rocket nozzles to custom jewelry to medical implants illustrate a new world of freedom in design and fabrication, creating objects otherwise not possible by conventional means. The author describes the various methods and advanced metals used to create high value components, enabling readers to choose which process is best for them. Of particular interest is how harnessing the power of lasers, electron beams, and electric arcs, as directed by advanced computer models, robots, and 3D printing systems, can create otherwise unattainable objects. A timeline depicting the evolution of metalworking, accelerated by the computer and information age, ties AM metal technology to the rapid evolution of global technology trends. Charts, diagrams, and illustrations complement the text to describe the diverse set of technologies brought together in the AM processing of metal. Extensive listing of terms, definitions, and acronyms provides the reader with a quick reference guide to the language of AM metal processing. The book directs the reader to a wealth of internet sites providing further reading and resources, such as vendors and service providers, to jump start those interested in taking the first steps to establishing AM metal capability on whatever scale. The appendix provides hands-on example exercises for those ready to engage in experiential self-directed learning.

3d metal printing technology: Inkjet Based 3D Additive Manufacturing of Metals Mojtaba Salehi, Manoj Gupta, Saeed Maleksaeedi, Nai Mui Ling Sharon, 2018-01-02 Additive Manufacturing (AM) is a highly promising rapid manufacturing process. Based on incremental layer-upon-layer deposits, three dimensional components of high geometrical complexity can be produced; applications ranging from aerospace and automotive to biomedical industries. Laser, electron beam and wire-based techniques are reviewed. Particular emphasis is placed on 3D inkjet printing of metals, which is reviewed here in great depth and for the first time. This is an ambient temperature technology which offers some unique advantages for printing metals and alloys, as well as composite and functionally graded materials. Material selection guidelines are presented and the various deposition techniques and post-printing treatments are discussed; together with the resulting properties of the printed components: Density, shrinkage, resolution and surface roughness, porosity-related and mechanical properties, as well as biological properties The various metal printing techniques are compared with each other and case studies are referred to. Additive Manufacturing, Inkjet Printing of Metals, 3D Printed Components, Laser Melting, Laser Sintering, Laser Powder Deposition, Material Selection Guidelines for Inkjet Printing of Metals, Biological Properties of AM Metals, Surface Properties of AM Metals, Porosity of AM Metals, Shrinkage of AM Metals, Mechanical of Properties of AM Metals, Density of Properties of AM Metals

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Jyothish Kumar, Pulak M. Pandey, David Ian Wimpenny, 2018-06-07 This book presents a selection of papers on advanced technologies for 3D printing and additive manufacturing, and demonstrates how these technologies have changed the face of direct, digital technologies for the rapid production of models, prototypes and patterns. Because of their wide range of applications, 3D printing and additive manufacturing technologies have sparked a powerful new industrial revolution in the field of manufacturing. The evolution of 3D printing and additive manufacturing technologies has changed design, engineering and manufacturing processes across such diverse industries as consumer products, aerospace, medical devices and automotive engineering. This book will help designers, R&D personnel, and practicing engineers grasp the latest developments in the field of 3D Printing and Additive Manufacturing.

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gene and drug delivery, and conjugated conducting polymers

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Rapid Prototyping of Biomaterials: Principles and Applications provides a comprehensive review of established and emerging rapid prototyping technologies (such as bioprinting) for medical applications. Rapid prototyping, also known as layer manufacturing, additive manufacturing, solid freeform fabrication, or 3D printing, can be used to create complex structures and devices for medical applications from solid, powder, or liquid precursors. Following a useful introduction, which provides an overview of the field, the book explores rapid prototyping of nanoscale biomaterials, biosensors, artificial organs, and prosthetic limbs. Further chapters consider the use of rapid prototyping technologies for the processing of viable cells, scaffolds, and tissues. With its distinguished editor and international team of renowned contributors, Rapid Prototyping of Biomaterials is a useful technical resource for scientists and researchers in the biomaterials and tissue regeneration industry, as well as in academia. - Comprehensive review of established and emerging rapid prototyping technologies (such as bioprinting) for medical applications - Chapters explore rapid prototyping of nanoscale biomaterials, biosensors, artificial organs, and prosthetic limbs - Examines the use of rapid prototyping technologies for the processing of viable cells, scaffolds, and tissues

