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Review
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Problems and Difficulties in the Additive Manufacturing of Composites with Carbon Fiber Reinforcement for Medical Application

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Abstract

Amputation is more prevalent than one may think due to an accident, war, or disease. Prosthetics and associated orthotics have a combined global market value of $2.8 billion. Carbon fibre has found a market due to increased demand for foot prostheses. Fused deposition modeling (FDM) is a rapidly advancing three-dimensional (3D) printing technique. PEEK (polyether-ether-ketone) is a biocompatible, high-performance polymer that could potentially be utilised as an orthopedic surgery implant material. The mechanical properties and biocompatibility of FDM-printed PEEK and its composites are presently not well-defined; therefore, the development of FDM-printed CFR-PEEK composites with suitable mechanical attributes holds promise for their utilization as biocompatible materials in bone grafting and tissue engineering applications. The goal of this study is to recommend the best implant, which must be robust yet relatively flexible, with a modulus of elasticity as near to that of bone as is feasible. To meet this goal, new polymeric and composite materials must be created.

Keywords: Carbon Fiber, PEEK, Biocompatible Material, Modulus of Elasticity, Fused Deposition Modeling

INTRODUCTION

In the manufacturing process known as three-dimensional (3D) printing, materials are fused or deposited to create things. To create a 3D shape, a wide range of materials, including plastic, metal, ceramics, powders, liquids, and even biological cells, are accessible. This method is also called solid free-form technology," "fast prototyping, and additive manufacturing (AM). Several 3D printers resemble conventional inkjet printers. Even though 3D printing produces 3D objects as the final output, it is predicted that 3D printing will change several industries, including medicine [1].

The many 3D printing techniques use various printer technologies, speeds, resolutions, and materials. Using these technologies, we may create nearly any shape of the structure specified in a computer-aided design (CAD) file. The 3D printer first builds the object's framework by following the CAD file's instructions and moving the print head in the x-y direction. Then, the print head is continually moved vertically in the z-direction layer by layer to create a three-dimensional object [1].

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ADDITIVE MANUFACTURING IN THE MEDICAL INDUSTRY

According to the demands of specific medical applications and unique patient data, additive manufacturing (AM) offers extensive customization. Specialized software creates specific patient models in three-dimensional (3-D) parts. They include arterial structures, implants, soft tissue, foreign bodies, etc. [2, 3]. Several medical fields have benefited from 3D printing, including dentistry, creating personalized maxillo-facial prostheses, and developing innovative orthopedic goods [2, 4]. In addition to this, additive manufacturing also produces good skeleton model results [2, 5]. In addition to numerous well-established methods for creating rapid medical prototypes, such as fused deposition modeling (FDM), stereolithography (SLA), and inkjet 3D printing, more recent advanced methods, such as direct metal laser sintering (DMLS), selective laser sintering (SLS), selective laser melting (SLM), and electron beam melting (EBM), are being used to create implants with adequate metallic density. The DMLS machine can create very accurate and complicated 3D items in a short amount of time [6]. Other methods include direct ink writing (DIW), laminated object manufacture (LOM), multi-jet modeling (MJM), digital light processing (DLP), and inkjet printing. In general, these technologies may be divided into four groups: liquid-based (SLA, MJM, and RFP), powder-based (SLS, EBM, 3DP, and LOM), solid sheet-based (LOM), and filament-based (FDM and FEF) [6].

MAJOR APPLICATIONS IN THE MEDICAL SECTOR

Bioprinting Tissues and Organoid

In a lab, synthetic living tissue may be created using bioprinters by layering living cells, also known as bio-ink, using a computer-guided pipette. They can be used for medical research since they are miniature organ replicas. In addition, it could be one of the less expensive possibilities for transplanting human organs.

Applying 3D-printed Models to Support Surgical Treatment

Making patient-specific organ reproductions is another use of 3D printing in the medical industry. Surgeons can practice on these replicas before carrying out complicated surgeries. It can expedite processes and lessen patient stress. Also, it may be crucial in clinical care and medical education. In such circumstances, the biocompatibility of materials is not required.

3D Printing of Medical Equipment

3D printers are utilised to create sterile surgical tools that can operate on specific areas without endangering the patient in any way that may be avoided. This will cut down on the patient's healing time as well.

