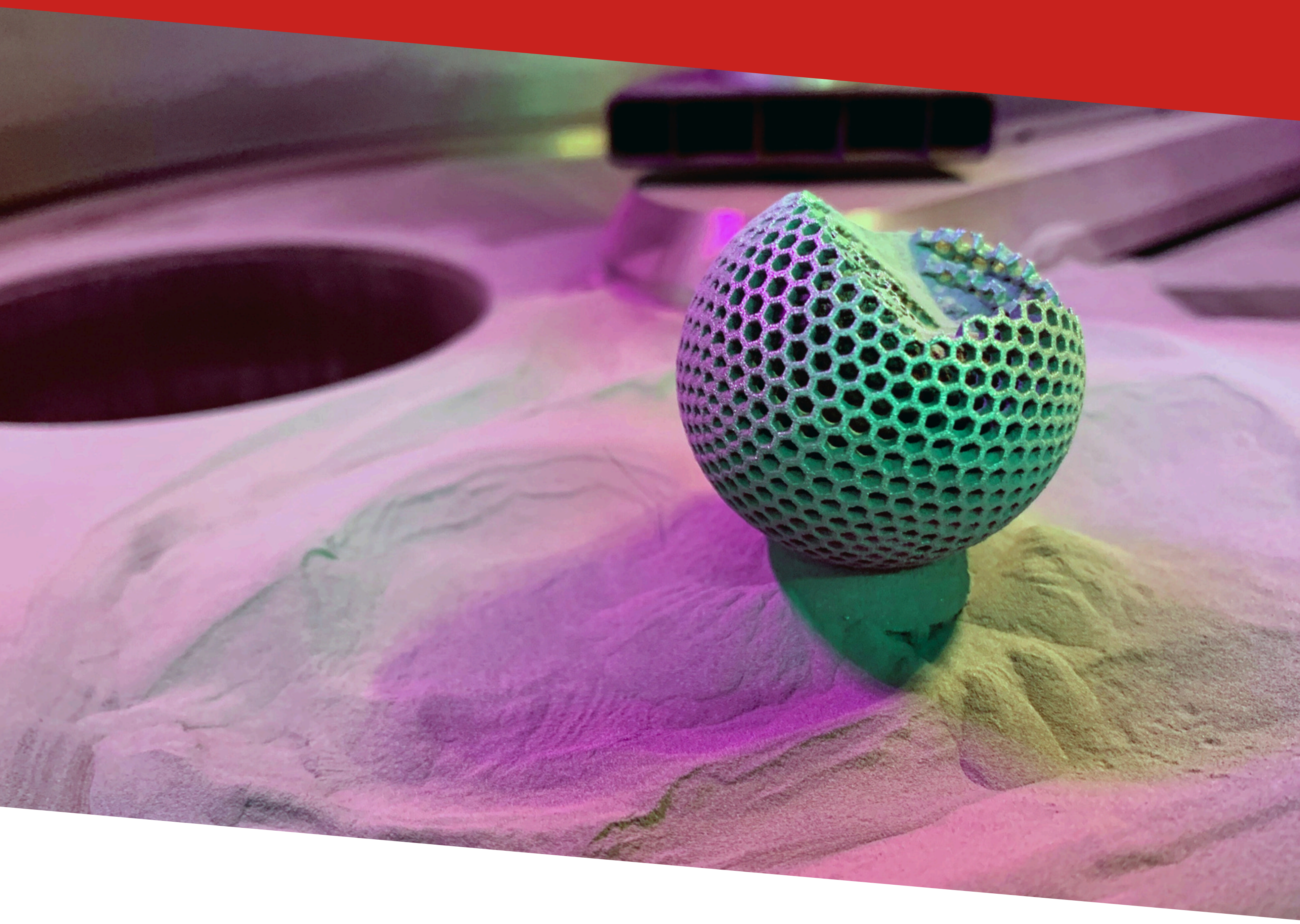
Industry Focus



3D Printing

An exclusive collection featuring top-tier articles, visionary experts, and essential industry insights

AZO NETWORK sponsored by BMF BOSTON MICRO FABRICATION

TABLE OF CONTENTS

Foreword

Welcome to the latest edition of our Industry Focus eBook, where we delve into the transformative world of 3D printing. This cutting-edge technology continues to redefine the boundaries of innovation,offering groundbreaking solutions to some of the most pressing challenges across various industries.

In healthcare, 3D printing is unlocking unprecedented possibilities, from creating advanced surgical tools to enabling remarkable breakthroughs in organ transplantation. The energy sector is harnessing its potential to revolutionize battery manufacturing, paving the way for a more sustainable future. Meanwhile, bioprinting is advancing the frontiers of neuroscience and regenerative medicine with the creation of 3D neural tissues that push the limits of what we once thought possible.

Discover how *Mastering Precision: The 3D Printer that Can Achieve Tight Tolerances* showcases a revolutionary 3D printer that achieves exceptional accuracy. Learn how this innovation is redefining tight tolerances in advanced manufacturing. Brought to you by our sponsor, Boston Micro Fabrication.

In *Comparing SLA, DLP, and PμSL Additive Manufacturing Methods*, we break down each technique's unique advantages. This quick guide will help you choose the best fit for your manufacturing needs. Sponsored by Boston Micro Fabrication.

Exploring the Differences Between 3D Printing and Soft Lithography explores how these two technologies differ in process and application. Thanks to our sponsor, Boston Micro Fabrication, you can gain key insights into microfabrication.

Beyond Earth, 3D printing is shaping the next wave of space exploration, particularly through its role in advancing thin-film solar technology. Back on the ground, eco-friendly innovations in 3D-printed concrete are reimagining sustainable construction, while breakthroughs in metallurgical applications are demonstrating the power of 3D printing to produce high-performance plain carbon steel. The burgeoning field of 3D bioprinting also continues to evolve, reflecting key market trends and introducing new innovations that could transform personalized medicine.

This eBook captures the essence of these developments, offering a comprehensive look at the ways 3D printing is shaping the future. It is a testament to the ingenuity and creativity of those driving this technology forward, with applications that span disciplines and touch lives.

Lexie Corner
Editor

AZO NETWORK

3D Printing in Healthcare: From Surgical Tools to Organ Transplant Breakthroughs

3D printing is still a relatively novel method of manufacture, and has already diversified massively in terms of printing methods, materials, and design possibilities, finding niche application in a range of fields, including healthcare and the life sciences.

3D printing is having a transformative impact on the way surgery and dentistry is performed, and how prosthetics and implants are designed, allowing the creation of custom, personalized items fit for the patient or the particular task at hand.

This article will explore the wide-ranging applications of 3D printing in healthcare, from creating surgical tools to facilitating organ transplants.

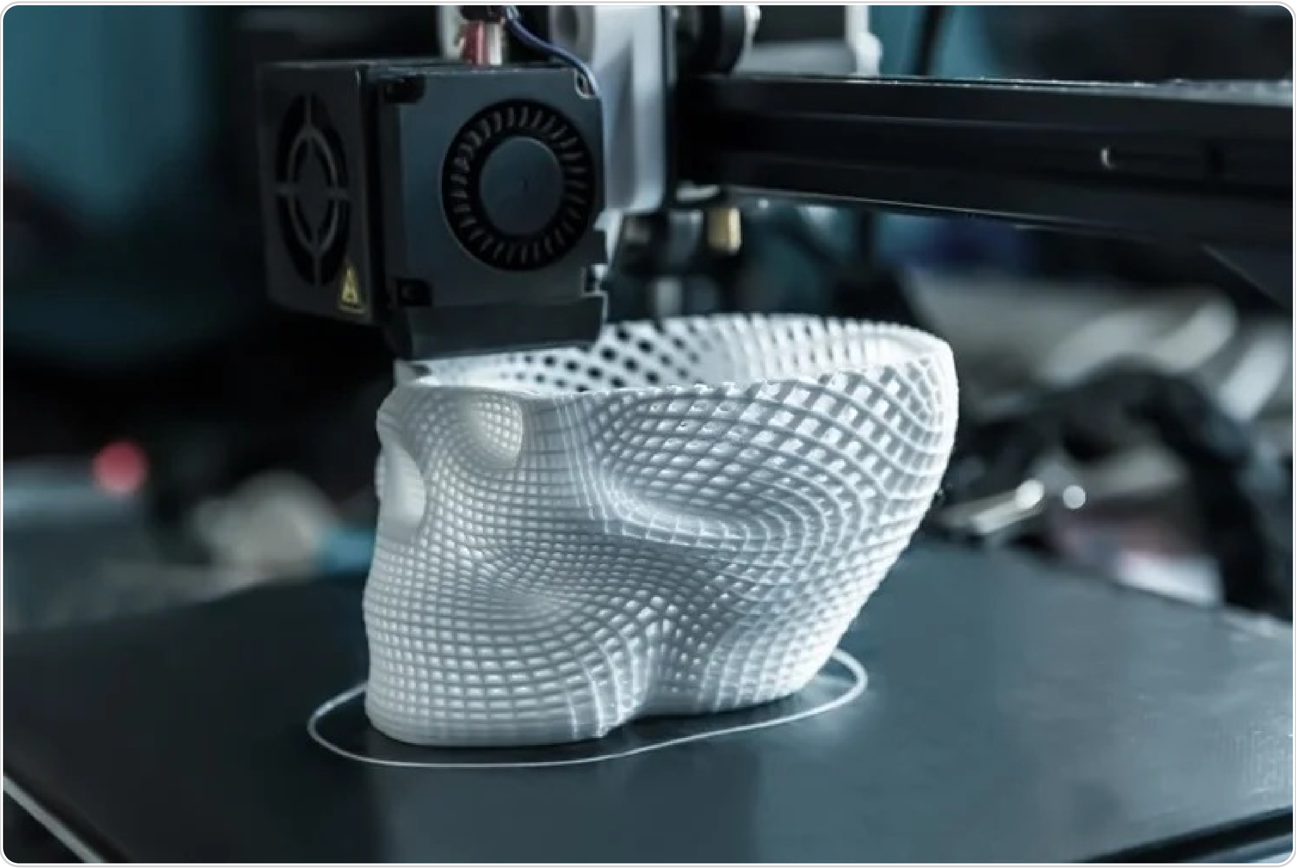


Image Credit: Olga Ilina/Shutterstock.com

Brief history of 3D printing technology

3D printing typically refers to an additive manufacturing process, i.e. one where material is added in successive layers or stages, rather than being removed from bulk material (subtractive) or directly molded to shape, as with materials such as thermosetting plastics.