3d metal printing technology: Tribology of Polymer and Polymer Composites for Industry 4.0 Hemalata Jena, Jitendra Kumar Katiyar, Amar Patnaik, 2021-08-23 This book first introduces polymers and polymer composites which are widely used in different industrial and engineering applications where the proper selection of fiber, filler, and polymer can be tailored for particular application. The primary objective of this book is to broaden the knowledge of tribology of polymer composites in a new dimension for Industry 4.0. For instance, the book covers polymer composites used as self-lubricating material used in the automotive industry and other manufacturing equipment to reduce the effect of energy loss due to friction and wear. This book is of interest to researchers and industrial practitioners who work in the field of tribology of polymer composites, manufacturing equipment and production engineering.

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leading experts.

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3d metal printing technology: Laser Additive Manufacturing Milan Brandt, 2016-09-01 Laser Additive Manufacturing: Materials, Design, Technologies, and Applications provides the latest information on this highly efficient method of layer-based manufacturing using metals, plastics, or composite materials. The technology is particularly suitable for the production of complex components with high precision for a range of industries, including aerospace, automotive, and medical engineering. This book provides a comprehensive review of the technology and its range of applications. Part One looks at materials suitable for laser AM processes, with Part Two discussing design strategies for AM. Parts Three and Four review the most widely-used AM technique, powder bed fusion (PBF) and discuss other AM techniques, such as directed energy deposition, sheet lamination, jetting techniques, extrusion techniques, and vat photopolymerization. The final section explores the range of applications of laser AM. - Provides a comprehensive one-volume overview of advances in laser additive manufacturing - Presents detailed coverage of the latest techniques used for laser additive manufacturing - Reviews both established and emerging areas of application

3d metal printing technology: Additive Manufacturing of Metals: The Technology, Materials, Design and Production Li Yang, Keng Hsu, Brian Baughman, Donald Godfrey, Francisco Medina, Mamballykalathil Menon, Soeren Wiener, 2017-05-11 This book offers a unique guide to the three-dimensional (3D) printing of metals. It covers various aspects of additive,

subtractive, and joining processes used to form three-dimensional parts with applications ranging from prototyping to production. Examining a variety of manufacturing technologies and their ability to produce both prototypes and functional production-quality parts, the individual chapters address metal components and discuss some of the important research challenges associated with the use of these technologies. As well as exploring the latest technologies currently under development, the book features unique sections on electron beam melting technology, material lifting, and the importance this science has in the engineering context. Presenting unique real-life case studies from industry, this book is also the first to offer the perspective of engineers who work in the field of aerospace and transportation systems, and who design components and manufacturing networks. Written by the leading experts in this field at universities and in industry, it provides a comprehensive textbook for students and an invaluable guide for practitioners

3d metal printing technology: Standards, Quality Control, and Measurement Sciences in 3D Printing and Additive Manufacturing Chee Kai Chua, Chee How Wong, Wai Yee Yeong, 2017-06-03 Standards, Quality Control and Measurement Sciences in 3D Printing and Additive Manufacturing addresses the critical elements of the standards and measurement sciences in 3D printing to help readers design and create safe, reliable products of high quality. With 3D printing revolutionizing the process of manufacturing in a wide range of products, the book takes key features into account, such as design and fabrication and the current state and future potentials and opportunities in the field. In addition, the book provides an in-depth analysis on the importance of standards and measurement sciences. With self-test exercises at the end of each chapter, readers can improve their ability to take up challenges and become proficient in a number of topics related to 3D printing, including software usage, materials specification and benchmarking. - Helps the reader understand the quality framework tailored for 3D printing processes - Explains data format and process control in 3D printing - Provides an overview of different materials and characterization methods - Covers benchmarking and metrology for 3D printing