3D Printing for Customised Prostheses

3D printing can be implemented to create prosthetic limbs that are customised to the wearer's needs. This ensures that the appropriate specialised product can be manufactured in the shortest amount of time. It is common for amputees to wait a few weeks to months to start receiving prosthetics through the traditional route; however, 3D printing significantly speeds up the process while also producing quite enough inexpensive items that give patients identical and sometimes more excellent performance than traditionally manufactured prosthetics. Because of their low cost, these items are especially suitable for youngsters who rapidly develop their prosthetic limbs.

Permanent Non-bioactive Implants

Permanent surgical implants, extensively used in dentistry and orthopedics, require non-degradable biomaterial biocompatible after surgery. Unlike conventional machining, 3D printing can enable individualised, real-time fabrication of any complicated implant with great dimensional precision and fast production cycles. In addition, stress-shielding events occur every day during conventional bone treatments because typical metallic implants are stiffer than bone, eventually compromising bone integrity [6, 7].

ADVANTAGES OF 3D PRINTERS IN HEALTHCARE

In healthcare and 3D printing, a significant amount of work has already been done, including creating precise prostheses, preoperative models for educational use, surgical training, and human tissue fabrication. Prototyping with 3D printers is a huge advantage but may also be used for customised manufacturing. The applications and advantages of 3D printing in the healthcare industry are pretty straightforward.

Customise

Considering that human anatomy is as unique as each individual on the globe, the ability of a 3D printer to modify its output is an essential tool for grasping anatomy on a surprising level. This holds for prostheses based on the patient's traits, the creation of various tissue types, the recreation of challenging bone problems to suit each person's demands, and tools and medications. The healthcare sector will be revolutionised because every patient may receive the appropriate treatment they require. Jigs and fittings can be created using 3D printing in operating rooms. Custom-made surgical instruments, fixtures, and implants can save operating room time, speed up patient recovery, and increase the likelihood that a procedure or implant will be successful.

Cost-Effective

Large-scale productions are preferable to batch or small productions since they are less expensive. The use of 3D printers allows for prototyping and more affordable small production runs. Even simple operations may be evaluated and developed repeatedly according to the end user's needs without increasing overall costs. Due to the absence of the expense of human resources, all outputs will be cost-effective. This is particularly true for small-sized conventional implants or prostheses, such as those used for treating spinal, dental, or craniofacial abnormalities, as well as for highly complicated goods or requiring frequent adjustments, such as in children and young adults.

Efficient

The traditional method for creating a prosthesis, an implant, or a prototype requires much time and labor. The patient will have to wait years as a result. The benefit of 3-D printing is that it is a fully automated procedure with precise readings. This will lead to prompt and reliable production. In addition, because several scale reproductions can be produced quickly, the process is more structured and efficient. As a result, a product may be created using 3D printing in a short period. This allows 3D printing technology to produce products far quicker than current production processes like implants and prostheses. The traditional approaches need several mechanical procedures, such as milling, forging, etc., coupled with a more extended delivery period. Three-dimensional printing offers additional benefits in addition to speed, including resolution, precision, dependability, and repeatability. The traditional approaches need several mechanical procedures, such as milling, forging, etc., coupled with a more extended delivery period. Three-dimensional printing offers additional benefits in addition to speed, including resolution, precision, dependability, and reproducibility.

ADDITIVE MANUFACTURING FOR BONE

Bone is a sophisticated tissue undergoing dynamic biological remodeling and can mend itself. Metal and alloy implants have a long history of use as bone implants. Due to their excellent biocompatibility, adequate mechanical strength, and superior corrosion resistance, stainless steels, cobalt-based alloys (Co, Cr, and Mo), titanium (Ti), and related alloys are widely employed. However, the fundamental issue is stress shielding because of the variation in stiffness between implants and normal bones. Moreover, stress shielding is a significant factor in bone loss and the inevitable destruction of such implants [8]. The need for affordable, cost-effective prosthetic devices is especially critical for children who are still developing and incur higher expenditures. Although many different populations—including children, diabetic patients, and veterans—are affected by limb loss, developing more advanced prostheses for kids and teenagers is especially important. As a result, 3D-printed prostheses could pose as a workable alternative. Children and adolescents require many prostheses because of their rapid development. Growth trends for adults with prosthetics fitted are often stable, requiring only periodic adjustments [9]. Using FDM (Fused Decomposition Modeling) technology, AM brings up new possibilities and difficulties for building complicated geometries while defining the infill ratio, internal structural geometry, and locally manipulating material composition and behavior [10]. In a digital environment, 3D printability simulates the conventional manual production method. Instead of a plaster cast, a scanner is used to record the external contour of the limb. It adds or subtracts material using 3D modeling software rather than altering the prosthetic device by adding or removing plaster [9].