One of the earliest forms of 3D printing was stereolithography, now more commonly termed resin printing, in which a UV laser is aimed in the desired pattern in a layer-by-layer manner at photopolymer resin, hardening it and transforming the liquid into a solid three dimensional structure.

Research into this technology was ongoing throughout the 1970s and patented in 1984, and is broadly utilized to produce custom manufactured parts. The type of resin employed can be adapted to purpose; for biocompatibility in cases of biological implant or prosthesis, for toughness and rigidity where required, and so on.

The term 3D printing was not actually coined until 1995, by Professor Ely Sachs, MIT, who worked on modifying inkjet printers to extrude a binding solution onto a powder bed, known as powder bed fusion 3D printing (of which there are many types: selective laser sintering, direct metal laser sintering, electron beam melting, etc.).

This method of printing evolved into many of the types perhaps more commonly used today, which employ a frame capable of moving an extrusion head in three dimensions above a platform, such as fused deposition modeling (FDM) 3D printing.

Now, there are over 18 methods of 3D printing, each with numerous modifications, allowing custom products to be manufactured in a broad range of materials, with differing degrees of ease and accessibility, quality, and suitability towards medical applications.

Innovations in surgical tools and equipment

3D printing is increasingly employed in the creation of surgical aids, including the design and production of accurate training models, specialized instruments, and scaffolds that aid in implantation or tissue repair.

One of the major advantages of 3D printing technologies is that iterative changes can be made to newly designed tools based on immediate feedback from surgeons and other medical professionals; design changes can be implemented *in silico* and a new device printed overnight.

The facility of producing patient specific training models could potentially be revolutionary in terms of the way surgery is performed, as the highly particular details of a patient’s internal organs, as ascertained from various scanning technologies, can be reproduced in detail.

This leaves fewer surprises for surgeons during surgery, and would massively assist in preparation for more complex surgeries.

Image Credit: belekekin/Shutterstock.com

Personalized prosthetics and implants

Some of the major issues with ordinary mass-produced prosthetics is surrounding abandonment; the user ceases to wear the prosthetic as they are uncomfortable, awkward, or unappealing aesthetically.

Bionic prosthetics, which are capable of coordinating roboting movement by muscle contractions, must in particular be positioned and secured carefully in order to maintain their function and comfortable usability.

The custom sizing possible using 3D printing technologies allows much more comfortable prosthetics to be manufactured from biocompatible components, potentially in more complex designs and lower mass than traditional prosthetics.

In 2014 a conference was held at Johns Hopkins Hospital titled: Prosthetists Meet 3D Printers, in which medical and 3D printing experts met to discuss the state and future of 3D printing of prosthetics.

A broad range of collaborative efforts are currently underway with a view to utilizing 3D printing in prosthetics. For example, prosthetic devices are freely available to download and print at home on a number of dedicated websites, while many companies dedicated to producing prosthetic devices for particular markets have emerged.

For example, Openbionics is a UK based company that prints custom prosthetics, with superhero designs aimed at children, ones with specialized fittings for musicians, and so on.

Breakthroughs in 3D-printed organs

Various biomaterials can be laid down in an additive manufacturing method such as 3D printing to produce implantable scaffolds, tissues, and even whole new organs.

Bioinks containing living cells are deposited in a layer-by-layer manner to print the organ, typically employing a scaffold and/or natural polymers within the bioink, which harden and keep the cells in place; hydrogel polymers such as fibrin, gelatin, alginates, chitosan, and hyaluronic acids are typically employed. 3D printed organs such as this contain cells cultured from the patient, and thus are much more biocompatible than a donor organ.

There are several types of organ 3D printing, and the technology is still in its infancy. One of the earliest and most broadly employed methods is known as cell seeding, wherein a supporting scaffold is 3D printed from biocompatible materials and then seeded with cells that will propagate to fill the structure, potentially *in situ* in order to aid in wound healing.

Where custom organs are 3D printed they can be made to best suit the patient, not only in terms of biocompatibility but also in terms of shape and size; for example, adjusting the size of the heart valves to patient size.

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Innovation in Minimal Invasive Surgery with 3D Printing

In 2008, during his recovery from a broken ankle, Alex Berry, the Founder and Engineering Director of Sutrue, conceived the notion of an automated suturing device tailored for minimally invasive surgery.

This surgical approach reduces patient recovery periods, improves outcomes, and decreases complications. Nevertheless, the dearth of suitable instruments for these intricate and precise tasks hampers surgeons in providing minimally invasive options to their patients.

Sutrue, with its dedicated focus on keyhole surgery encompassing both laparoscopic and robotic procedures, has developed a minimally invasive suturing device. Surgeons are entrusted with the vital responsibility of suturing, yet the absence of an instrument capable of achieving the requisite scale for minimally invasive surgeries (8 mm diameter) persists.

Sutrue's innovative design tackles this void by emphasizing extreme accuracy in the compact size of its prototype devices.

Suturing for Minimally Invasive Surgery

After years of research and experimenting, Berry's team designed a device that passes a suturing needle and thread through tissue and returns to the device securely.

The needle rotates out and back into the device on a fixed path while staying level on the third axis. The team had prototypes of the device machined from steel, which required significant time and help accommodating design iterations.

Sutrue's device machined from steel. Image Credit: Boston Micro Fabrication (BMF)

Sutrue's device machined from steel. Image Credit: Boston Micro Fabrication (BMF)

Prototyping the Device

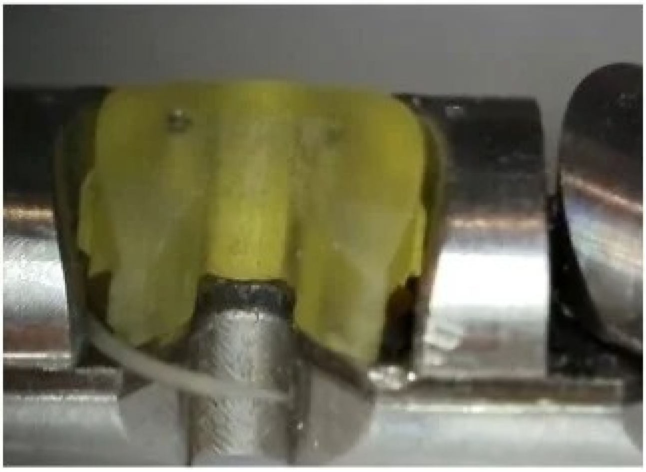
During the development of the suturing device, Berry's team encountered an obstacle related to the stability of the needle's path, which necessitated an update to one of the most crucial device components. Reproducing the part via machining would have caused a considerable delay in product testing by several months and incurred significant expenses.

The machining process presented another limitation as the team would receive only one replacement design, leaving no room for experimentation.

By utilizing 3D printing technology to manufacture the replacement parts, the team could swiftly test various versions of the part with slight differences and determine various tolerances within a shorter timeframe.

The 3D printing approach allowed the team to consider the parts' aesthetics, resulting in the printing of the parts in two distinct colors.

Sutrue's device with the 3D-printed component. Image Credit: Boston Micro Fabrication (BMF)



3D-printed component to stabilize the needle path. Image Credit: Boston Micro Fabrication (BMF)

> *The accuracy of BMF printers at small scale means that we could try three different parts to find the ideal fit. This allowed for our device to finally function as designed without the cost and time delay of machining the part. This has led to us being able to do initial testing and advance the development of a unique medical device with the assurance that the BMF printed parts are true to the design and consistently accurate.*
>
> *Alex Berry, Founder and Engineering Director, Sutrue*

Continuing Advancements for Minimally Invasive Surgery

Ongoing progress in medical devices is set to further enhance the accessibility of minimally invasive surgery.

The capacity to fabricate prototypes through 3D printing, with resolutions, sizes, and tolerances comparable to precision injection molded components, offers extensive prospects for advancements in the instruments essential for minimally invasive procedures.

Watch the suturing device in action. Video Credit: Boston Micro Fabrication (BMF)

This information has been sourced, reviewed and adapted from materials provided by Boston Micro Fabrication (BMF).

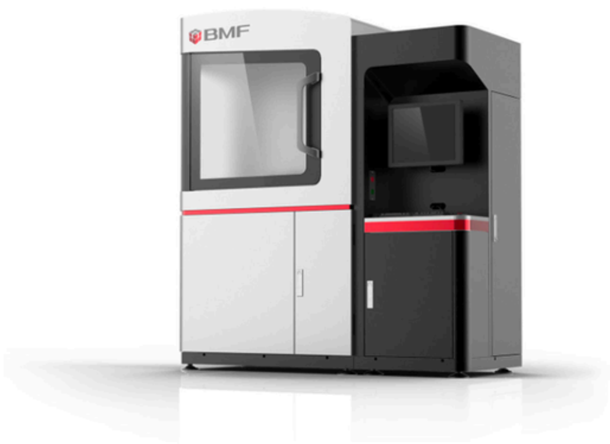
For more information on this source, please visit Boston Micro Fabrication (BMF).