3d metal printing technology: Metal Additive Manufacturing Dyuti Sarker, Ehsan Toyserkani, Osezua Obehi Ibhadode, Farzad Liravi, Paola Russo, Katayoon Taherkhani, 2021-10-26 METAL ADDITIVE MANUFACTURING A comprehensive review of additive manufacturing processes for metallic structures Additive Manufacturing (AM)—also commonly referred to as 3D printing—builds three-dimensional objects by adding materials layer by layer. Recent years have seen unprecedented investment in additive manufacturing research and development by governments and corporations worldwide. This technology has the potential to replace many conventional manufacturing processes, enable the development of new industry practices, and transform the entire manufacturing enterprise. Metal Additive Manufacturing provides an up-to-date review of all essential physics of metal additive manufacturing techniques with emphasis on both laser-based and non-laser-based additive manufacturing processes. This comprehensive volume covers fundamental processes and equipment, governing physics and modelling, design and topology optimization, and more. The text addresses introductory, intermediate, and advanced topics ranging from basic additive manufacturing process classification to practical and material design aspects of additive manufacturability. Written by a panel of expert authors in the field, this authoritative resource: Provides a thorough analysis of AM processes and their theoretical foundations Explains the classification, advantages, and applications of AM processes Describes the equipment required for different AM processes for metallic structures, including laser technologies, positioning devices, feeder and spreader mechanisms, and CAD software Discusses the opportunities, challenges, and current and emerging trends within the field Covers practical considerations, including design for AM, safety, quality assurance, automation, and real-time control of AM processes Includes illustrative cases studies and numerous figures and tables Featuring material drawn from the lead author's research and professional experience on laser additive manufacturing, Metal Additive Manufacturing is an important source for manufacturing professionals, research and development engineers in the additive industry, and students and researchers involved in mechanical, mechatronics, automatic control, and materials engineering and science.

3d metal printing technology: Mastering 3D Printing Joan Horvath, Rich Cameron, 2020-05-30 Get the most out of your printer, including how to design models, choose materials, work with different printers, and integrate 3D printing with traditional prototyping to make techniques like sand casting more efficient. This book is for new 3D printer owners, makers of all kinds, entrepreneurs, technology educators, and anyone curious about what you can do with a 3D printer. In this revised and expanded new edition of Mastering 3D Printing, which has been a trusted resource through five years of evolution in the 3D printing industry, you'll gain a comprehensive understanding of 3D printing. This book presumes no foreknowledge and describes what you need to know about how printers work, how to decide which type of printer (filament, resin, or powder) makes the most sense for you, and then how to go forward in the case of filament and resin printers. This new edition now includes material about consumer resin printing, the evolution of lower-cost metal printing, and the plethora of both materials and applications. What You'll Learn Choose among the different 3D printing technologies Create or find 3D models to print Make both easy and challenging prints come out as you imagined Assess whether your business, factory, home or classroom will benefit from 3D printing Work with applications that are good candidates for first projects in home and industrial applications Who This Book Is For People who are encountering 3D printing for the first time, or for those who want to level up their skills. It is designed for the nontechnical adult and minimizes jargon. However more sophisticated users will still find tips and insights of value.

3d metal printing technology: 3D Printing Dragan Cvetković, 2018-10-10 This book, 3D Printing, is divided into two parts: the first part is devoted to the relationship between 3D printing and engineering, and the second part shows the impact of 3D printing on the medical sector in general. There are five sections in the first part (sections are dedicated to stereolithography, new techniques of high-resolution 3D printing, application of 3D printers in architecture and civil engineering, the additive production with the metal components and the management of production by using previously mentioned technology in more complex ways). There are four chapters in the second part with the following topics: education of medical staff through surgical simulations, tissue engineering and potential applications of 3D printing in ophthalmology and orthopedics.