MATERIALS FOR BONE COMPONENTS

Natural fibres, such as bamboo fibres and wood particles, are also being investigated and may apply to inexpensive O&P devices. The use of composite materials in bio-implant production is not a recent discovery; composite materials have been developed for orthopedic purposes for more than three decades. As implant materials, carbon fibre/PEEK (C/PEEK) polymer composites were created in 1994 (Albert et al., 1994) [11]. Carbon fibres provide several potential benefits to create high-strength biomaterials with a density that is near bone for improved stress transmission. Compared to a titanium-alloy implant, this composite implant had 10–40% reduced contact stresses in the distal area. Due to their specialised features that are analogous to those of the host tissues, polymer-based composite biomaterials have grown in popularity. Thus, the likelihood of increased implant performance is rising due to improvements in composite material production [12]. Magnesium (Mg) is a sustainable implant material with high biocompatibility and necessary mechanical qualities. Mg-based implant research has shown that this element is appropriate because it is found in humans. In addition, magnesium alloys have better mechanical characteristics than other kinds of biodegradable synthetic polymers [13]. Modern innovations have increased the qualities of a polymer by increasing or doubling its specific strength and adding more filler elements to the polymer, including glass, carbon fibre, etc.

LIMITATIONS & PROBLEMS WITH CURRENT MATERIALS

For a material powder to be considered for additive manufacturing, it must have a uniform or spherical geometry and a homogeneous particle distribution free of agglomeration. Thus, a technique that can produce particles with a precise spherical shape is crucial for different additive manufacturing technologies. One likely option is examining the next-generation systems and concentrating on a single process that allows the user to generate substances (polymers, ceramics, composites, and metals) with a spherical shape [7]. The major challenge in additive manufacturing is obtaining material in powdered form with the desired particle size. The majority of commercially accessible products are not produced in fine powdered form. These materials must be mechanically altered to sufficient particle size, resulting in a distorted or uneven shape. Several production methods currently used to create microparticles for additive manufacturing need to be improved in homogenous distribution, distinctive size dispersion, spherical shape, and batch-to-batch repeatability. The majority of the particles produced have irregular spherical forms, are angular, rounded, and acicular, are flaky, spongy, or potato-shaped, and ultimately condense into a weak component with a very low density and insufficient characteristics. The accuracy of AM components will tend to decrease when irregular and non-uniform particles are used, and 3D part characteristics like surface roughness, minimum particle size, and porosity will be impacted. This, in part, makes it difficult to remove the unsintered granules. The concept of a prototype and its transformation into a finished product need to be improved by the absence of certain distinctive traits. In 3D printing, flow time and packing density could be adversely impacted by flaws in the manufacturing process. The varying particle size and agglomeration cause an increase in flow time and a decrease in packing density [14].

Anisotropy is a significant issue that AM must handle. Due to the difficulty of managing in Z-directions, the adequate strength in the Z-direction (build direction) is always lower than in the x and y directions. Inkjet printing technology has also been utilised to produce 3D objects for applications requiring great accuracy, similar to most additive manufacturing methods.

CONCLUSION

It is necessary to conduct experimental investigations for each kind of material to define product attributes and optimise process parameters since each material's response to the various additive manufacturing techniques may vary. The EBM-produced samples' bending strength, stiffness, and hardness varied significantly. The strength and material variety of finished items need to be improved, and they cannot satisfy anticipated demands. For any 3D printer, biomaterials and biocompatible nano additives must be produced. The additive manufacturing file formats (AMF, recommended by ASTM) used by additive manufacturing technologies, such as STL, do not contain information on the manufacture of the products. This will cause some process defects and make achieving the required dimensional accuracy and repeatability easier. Post-processing tasks are crucial to obtaining the appropriate surface quality. One of the fastest-evolving and most exciting fields of AM technology is using new materials, including polymers, metals, ceramics, and composite structures. Moreover, the software is being enhanced to better accurately produce orthopedic and dental implants by transferring patient imaging data to the additive manufacturing system.

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