BOSTON MICRO FABRICATION

ULTRA-HIGH RESOLUTION 3D PRINTERS

2μm Series Printers

The 2μm series is our highest-resolution system, perfect for applications that require ultra-high resolution and tight tolerances. Compatible with a wide range of materials, the 2μm series is the ultimate choice for prototyping parts that are true to CAD and look exactly like the finished product.



Find Out More

Data Sheet

Customizable high-resolution optical system and movement platform (with resolution down to 2μm)

Step-and-repeat process that allows for achievement of both high resolution and large area

Controlled processing technology to produce highly precise 3D printed objects

Real-time image monitoring, auto focus, and exposure compensation

Operation software with microArch graphic interface system and customer parameter setting

The Role of 3D Printing in Battery Manufacturing

Additive Manufacturing (AM), or 3D printing, is a process in which a complete product is created from a 3D computer model by joining material layer by layer.[1] With 3D printing replacing traditional manufacturing techniques, industries are utilizing AM for rapid production, reduced fabrication costs, and promoting sustainable practices. The battery manufacturing sector, in particular, has adopted AM for its customization capabilities.

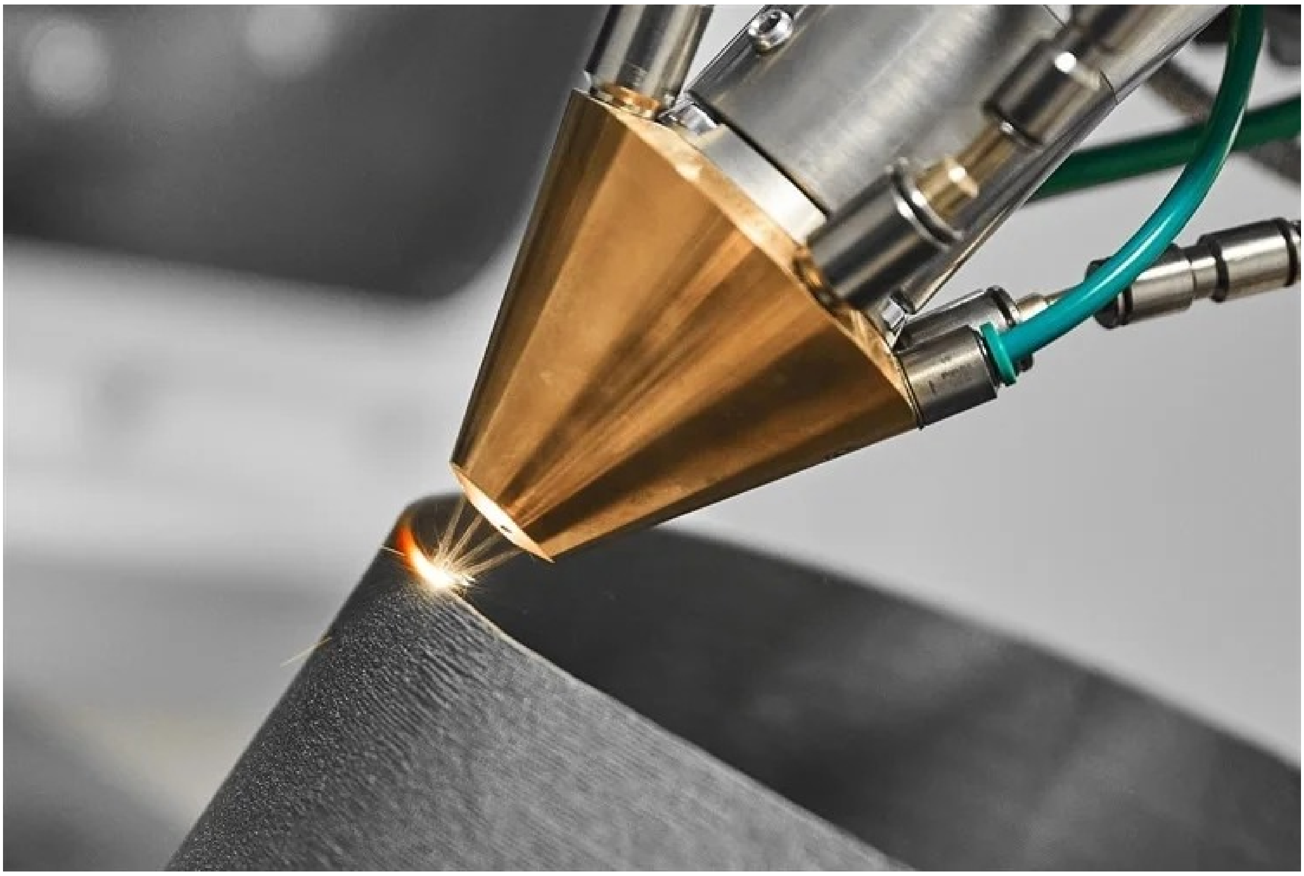


Image Credit: Nordroden/Shutterstock.com

3D Printing of Lithium-Ion Batteries

With sustainability becoming a key focus, electric vehicles are becoming popular to reduce the consumption of fossil fuels. In these vehicles, batteries are critical, with shorter charging times and durability being preferred features.[2]

Structural batteries provide many benefits and can be easily integrated into the electric system without added technology. Recently, researchers at Shanghai University used 3D printing to manufacture customizable Li-ion batteries that can be shaped to specific user requirements. Integrating 3D printing with electrical energy storage (EES) systems also reduces strain on energy storage materials.[3]

The 3D printing technology used enables robust design configurations, allowing the batteries to withstand higher tensile stress. Researchers developed a composite-based Li-ion battery made from Carbon Fiber Reinforced Polymer (CFRP) that operated safely under a maximum 3-point bending stress of 123 MPa, with an energy density of 120 Wh kg^{-1} and a charge retention of 92 % after 500 cycles.

Experimental data indicates that the customizable 3D-printed lithium battery performs effectively for autonomous vehicles and can be scaled for broader industrial engineering applications.[4]

Advancements in 3D-Printed Electrolytes

Various strategies are being implemented globally to enhance battery performance and support sustainable battery development. Solid polymer electrolytes (SPEs), an improved alternative to traditional liquid electrolytes, offer superior electrochemical stability, thereby extending battery life.[5]

Vat photopolymerization has been used to fabricate 3D-printed polyethylene oxide (PEO) electrolytes with an ionic conductivity of 3.7×10^{-4} $S{\cdot}cm^{-1}$, a suitable range for battery applications. Researchers have also applied Direct Ink Writing (DIW) to produce 3D-printed poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF) solid electrolytes, which demonstrated superior performance compared to conventional electrolyte-containing batteries and most other solid electrolytes.

Fused Filament Fabrication (FFF) is the most widely used 3D printing technique for manufacturing solid electrolytes in lithium batteries. However, this technique has been less effective for producing components for sodium batteries.[6]

The rise in manufacturing high-performance solid-polymer and composite electrolytes through 3D printing is attracting several companies to develop bipolar multilayer batteries. This method enhances the flexibility and performance of modern batteries, particularly benefiting applications in wearable devices and electric vehicles.

Fabrication of All-Solid-State Batteries

Among high-energy density storage options, all-solid-state battery (ASSB) technology is a leading choice. A new method for fabricating ASSBs using aerosol jet 3D printing technology was introduced, achieving excellent conductivity ($>10^{-3}$ S cm^{-9} at 30 °C) and strong electrochemical stability.

With a relatively high mass loading (approximately 10 mg cm^{-2} of LFP), the composite electrode achieved a specific capacity of over 160 mAh g^{-1}. This technology holds significant potential for energy storage systems in modern vehicles and aircraft electronics.[7]

Applications and Innovations in 3D-Printed Batteries

NASA's Use of 3D Printing for Artemis Mission Batteries

Using AM for battery electrodes has enhanced ion diffusion properties. NASA experts, collaborating with U.S. researchers, employed the Vat Photopolymerization (VPP) technique to create composite photocurable resin loaded with TiO_2 for developing negative electrodes for NASA's Artemis mission. TiO_2 has been shown to accelerate the charging process of Li-ion batteries while also improving storage capacity.

The electronic conductivity of the 3D-printed electrode was measured at 3.5 mS·cm^{-1}, marking a significant improvement over traditional battery components. The electrodes also demonstrated a stronger electrochemical response due to higher electronic conductivity and enhanced porosity. This study establishes a foundation for developing complex 3D-printed electrodes for sustainable batteries in modern vehicles.

Future research should aim to optimize particle size to further enhance electrochemical properties by reducing ion diffusion distances.[8]

Industry Adoption of 3D Printing in Battery Production

Established battery manufacturers are increasingly adopting 3D printing techniques to reduce costs and improve performance. Johnson Matthey Battery Systems, a well-known Polish battery manufacturer, has implemented laser sintering 3D printing to produce complex battery components. Manufacturing over 3.5 million Li-ion batteries annually, the company's shift to 3D printing has resulted in a significant reduction in production time.[9]

UK-based company Laselines also provides 3D printers, including PolyJet and Fused Deposition Modeling (FDM) printers, suitable for printing electrodes for modern batteries.[10]

Similarly, Sakuu Manufacturing has developed an innovative dry Kavian process for 3D printing battery electrodes, which is environmentally friendly. This process eliminates hazardous waste and reduces the carbon footprint by approximately 40 %. Electrodes produced using Kavian technology perform better than those manufactured through traditional methods.[11]

Future Innovations: AI and 3D Printing for Sustainable Batteries

3D printing is enhancing battery performance while reducing the use of harmful chemicals. Recently, researchers have incorporated AI-driven optimization strategies with 3D printing to extend battery life cycles. Advanced AI computations are establishing a foundation for innovative electrode designs, ensuring that 3D printing continues to advance Li-ion batteries for modern applications.