3d metal printing technology: Research Anthology on Emerging Technologies and Ethical Implications in Human Enhancement Management Association, Information Resources, 2020-12-18 Along with the introduction of technology in nearly every facet of human life comes the question of the ethical side of using technology to improve the human condition, whether that be physically or mentally. The capabilities of human enhancement technologies have created a dual-sided approach to discussing human enhancement: the critical approach of attempting to reach human perfection and the ethics within that idea and the endless capabilities of technology that have greatly impacted the medical field. It is essential to discuss both aspects within these emerging technologies, whether as separate entities or as cohesive units. Ranging from disease detection and treatment to implants and prosthetics to robotics and genetic engineering, human enhancement technologies are widespread and multi-purposed. By going beyond the capabilities of human hands, these technologies have propelled modern medicine and healthcare to new levels that have allowed humans to face new treatments or assistive technologies not seen before. The Research Anthology on Emerging Technologies and Ethical Implications in Human Enhancement covers the primary technologies and tools being used in medicine and healthcare along with discussions on the ethics of enhancing the human body. Topics covered include prosthetics and implants, robotics, human disorders/diseases and treatments and smart technologies, along with law and theory. This publication serves as a valuable reference work for doctors, medical professionals, researchers, students, professionals, and practitioners involved in fields that include ethics, medicine, computer science, robotics, genetics, assistive technologies, nanotechnology, biomedical engineering, and biotechnology.

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three-dimensional printing at the point of care. Focusing on opportunities and challenges in radiology practice, this up-to-date reference covers computer-aided design principles, quality assurance, training, and guidance for integrating 3D printing across radiology subspecialties. Practicing and trainee radiologists, surgeons, researchers, and imaging specialists will find this an indispensable resource for furthering their understanding of the current state and future outlooks for 3D printing in clinical medicine. - Covers a wide range of topics, including basic principles of 3D printing, quality assurance, regulatory perspectives, and practical implementation in medical training and practice. - Addresses the challenges associated with 3D printing integration in clinical settings, such as reimbursement, regulatory issues, and training. - Features concise chapters from a team of multidisciplinary chapter authors, including practicing radiologists, researchers, and engineers. - Consolidates today's available information on this timely topic into a single, convenient, resource.

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issues, along with sections on the preparation of polymer composite materials for 3D and 4D printing. Across the book, advanced printing techniques are covered and discussed thoroughly, including fused deposition modeling (FDM), selective laser sintering (SLS), selective laser melting (SLM), electron beam melting (EBM), inkjet 3D printing (3DP), stereolithography (SLA), and 3D plotting. Finally, major applications areas are discussed, including electronic, aerospace, construction and biomedical applications, with detailed information on the design, fabrication and processing methods required in each case. - Provides a thorough, clear understanding of polymer preparation techniques and 3D and 4D printing processes, with a view to specific applications - Examines synthesis, formation methodology, the dispersion of fillers, characterization, properties, and performance of polymer nanocomposites - Explores the possibilities of 4D printing, covering the usage of stimuli responsive hydrogels and shape memory polymers

3d metal printing technology: 3D Printing with Biomaterials A.J.M. van Wijk, I. van Wijk, 2015-01-15 Additive manufacturing or 3D printing, manufacturing a product layer by layer, offers large design freedom and faster product development cycles, as well as low startup cost of production, on-demand production and local production. In principle, any product could be made by additive manufacturing. Even food and living organic cells can be printed. We can create, design and manufacture what we want at the location we want. 3D printing will create a revolution in manufacturing, a real paradigm change. 3D printing holds the promise to manufacture with less waste and energy. We can print metals, ceramics, sand, synthetic materials such as plastics, food or living cells. However, the production of plastics is nowadays based on fossil fuels. And that's where we witness a paradigm change too. The production of these synthetic materials can be based also on biomaterials with biomass as feedstock. A wealth of new and innovative products are emerging when we combine these two paradigm changes: 3D printing and biomaterials. Moreover, the combination of 3D printing with biomaterials holds the promise to realize a truly sustainable and circular economy.

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