

# Additive Manufacturing Technology for Biomedical Components: A review

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**Abstract.** Over the last decades, additive manufacturing has shown potential application in ranging fields. No longer a prototyping technology, it is now being utilised as a manufacturing technology for giant industries such as the automotive, aircraft and recently in the medical industry. It is a very successful method that provides health-care solution in biomedical sectors by producing patient-specific prosthetics, improve tissues engineering and facilitate pre-operating session. This paper thus presents a brief overview of the most commercially important additive manufacturing technologies, which is currently available for fabricating biomedical components such as Stereolithography (SLA), Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Fused Deposition Modelling (FDM) and Electron Beam Melting (EBM). It introduces the basic principles of the main process, highlights some of the beneficial applications in medical industry and the current limitation of applied technology.

## 1. Introduction

AM is the process of joining materials, usually layer upon layer, to make objects from 3D model data, as opposed to subtractive manufacturing technologies [1]. This technology started originally in 1988 for producing prototype model and was known as rapid prototyping (RP). Within three decades, RP has evolved from simple 3D prototyping to complex structure known as rapid manufacturing (RM). As improvements to output quality from this technique and looking at the basic principle of fabricating parts using additive of material approach, the term RP and RM are used interchangeably with the term additive manufacturing [2]. Lately, AM technologies is progressively employed in medical field and slowly taking over the conventional method of producing patient-specific medical device. With further evolution of bio-cell printing AM, this technology has a potential to print the whole body organs within the next 20 years [3]. AM principle involves the process of cutting 3D drawing into 2D slices, where the data set is derived from original CAD data. 2D slices will be printed layer upon layer until a solid 3D model is formed. Essentially, AM is based on two-stage process: 1) virtual stage that includes modelling and simulating, requires a computer and 3D modelling software (CAD), 2) physical stage which is manufacturing, occupies layering material and machine equipment [4]. AM equipment reads the data from produced CAD files and defines the data by depositing successive layer of material in layers, to build 3D physical object [5].

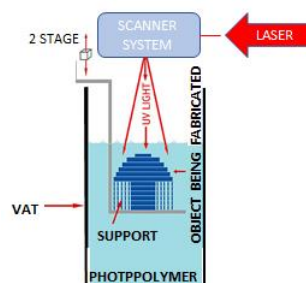


## 2. Image Developing and Processing for Additive Manufacturing

Bio-model based on additive manufacturing technique designates one-to-one scale of the human anatomical part acquired from 3D medical imaging [6]. The source of the image should be cleared to produce a good medical model. Currently, image data comes from computed tomography scan (CT scan), magnetic resonance (MRI) or other imaging modalities. MRI scanner delivers the energy produced by water molecules with the pulse given by radio waves to generate volumetric data set. Due to the bone nature which is nearly void of water, bone image is left out as ingenerated data. Meanwhile, CT scan uses x-rays to generate images of human body and displays better contrast between bones and soft tissue. Subject to the bio-model to be formed, MRI images are more suitable to deal with soft tissues while CT images are usually used as the source image when dealing with bones. Next, unwanted images are executed and the region of interest is extracted using image processing software. There are few imaging software packages that are reliable in processing medical data, repositioning the fracture and partly designing the new model of medical prosthesis. For instance, MIMICS and 3-Matics software developed by Materialise [7]. This software is used in the production of hearing aids. The medical images in DICOM (Digital Imaging and Communication in Medicine) format (.dcm) will be loaded into the software and selected data set can be opened in DICOM viewer software as 2D and 3D view. Model image can be reconstructed, smoothed, leaned and repaired by modifying mathematical algorithm developed by the software. The edited version of model image is exported and saved into supported 3D printing format which are, Object file (.OBJ) or Standard Triangulation Language (.STL) file formats. Data is further modified and optimized by Computer-aided Design (CAD) software where the region of interest is selected and generated as 3D model. This data is sliced using RP Tools and sent to AM machine for fabrication [6], [8]. The usage of integrated systems to transfer DICOM into CAD had been studied [9] and successful results were achieved in the design and modification process using CAD.

## 3. Stereolithography

Stereolithography (SLA) is a form of three-dimensional printing technology also known as photo-solidification or resin printing. This technique is used to construct 3D parts using a layer by layer concept through a process called photopolymerization. In photopolymerization process, energy source usually optical light is used to scan over a vat of light-curable resin causing the molecules to link and solidify specific region on the liquid surface. The depth of material is increased gradually by moving the floor of vat steadily downward. Successively, cured resin in layers and solid object is formed. The surrounding resin does not provide mechanical stability; thus, a support structure is required for the forming of the overhanging layers (Figure 1). The fabricated 3D object is taken off by draining and washing-off excess resin. SLA part are semi-transparent and very good in allowing visual access especially to body cavities, for example marrow spaces, sinuses and neurovascular channel [10]. However, the model structure has considerably poor mechanical properties. It needs to go through post-curing process under the exposure of ultraviolet light to improve mechanical properties of the structure [11]. Typical material use in SLA are liquid photopolymer and composites.