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Enabling Miniaturization with Micro Precision 3D Printing

insights from industry

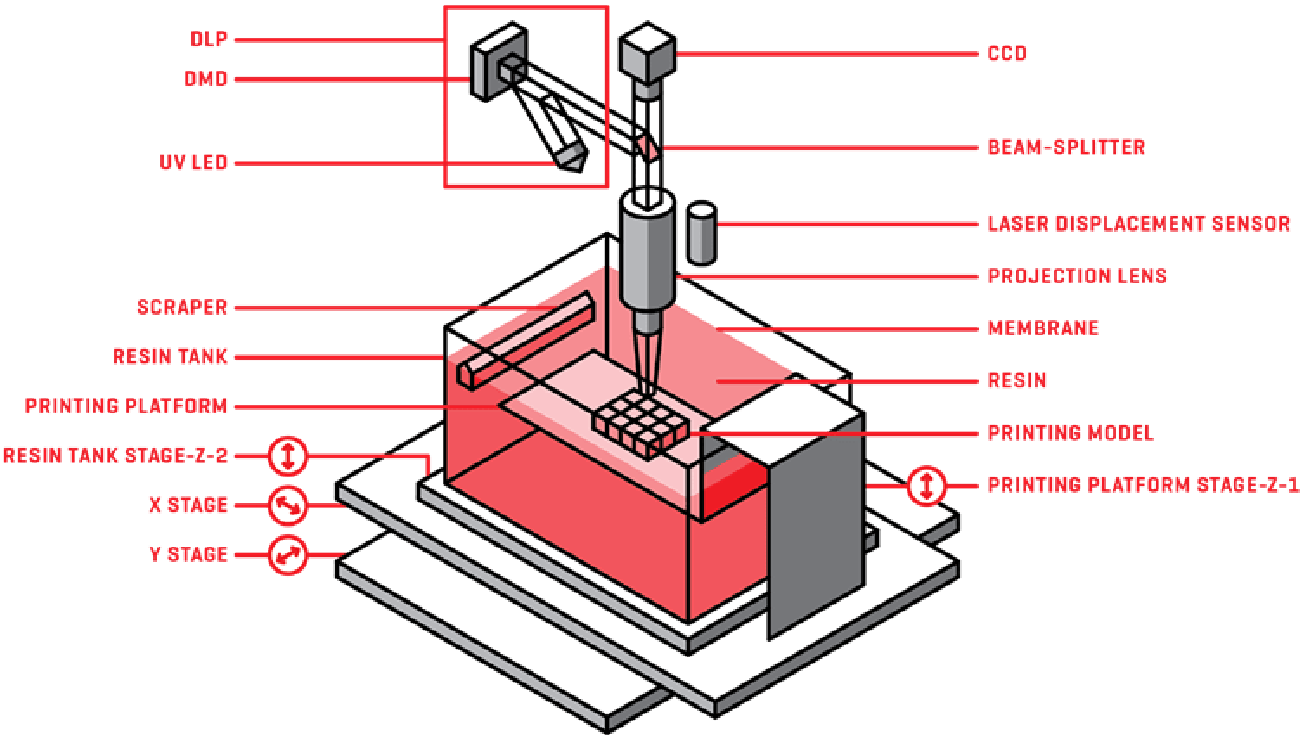
John Kawola
CEO
Boston Micro Fabrication

In this Interview, AZoMaterials speaks to Boston Micro Fabrication's CEO John Kawola, about micro precision 3D printing.

What is micro-precision 3D printing, and how is it different from other 3D printing processes?

Micro-precision 3D printing is a technique used to create 3D parts with extremely high resolution, accuracy and precision, typically with features that are smaller than 100µm.

Boston Micro Fabrication uses a 3D printing approach called PµSL (Projection Micro Stereolithography) that leverages light, customizable optics, a high quality movement platform and controlled processing technology to produce the industry's most accurate and precise high-resolution 3D prints for product development, research and industrial short run production. The technology represents a true industry breakthrough by empowering product manufacturers to capitalize on the benefits of 3D printing without sacrificing quality or scale, helping push new boundaries in innovation.



BMF's PμSL technology

The smaller the part and the more complex the geometry, the trickier it is to manufacture. So, at BMF, we are fulfilling a real need, making prototypes and end-use parts for small, complex geometries - available faster and at much cheaper costs than other methods.

How are these parts traditionally manufactured, and how can micro 3D printing fit into the manufacturing process?

Conventionally, these parts are manufactured using injection molding. The smaller and more complex a part is, the higher the cost associated with creating a mold and the turnaround time can be months. BMF is disrupting traditional manufacturing with 3D printing, enabling engineers to create prototypes at a fraction of the time and cost to be used for fit and form testing, manufacturing aids, molding and casting tools, and end-use parts for production.

The trend toward miniaturization is growing, as the demand for smaller parts and components in the fields of medical devices, biotech, electronics, and wearables increases. However, the cost is a significant challenge in manufacturing miniaturized parts for medical devices, electronics, and optics. Traditional 3D printing struggles with producing smaller parts, but micro 3D printing can deliver precision for complex components at scales as small as a single micron.

At BMF, we are essentially helping engineers 3D print parts they have not been able to in the past - that match the quality of an injection molded part at a fraction of the cost.

Chip Socket, Arrays of 130μm through holes

What are the economic benefits of micro 3D printing?

The elevated cost of tooling for micro-injection molds and the minimal volume of the parts requiring less material greatly impacts the cost analysis. 3D printing can be more cost-effective and efficient than traditional manufacturing processes depending on the output volume needed, and this crossover point gets higher as the parts get smaller. The fact that 3D printing doesn't require tooling has always been an advantage. This advantage is even more obvious when looking at micro-injection molding. The cost of a single cavity complex micro mold can often cost upwards of $100k.

Also key to the cost analysis, the printed parts use very little material, so material costs are minimal. With micro 3D printing, you can print tens of thousands of parts before the amortization of the tool is realized. If you only need 100's of parts, the value of micro 3D printing skyrockets. Quite simply, fabricating micro parts through traditional manufacturing methods is costly and difficult. BMF's PμSL technology is a very attractive alternate solution for complex, micro parts.

What are some applications for micro 3D printing?

Often, 3D printing is used to accelerate prototyping and design testing across a number of industries. Single-use disposable medical devices are a great fit, as well as microfluidics, electronic connectors and components and drug delivery systems. On top of these applications, we're helping advance the industry's use of 3D printing through self-drive innovation.

This method is capable of manufacturing end-use parts for short-run production, which are challenging to produce using traditional methods. For small-scale injection molding, 3D printing is a cost-effective alternative to creating molds and casting tools, as traditional machining requirements become more expensive as parts decrease in size.

Endoscope Shell, 150μm wall thickness

Do you foresee this technology being used for more end-use production?

The shift towards short-run production using 3D printing is currently underway, with some of our early customers utilizing this technology to qualify their processes. Due to various economic factors, such as supply chain issues, many manufacturers are feeling the pressure and are thus considering this approach as an alternative solution.

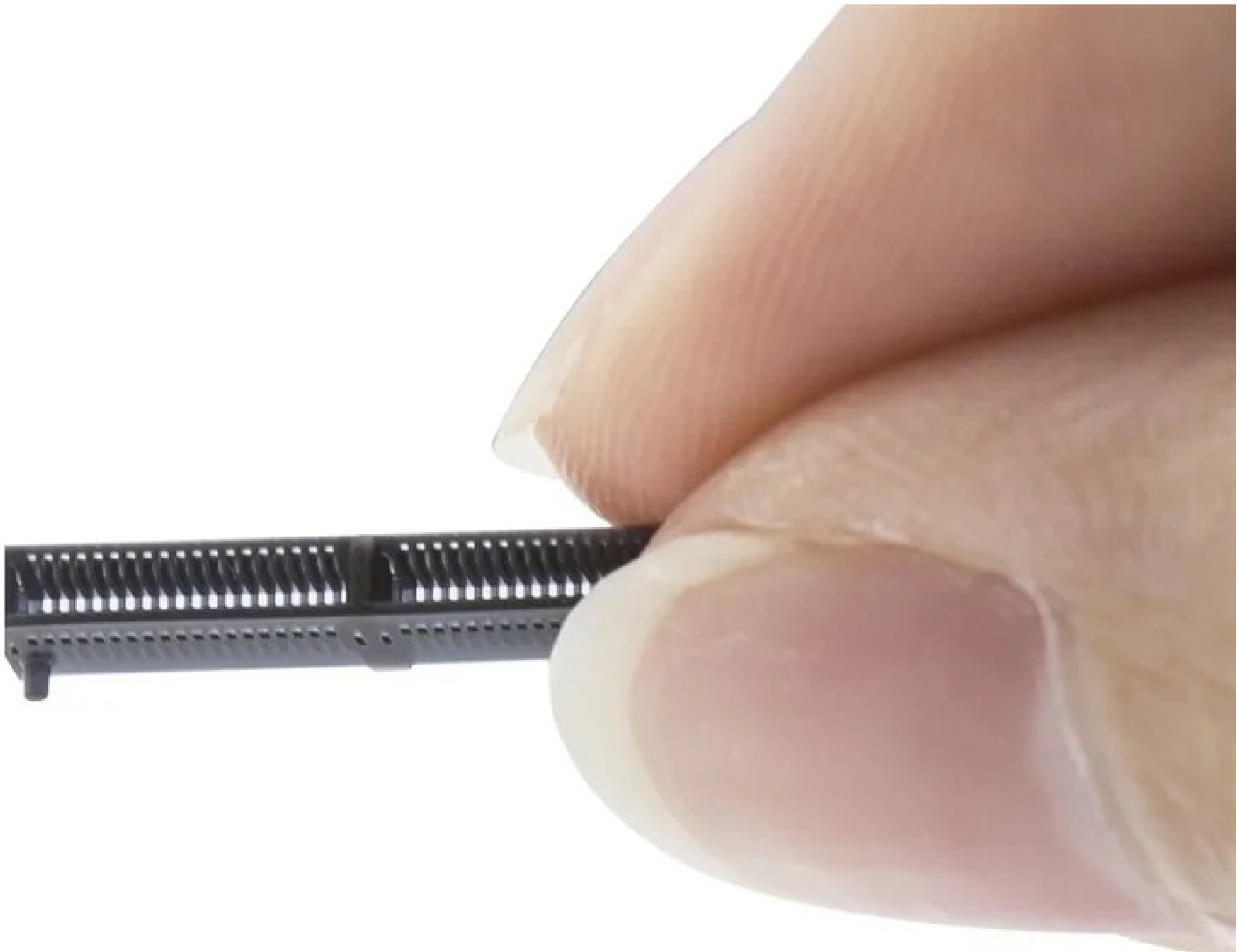
Additionally, as parts become smaller, they become more expensive to produce, and the cost of injection molds for micro components can be hundreds of thousands of dollars, as opposed to $10,000. This economic reality is leading many manufacturers to explore the potential of 3D printing for their manufacturing needs.

What are the new materials that BMF has recently introduced?

At BMF, we offer a range of materials with different properties for various applications. As an open-source material company, we have our own line of formulated liquid resins that are made specifically for our line of micro-precision 3D printers, but we also partner with material companies to provide third-party material options that give flexibility based on the application.

We have recently developed and validated several new materials which are now available for use on BMF's microArch platforms. These include BMF MED and LOCTITE 3D 3955. BMF MED powered by 3D Systems is a custom-formulated biocompatible resin that meets the requirements of FDA class II biocompatibility. This combined with its great aging properties makes it suitable for end-use medical devices, pharmaceutical, and research applications. This resin also features fast and simple post-processing requirements for improved ease of use.

We also recently collaborated with Henkel to validate LOCTITE 3D 3955 for use on the microArch platforms. This material is compatible with our new microArch S350 printer for printing flame-resistant parts at 25μm resolution. This high-performance halogen-free flame retardant UL94-V0 high modulus photopolymer resin is suitable for end-use parts including electrical connectors, housings, electronic components, and other parts requiring high flame resistance or the ability to withstand harsh environments.



3D Printed Electronic Connector, 280 μm spacing between connector teeth

How sturdy are these parts compared to plastic injection molded parts?

Recent advances in 3D printing have led to materials with mechanical properties approaching those of traditional injection molding materials. End-use materials are now reaching 90% of the strength and flexibility of injection molding materials. Functional designs are now possible using these materials.

What does the post-processing of parts involve?

Post-processing for DLP or SLA-based part production involves post-washing to remove uncured resin and removing supports. Our photo-polymer-based process follows the same steps, but our small parts require less solvent and support. Form Wash and Form Cure devices are used for post-processing and are effective for our micro 3D printed parts.

Can you tell us about your printers?

Boston Micro Fabrication delivers one of the highest levels of precision available on the market, and we manufacture and sell printers capable of achieving 2µm, 10µm and 25µm resolution parts. Our 2µm series includes the microArch S130 and S230, both capable of achieving tolerances within +/-10µm.

Our 10µm series includes the microArch S140 and S240, both capable of achieving tolerances within +/-25µm.

Our newest printer, the microArch S350 is a 25µm platform, capable of achieiving +/- 50µm tolerance.

MicroArch S350

What is the achievable surface roughness of the parts?

Surface finish ranges between 0.5 to 2 microns RA, depending on the orientation of the surface. Feature size is usually a multiple of the resolution, such as 10 microns or 2 microns.

For example, a 10-micron resolution can produce features of approximately 50 microns, while a 2-micron resolution can achieve features of around 10 microns.

Cleaning of the printing channels is essential. Can you provide an overview of this process and what it involves?

The uncured resin inside the channel must be removed after printing, which we have accomplished using various techniques, such as chemical washing and vacuum removal, developed in the past 18 months.

Do you offer sample parts?

We offer sample parts and benchmark parts at no cost to prospective customers to evaluate our technology, which is a crucial aspect of our sales process. If you'd like to request a sample part, please visit our website and submit a request.

About John Kawola

John is the CEO of Boston Micro Fabrication (BMF) an additive manufacturing technology company with a focus on high resolution, accuracy and precision. From 2016 to 2019, John served as President-Americas for Ultimaker, the leading open source desktop 3D printing company. From 2012 to 2016, John was the CEO of Harvest Automation. Harvest developed and deployed an autonomous mobile robotic platform that assists workers with difficult, repetitive material handling. John was VP of Sales and then CEO of Z Corporation from 1997 until 2012. Z Corporation led the way in introducing fast, easy to use and full color 3D printing into a wide range of industries. John is also currently the Chairman of Labminds, a laboratory automation technology company and a Board Director at Industrial ML, an industrial machine learning company. John received a BS in Mechanical Engineering from Cornell University, MS in Mechanical Engineering from Rensselaer and an MBA from Union College.

This information has been sourced, reviewed and adapted from materials provided by Boston Micro Fabrication (BMF).

For more information on this source, please visit Boston Micro Fabrication (BMF).

Bioprinting breakthrough: Tech platform creates 3D neural tissues in which neurons and glia connect

In a recent study published in *Cell Stem Cell*, researchers produced three-dimensional (3D) bioprinted human brain tissues, allowing for the creation of functioning neural networks that could simulate network activity in normal and pathological situations.

Study: 3D bioprinting of human neural tissues with functional connectivity. Image Credit: whitehoune/Shutterstock.com

Background

Understanding neural networks in the human brain is critical for understanding brain health and disease. However, animal-based models cannot effectively reproduce the human brain's high-order data processing due to variations in cell composition, neural networks, and synaptic integration. 3D bioprinting provides a more accurate method for creating human brain tissues by physically repositioning hydrogels and live cells inside a physiologically complicated cytoarchitecture. However, bioprinting soft tissues, such as the brain, is of concern since soft biomaterials cannot sustain intricate 3D architectures or rigid gels.

About the study

In the present study, researchers developed a 3D bioprinting platform to manufacture tissues with defined human brain cell types in any desired dimension.

The team aimed to build layered neural tissues, including neural progenitor cells (NPCs) that generate connections inside and between the brain layers, maintaining the structure intact. They created a bioink for printing. They used fibrin gel to print the tissues. Methods for bioprinting include extrusion-based, laser-based, and droplet-based techniques. The extrusion three-dimensional bioprinting technique deposited gel in layers to simulate brain structures such as human cortex laminations.

The researchers selected a 50 mm thickness for every layer and built multi-layered tissues by placing the layers in a horizontal arrangement adjacent to one another. They designed 3D-printed brain tissues to be relatively thin but functional and multi-layered, with established cell compositions and desirable dimensions, and easily maintained and tested in a standard laboratory setting.

The researchers determined that 2.50 mg per mL fibrinogen and 0.50 to 1.0 U of thrombin were optimum concentrations for hydrogel formation, resulting in a gelation duration of 145 seconds, which allowed for 24-well plate printing. After six hours, most (85%) of the cells were viable and survived for seven days. The team created medial ganglionic eminence (MGE)-derived gamma-aminobutyric acid (GABA) and cortical (glutamate) progenitors from green fluorescent protein-expressing (GFP^+) and GFP^- human pluripotent stem cells (hPSCs) to investigate whether GABAergic interneurons and glutamatergic neurons form synaptic connections when inserted into printed tissues. Before printing, they combined the two progenitor populations in a 1:4 ratio to match the ratio of interneurons to cortical projection neurons in the cerebral cortex.

The researchers recorded electrophysiological data from tissues printed with GFP+ glutamatergic cortical progenitors, noncolored MGE GABAergic progenitors, and hPSC-derived astrocyte progenitors incorporated into glutamate neurons and GABA interneurons. The printed tissue was immunostained with an axonal marker, SMI312. They studied Alexander disease (AxD), a neurodegenerative disease caused by GFAP gene abnormalities, to investigate pathogenic mechanisms. They used live imaging of glutamate uptake by glutamate-sensitive fluorescent reporters (iGluSnFR) to investigate neuron-astrocyte interactions and neuron-glial connections in AxD.

Results

The printed neuronal progenitors developed into neurons within weeks, forming functional neural networks inside and across tissue layers. Printed astrocyte progenitors matured into astrocytes with complex processes to function in neuron-astrocyte networks. Conventional culture techniques could retain the 3D brain tissues, making them easier to investigate in physiological and pathological settings. Cell viability declined with rising concentrations of thrombin at 2.50 mg/mL fibrinogen concentrations but remained unaltered at a constant concentration of 0.50 U fibrinogen, and cells aggregated at increased fibrinogen levels.

The bioprinted neural cells matured and retained tissue form, with GFP-expressing cells in one band transforming into microtubule-associated protein 2 (MAP2+) neurons a week after printing. The printed tissue maintained a stable configuration where neural progenitors multiplied and built neural networks. The neuronal subtypes established functional networks within the bioprinted tissues, with hPSC-derived MGE cells expressing NK2 homeobox 1 (NKX2.1) and GABA and cortical progenitors positive for forkhead-box G1 (FOXG1) and paired box 6 (PAX6). The bioprinted neural tissue constructions promote the growth of cortical glutamatergic neurons and GABAergic interneurons.

The researchers utilized a high-concentration potassium chloride solution to print tissues containing neurons and astrocytes, demonstrating functional connections. The astrocytes expressed glutamate transporter 1 (GLT-1), indicating maturation. The printed cortical and striatal neuronal bands remained intact 15 days after printing, and GFP and mCherry neurites developed towards each other. The printed human brain tissues might replicate diseased processes, with AxD astrocytes exhibiting intracellular GFAP aggregation. By 30 days, MAP2+ neurons and GFAP+ astrocytes exhibited complex morphology and synapsin expression.