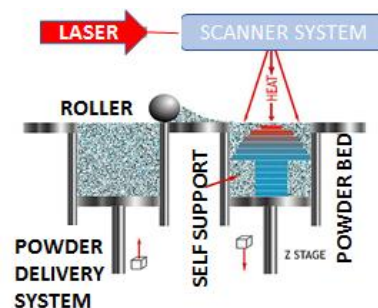


**Figure 1.** Stereolithography process diagram [12]

SLA products are reported to be very useful as an aid to diagnosis, teaching and surgical planning purpose [13]–[15]. With help from SLA technology, surgical duration and perioperative blood loss might decrease, while complication rate remain the same [16]. Surgeons also claimed that the preoperative planning is very effective [10] and minimizes the exposure of radiation during surgeries [17]. The SLA prototype is also used as a physical model to assist surgeons in better understanding of a complex fracture [18]. Besides that, SLA product can be used to fabricate patient-specific implant components. It was reported that there was no harmful effect shown under the dorsal skin of rats after one-month implantation period using implant prepared by SLA process [19]. SLA implant also has been reported to be an excellent method for treatment planning for maxillofacial trauma compared to conventional milling since it provides detail anatomical model. On the other hand, the disadvantages include the initial expense of SLA model such as cost for image processing and time taken for manufacturing and delivery [10].

#### 4. Selective Laser Sintering (SLS) and Selective Laser Melting (SLM)

Selective Laser Sintering (SLS) is a form of AM which uses high power laser as the source of heat energy to sinter polymer powder on defined region and binding them to becoming three-dimensional solid model. During this process, fine polymer powder is heated with CO<sub>2</sub> laser causing the powders to sinter together. As illustrated in Figure 2, a roller is placed alongside one of the feed beds and the powder is delivered by raising the feed bed steadily. Then, the roller pushes the raised powder across, covering the model platform with a powder layer. After that the laser, directed to the model platform, starts tracing cross section of the designed digital object onto the powdered material. Immediately after the first layer is created, the model platform descending gradually. This process continues with the same procedure until the entire three-dimensional object has been constructed. Unlike SLA, this process is self-supporting, where it allows for parts to be built on other part and unused material. However, SLS disadvantages include rough surface finish and less detailed features as compared to SLA [20]. SLS shows promising application for bone tissue engineering as the porous scaffolds can be computationally designed and fabricated [21]. Numerous biomedical applications of SLS shows promising results in oral, maxillofacial, neurological surgery, orthopaedics and tissue engineering applications [6], [8], [14], [22], [23]. Wide variety of process material for SLS in medical are polymers, metal alloy, biomaterial metal-polymer and metal-ceramics mixture.



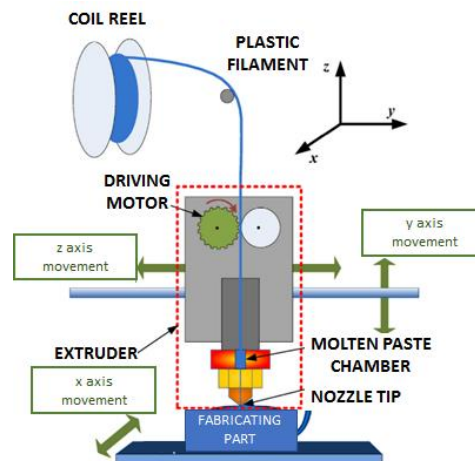
**Figure 2.** General concept of SLS/SLM [24]

Selective Laser Melting (SLM) basically is a subcategory of SLS. Instead of only fusing the metal powder to bond specific region, the laser is set up to fully melt the material and binding them in layers. Disadvantage of SLM process in comparison with SLS is that, it is not easy to control the production of surface tension because this process melts the material completely [22]. Common process materials for SLM are copper, aluminium, stainless steel and cobalt chrome. Application and advantages of SLM in medical have shown much progress over the years. It was mentioned that SLM maximizes the utilization of material because of the possibility to reuse un-melted powder [23]. In a scientific point of view, SLM can also solve aseptic loosening problem by controlling the mechanical properties of implant. It was

employed SLM method to fabricate implants by modifying the mechanical properties that mimics nearly like the natural human bone by developing open porous implants [25].