Conclusion

Overall, the study findings demonstrated the ability of 3D printing to generate functioning brain tissues for simulating network activity in normal and pathological settings. The bioink-created tissues establish functional synaptic connections between neuronal subtypes and neuron-astrocyte networks in two to five weeks. The 3D platform provides a defined environment for studying human brain networks in healthy and pathological settings; however, it has limitations, such as the softness of the gel and the 50mm thickness of the printed tissues.

Journal references:

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Eco-Friendly 3D-Printed Concrete Innovations

A recent article published in *Materials* presented three eco-friendly alternatives for creating artificial aggregates (AAs): organic hemp shives (HSs), pyrolyzed coal (charcoal), and solid waste incinerator bottom slag (BS). The usage of these aggregates was investigated in 3D-printed concrete (3DPC).

Study: Eco-Friendly 3D-Printed Concrete Innovations. Image Credit: sergey kolesnikov /Shutterstock.com

Background

Using sustainable building materials has become essential to achieve the 2050 goal of a carbon-neutral building industry. Consequently, 3D-printed concrete (3DPC) is prepared using sustainable mixing materials such as rice husk ash, marble dust, and burnt ashes from municipal solid waste incinerators.

Widely popular cogeneration power plants generate large amounts of waste and bottom slag (BS), the accumulation of which in landfills poses significant waste management challenges.

Alternatively, BS can be used as a replacement in mortar and as recycled fine/coarse lightweight aggregate in green concrete. Moreover, granules made from BS can replace all of the natural gravel in concrete.

Among different agricultural organic wastes used in 3DPC manufacturing, hemp is the most popular. It is well known for its insulating properties and environmental friendliness.

Another frequently used organic material in grilling today is charcoal. Its lightweight, insulating, and absorption properties make it attractive in lightweight concrete or concrete bricks as a sand replacement. Thus, this study combined artificial aggregates (AAs) made from organic hemp shives (HSs), charcoal, and BS to produce eco-friendly 3DPC.

Methods

Ordinary Portland cement (OPC; 30 %), hydrated lime (HL; 2 %), and burnt fly ash (BFA; 9 %) were the main binder materials for 3DPC production. Additionally, differing amounts of natural aggregate (ranging from 55 % to 41 %) and sand, along with BS, HS, and charcoal AAs, were used in 3DPC.

Before granulation, HS and charcoal were milled in a cutting mill. Sieving ensured that all AAs were less than 4 mm in size. Since the sugars present in HS could affect the properties of the concrete, a sugar refractometer was used to measure the sucrose content in the investigated organic components.

Agitation granulation was performed to produce AAs with nine different compositions mechanically. The granule diameter was kept under 4 mm for comparison with the natural aggregate-containing 3DPC. Ten of the most-rounded granules from each type of AA were selected and heated at 105 °C until a constant weight was reached.

Subsequently, a thin layer of wax was applied to each granule, and they were weighed using hydrostatic scales. Additionally, the bulk density of the granules was measured through free fall in a one-liter bowl. Next, the strength of different granules was compared in 3DPC composites in the fresh state.

Energy dispersive spectroscopy (EDS) and scanning electron microscopy (SEM) were used to investigate the microscopic structure of AAs and 3DPC elements. The flow of newly mixed composites was assessed following the standard flow table test. Additionally, the flexural and compressive strength and freeze-thaw resistance of the 3DPC composites were examined by fabricating prism samples.

Results and Discussion

The parameters for mechanical agitation granulation were optimized to obtain granules suitable for 3D printing. Approximately 80 % of the total mass of these granules was achieved with slow water spray and a rotation speed of 35 rounds per minute.

SEM images of the AAs revealed absorption of the moist and dry mass of the binders in both organic materials, forming spherical or round granules. In contrast to charcoal, HS AAs became more brittle after sieving, with weaker bonding to the binder layer. However, loose granulated BS exhibited the most favorable strength in 3DPC.

Widely used burnt oil shale ash and lime exhibited weaker strength than the AAs proposed in this study. Additionally, concrete with BS performed comparably to reference concrete comprising natural aggregates. The reference mix performed poorly in deformation tests compared to the 3DPC compositions containing BS and HS granules, which is attributed to the high stability of BS and the fibrous nature of HS.

Regardless of the relative strength, these results highlight the benefit of granulating materials to obtain particles of similar dimensions, making them appropriate for 3D printing. Moreover, the processed organic aggregates made 3DPC more stable (with smaller deformations) than non-granulated organic aggregates.

Specimens without granulated organic AAs exhibited inferior performance in the freeze-thaw resistance test, with only 2.2-2.7 % accession. The deformation graphic indicated that the expansion regulator could control deformations in concrete only when the organic components were granulated. Otherwise, the regulator slowed the reactivity of organic materials in a concrete mix.

Conclusion

Overall, the researchers successfully demonstrated the potential of mechanically-produced AAs in manufacturing low-carbon 3DPC with enhanced properties. Specifically, the lightweight aggregates of HS, charcoal, and BS could constitute up to 14 wt.% in concrete without compromising performance.

The comparison between 3DPC comprising unprocessed and granulated HS, charcoal, and BS after 28 days of curing indicated the high performance of the latter. However, analysis of the granulation process indicated that organic materials like HS need to be safeguarded from the negative effects of humid environments.

Journal Reference

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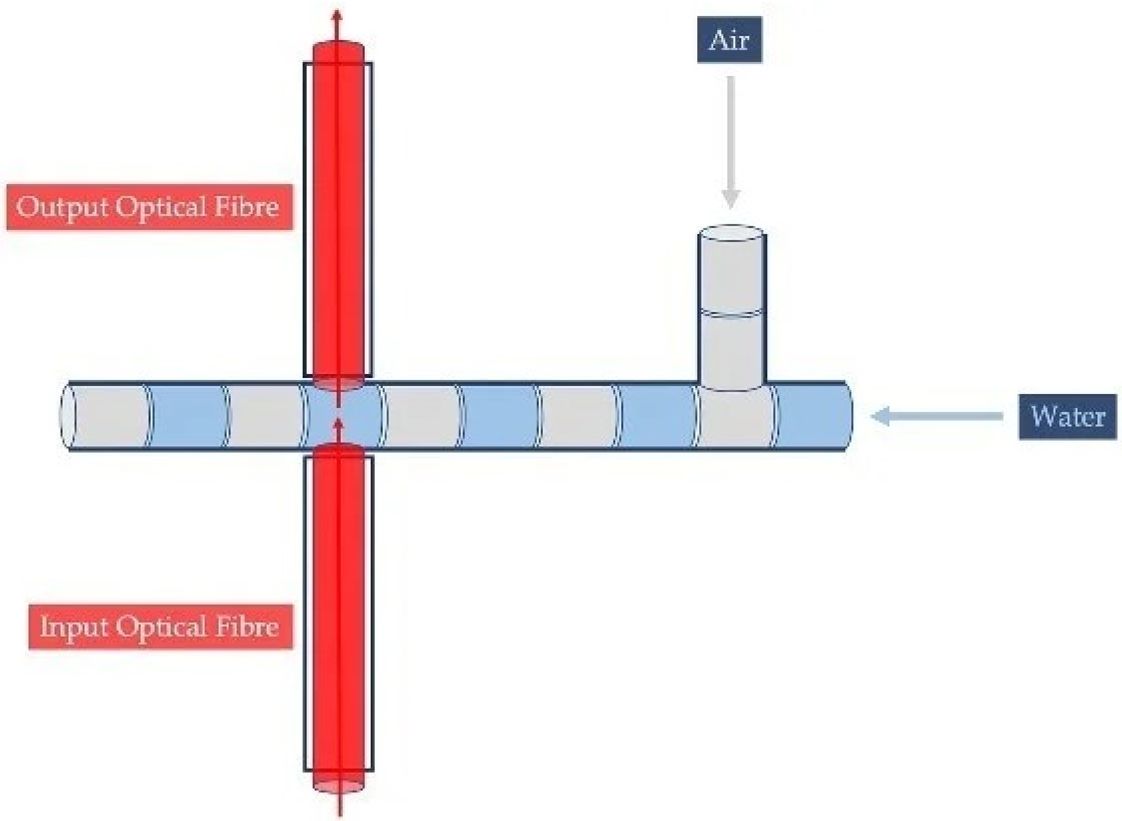
3D Printing of Micro-Optofluidic Devices

Lorena Saitta, PhD, was working on modeling micro-optofluidic devices suitable for the optical investigation of two-phase flow generated by immiscible fluids in the Polymers and Composites Lab at the University of Catania (responsible Professor Gianluca Cicala) in collaboration with the Microfluidic Lab (responsible Professor Maide Bucolo) and Inorganic Chemistry Lab (Professor Maria Elena Fragalà).

Saitta focused on a one-step manufacturing technique that provides optical transparency and customized surface chemistry without requiring additional assembly.

Finding the Right Materials to Achieve Necessary Functionality

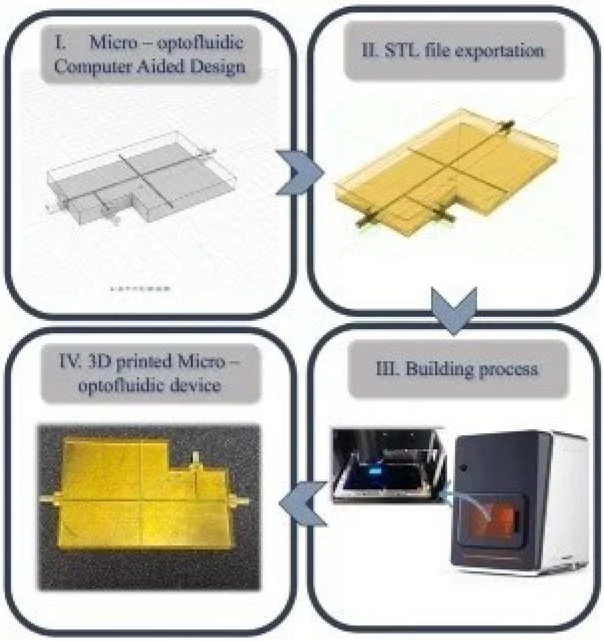
The optical detection of immiscible fluids requires optical transparency. Under the incident laser, the two fluids with differing reactive index values display distinct light transmission properties. To eliminate flow instability within the microchannels, the device also requires adequate surface roughness and hydrophilic behavior. Fluid leaking at assembly sites could result from further assembly. The ability to build the device in a single piece eliminates fluid leaks.



Schematic of the micro-optofluidic device. Image Credit: Boston Micro Fabrication

PDMS is a popular choice for micro optofluidic devices. However, PDMS has some significant drawbacks. When subjected to non-polar organic solvents, the microchannel walls deform slightly. It is difficult to permanently link molecules or polymers to PDMS, restricting the ability to form complex structures.

3D Printing the Micro-Optofluidic Devices

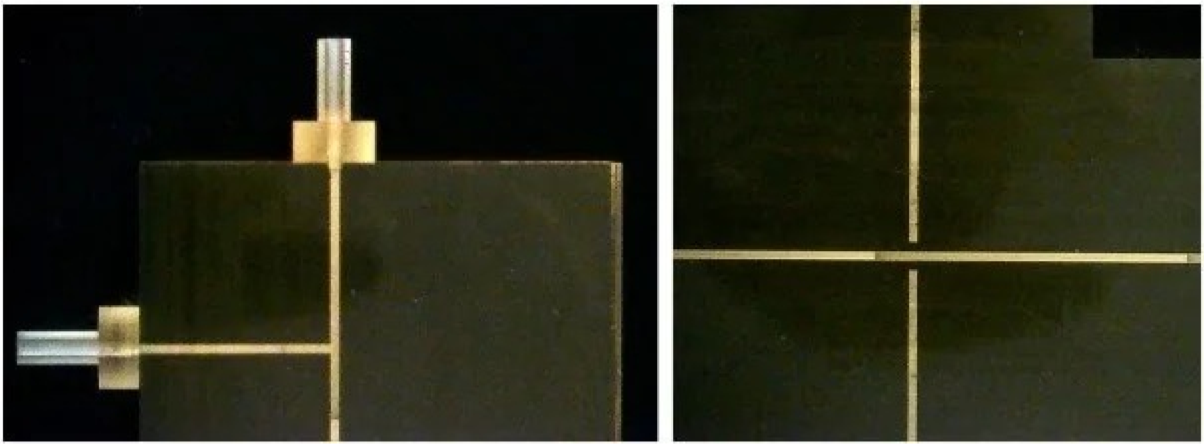


Steps for 3D printing the micro-optofluidic device. Image Credit: Boston Micro Fabrication

Micro 3D printed micro-optofluidic device. Image Credit: Boston Micro Fabrication

Saitta used 3D printing to create the micro-optofluidic device in a single piece. The group printed the device with embedded inlets, outlets, and insertions for micro-optical fibers using the microArch S140. BMF's HTL resin provided the capabilities required by Saitta's devices.

The resin's transparency and hydrophilic nature enabled stable fluid flow and the detection of a wide range of reactive index values. The microArch S140 was also capable of producing the micro-optofluidic device in a single piece, alleviating concerns about fluid leakage.



400 μm square channels in the micro 3D printing micro-optofluidic device. Image Credit: Boston Micro Fabrication

> *Projection Micro Stereolithography has opened new frontiers in the manufacturing of micro-optofluidic devices.*
>
> *Lorena Saitta PhD, University of Catania*

BOSTON MICRO FABRICATION

This information has been sourced, reviewed and adapted from materials provided by Boston Micro Fabrication (BMF).

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3D-Printing of High-Performance Plain Carbon Steel

A recent article published in *Nature Communications* reports the three-dimensional (3D) printing of plain carbon steels with tensile and impact properties comparable to, or exceeding, those of ultra-high-strength alloy steels such as Maraging steels.

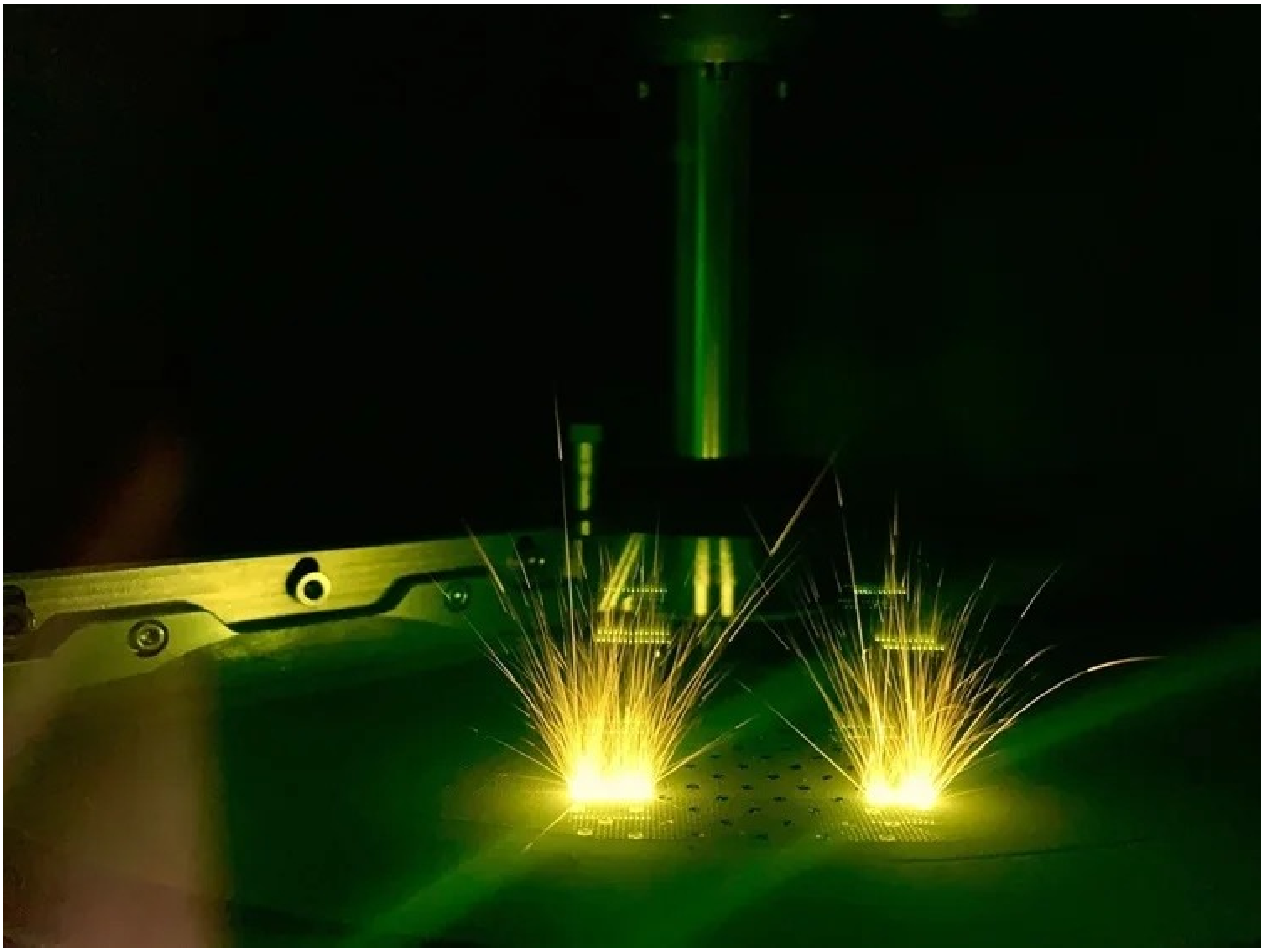

Image Credit: dr_christian_bay/Shutterstock.com

Background

Engineering alloys, such as aluminum and steel, are commonly used structural materials due to their high strength and damage tolerance. Over time, these alloys have evolved into compositionally complex variants with specialized properties.

The demand for improved mechanical performance, including ultra-high strength and wear resistance, has highlighted the need for precise control of microstructure formation. Metal 3D printing, particularly powder bed fusion (PBF), offers opportunities to simplify alloy compositions while achieving the desired performance. However, most 3D-printed components are fabricated using existing complex alloys rather than developing simplified compositions tailored for 3D printing.

PBF is a widely used metal 3D-printing method that employs a high-energy laser or electron beam to selectively melt thin layers of metal powder. This process constructs complex geometries layer by layer. This study utilized the characteristics of PBF to produce high-performance carbon steels.

Methods

Gas-atomized pure iron and steel powders were used as raw materials for the 3D-printing processes. Plain carbon steels with carbon contents of 0.4 wt.% (AISI 1040) and 0.8 wt.% (AISI 1080) were selected for the alloy compositions.

Steel samples (10×10×10 mm^3) were produced using a laser PBF 3D-printing system under an inert and high-purity (≥99.99%) argon atmosphere. Optimized printing parameters were then applied to fabricate larger samples for tensile testing, Charpy impact toughness evaluation, and hardness distribution analysis.

The 3D printability of plain carbon steels was assessed through sample densification using image analysis software (ImageJ). Rockwell hardness measurements were conducted on cubic samples at varying processing parameters, and the Jominy end quench test was performed to evaluate the low hardenability of plain carbon steels.