### 5. Fused Deposition Modelling (FDM)

Fused Deposition Modelling (FDM) is an AM process that uses a heated nozzle process. FDM consist of build platform, extrusion nozzle and control system. Initially, plastic filament from the coil reel is fed into heated nozzle by driving motor. Once the material is transferred into the heated nozzle, molten material is then extruded onto base plate in layer form based on pre-design toolpath until final 3D product is produced (Figure 3).



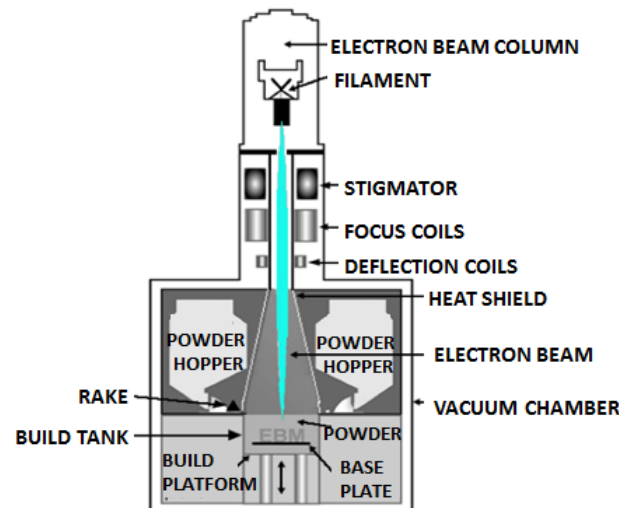
**Figure 3.** FDM working process [26]

FDM technique builds a functional model from available engineering thermoplastic such as investment casting wax, sulfones, ABS, polycarbonate and elastomers. FDM demands no special ventilation and involves no harmful chemicals by-products. It is also a good method of producing 3D parts with complex shapes. Nevertheless, this method suffers from disadvantages like long build time, poor surface finish and low mechanical strength [26]. It was investigated that FDM produced 3D scaffold with highly controllable channel size and porosity and fully interconnected channel, which can further be studied and modified to improve the mechanical strength of the manufactured model especially in bio-medical [27]. It was also demonstrated that the successful FDM fabrication of patient-specific implant with varying densities for cranial defect and femur part [28].

### 6. Electron Beam Melting (EBM)

Electron beam melting (EBM), like SLS and SLM use metal powder to fabricate metal parts. In contrary with SLS, EBM and SLM techniques achieved full melting for material to adhere. EBM works by melting metal powder with an electron beam in vacuum at a very high temperature (up to 1000°C). As a result, the EBM products have better mechanical properties (i.e.: strength, elasticity, fatigue, chemical composition, microstructure) than cast products and comparable with wrought material [29]. Since EBM takes place under vacuum condition, it is suitable to work with reactive materials that are highly reactive to oxygen such as titanium [30]. Vacuum environment in EBM also provides benefits such as maintaining a high-quality electron beam as collision between electrons and gas molecules is avoided, facilitating outgas impurities incorporated in the metal powder, and keeping good thermal insulation. EBM process starts with generated electron in electron beam column at the top of the vacuum chamber. High speed electrons are then accelerated in electrical field through two controlled magnetic fields. Stigmators and focus coils work as magnetic lens which help to focus beam into specified diameter while deflection coils redirect the focus beam to aimed region on the building table (Figure 4). Typical material used by EBM for medical field are commercial pure Titanium, Ti-6Al-4V, stainless steel,

magnesium alloys, and nickel alloys. Currently, main advantage of EBM is on titanium near-net-shape parts for medical implants. Few papers presented that EBM had been found to be a suitable method for manufacturing of patient specific porous implants [31]–[33]. EBM was utilised to modify the mechanical properties of titanium hip stem to reduce stress shielding effect [35]. The study showed promising result to fabricate custom and complex design of orthopaedic implants, although building non-stochastic lattice structure with correct lattice struts orientation to achieve a good stress distribution is a real challenge.



**Figure 4.** EBM working principle scheme [36]

## 7. Conclusion

AM technology in combination with medical imaging technique has shown to have a strong prospective for biomedical applications. This technique has successfully facilitated and improved the quality, duration of operating procedure and overcomes the problem of patient compromising the proper match of implant using individualised-tailor-made implant. Although AM technology has been greatly developed and improved, many limitations remain to be addressed. High cost of AM machines and materials, number of materials available, mechanical properties, size and accuracy of final parts produced are still the main challenges in adoption of AM in biomedical industry. However, AM is developing rapidly and is showing great potential in the future of biomedical manufacturing industry.

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