The potential of 3D printing to produce plain carbon steel parts with consistent microstructural and property homogeneity was demonstrated through the fabrication of a bevel gear (40 mm height, 80 mm diameter) using 1080 steel powder and optimized parameters.

To further compare processes, two L-shaped parts were prepared: one machined from commercial 1080 wrought steel and subjected to austenitization and quenching, and the other directly 3D-printed using 1080 steel powder. The 3D-printed part avoided issues such as quenching-related cracking and distortion, highlighting the advantages of the 3D-printing approach.

Results and Discussion

The uniform hardness distribution and precise geometric accuracy of the 3D-printed gear highlighted the ability of 3D printing to address issues associated with conventional water quenching, such as distortions and non-uniform hardness in alloys.

The L-shaped demonstration part machined from commercial 1080 steel exhibited cracking and distortion at the corner due to water quenching. In contrast, the 3D-printed part showed no cracks or distortion. This was attributed to the micro-melting process during printing, which compartmentalized thermal stress and provided an *in-situ* tempering effect through the melting of successive layers, reducing residual thermal stress.

X-ray diffraction analysis of the 3D-printed 1080 steel revealed a single ferritic phase (α') with no detectable austenite or carbides. Field emission scanning electron microscopy showed fine, plate-like ferrite structures uniformly distributed without preferential orientations.

An approximate Greninger-Troiano relation was observed between the orientation of the α′-blocks and prior γ grains, indicating martensitic and bainitic transformations during 3D printing and the suppression of pearlite transformation at the applied energy inputs.

In 1080 steel, low laser energy input produced high-carbon martensite, resulting in a yield strength (YS) of 1773 MPa and an ultimate tensile strength (UTS) of nearly 2000 MPa. Higher energy input shifted the microstructure from martensitic to bainitic, reducing the YS and UTS to 1100 MPa and 1327 MPa, respectively.

3D-printed 1040 steel also demonstrated strong mechanical properties. Low laser energy input produced a YS of 1340 MPa and UTS of 1430 MPa, while higher energy input reduced these values to 1000 MPa and 1100 MPa. These properties were achieved directly after printing, with subsequent tempering treatments having minimal effect on mechanical performance.

Conclusion

The study demonstrated that 3D-printed plain carbon steels can achieve high mechanical performance without significant alloying additions. The proposed approach offers advantages in cost, recyclability, and raw material availability.

The researchers recommend further investigation into the fatigue resistance, fracture toughness, and stress corrosion cracking of 3D-printed plain carbon steels for practical applications. Enhancing properties such as corrosion resistance may require the addition of elements like chromium, while other alloying elements could be considered for specific requirements, such as improving oxidation resistance.

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3D Bioprinting: Market Trends and Innovations

3D bioprinting has significant potential in tissue engineering, the artificial development of tissues and organs for implantation, and the creation of tissue and organ models for pharmaceutical and toxicological research.[1] This article explores recent innovations that have advanced the 3D bioprinting field.

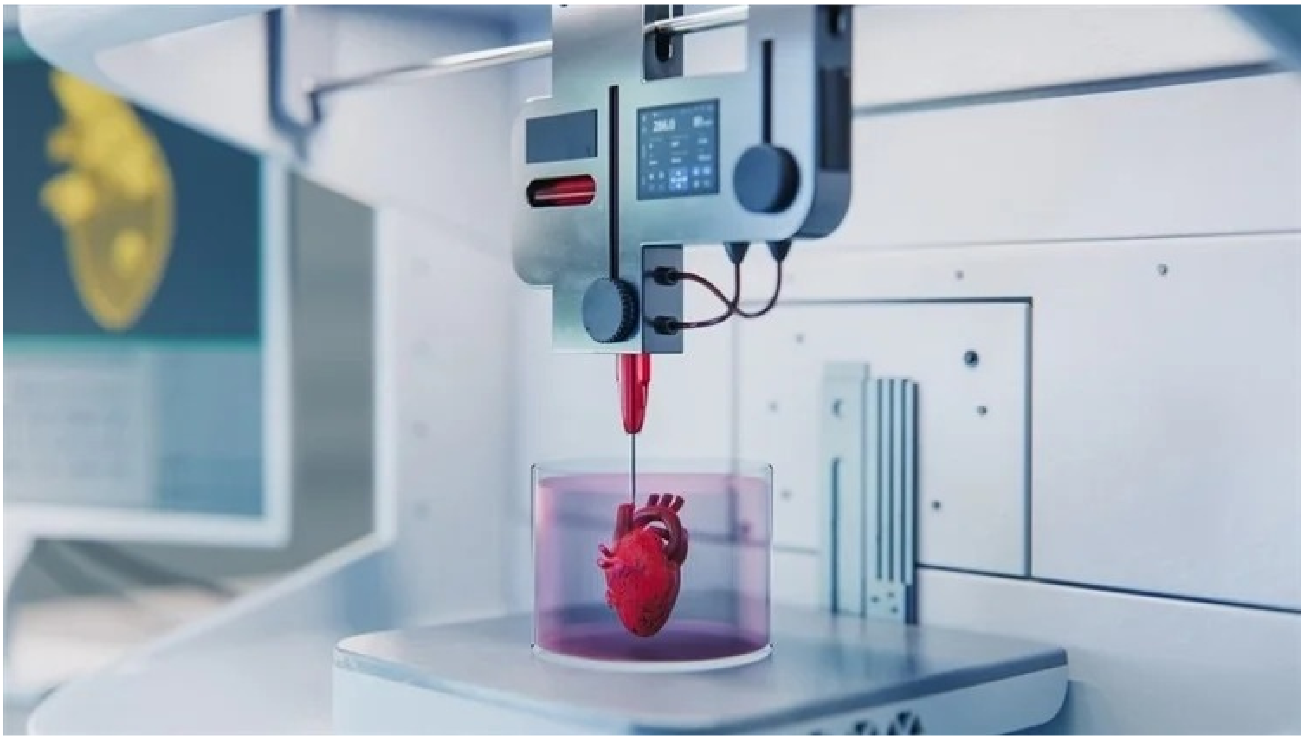

Image Credit: Gorodenkoff/Shutterstock.com

What is 3D Bioprinting?

The rapid advancement of 3D bioprinting technology has revolutionized surgery, medicine, and dentistry. It allows for the creation of customized artificial implants and prosthetics tailored to individual patient preferences or specific surgical requirements.[2]

Tissue and organ damage is a major medical issue arising from aging, illness, trauma, and genetic conditions. Organ transplants from living or deceased donors have been the primary treatment, but there is a severe shortage of donor organs, exacerbated by the increasing number of recipients.

Organ transplants often face rejection by the recipient's body. Researchers have turned to 3D bioprinting, which uses a patient's genetic material to generate replacement organs. This personalized approach reduces the risk of rejection and eliminates the need for lifelong immunosuppressive medications.[3]

Moreover, bioprinting technologies support personalized medicine by manufacturing 3D organ cultures for various purposes. These cultures are crucial in drug development and toxicity testing, allowing researchers to observe tissue and disease formation and progression in controlled environments.[4]

Among the many advantages of 3D bioprinting, reproducing the complexities of body physiology in vitro is particularly promising. This capability opens new horizons for personalized medicine, enabling more customized implants and better drugs for individual patients.[5]

Current Market Trends in 3D Bioprinting

In the past five years, innovative 3D printing technology has led to the emergence of 3D bioprinting. The market size is estimated at 2 billion U. S. dollars.[6] Recent technological innovations have significantly reduced the time required for bioprinting tissues and organs, leading to substantial revenue growth.

The research and commercial sectors have become significantly interested in 3D bioprinting, with substantial global investments. Market specialists expect a nearly 12 % increase in market value.

According to the "Technology Foresight Tool," the number of 3D bioprinting patents has grown significantly from 2015 to 2023, totaling 2,868. Additionally, 24 new companies joined the patent race last year, bringing the total to 121 companies, indicating a growing focus and investment in advancing bioprinting technologies.

Key Innovations Shaping the Future of 3D Bioprinting

The University of Wisconsin–Madison has created the first 3D brain tissue that can grow and function like natural brain tissue. This discovery provides hope for treatments for neurological and neurodevelopmental disorders, including Alzheimer's and Parkinson's diseases.[8]

L'Oréal's Advanced Research team, in collaboration with the University of Oregon, has developed an artificial skin model closely matching human skin using 3D bioprinting.[9] This innovation involved using melt electro-writing (MEW) to produce plastic scaffolds that mimic the extracellular matrix of natural skin.

3D bioprinting is also proving to be crucial in cancer research, playing a key role in combating dangerous diseases.

Challenges Limiting Wider Adoption

Selecting optimal biological materials that will not trigger immune rejection is crucial in 3D bioprinting. However, finding the right bioinks and scaffold materials remains challenging. Ensuring the survival and adjustment of embedded cells during the bioprinting process is essential, but this does not always happen, leading to damage and delays.

The created structures must remain stable and interact safely with surrounding tissues to avoid infection. Efforts are ongoing to ensure these structures are biocompatible, stable, and long-lasting.[10] Public awareness and education are needed to address ethical concerns and confusion regarding bio-printed tissues.

The Future of 3D Bioprinting

The impact of 3D bioprinting technology on medicine and surgery is profound.

Recently, 4D printing has gained attention for its ability to create objects that reshape themselves, particularly shape-memory materials. These techniques offer applications in neural regeneration, drug screening, and disease modeling. They also hold promise for personalized diagnostics and precise therapeutic approaches for conditions like brain cancers.[11]

The potential of 3D to 6D printing offers exciting opportunities, marking a significant advancement in the field and fully unlocking the potential of bioprinting technology.

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