Additive manufacturing as an emerging technology in the field of medical science

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Abstract:

The utilization of Additive Manufacturing (AM) is rapidly progressing in the field of medical science and bio-manufacturing engineering, in which scientists, engineers, and clinicians are contributing equally. Additive manufacturing is the process of manufacturing solid objects with the help of 3D data of the required model by materials fixing or joining, generally by attaching layer upon layer. This paper mainly focuses on the application of AM in biomedical engineering, medicines and medical science. In this regard various case studies related to the replacement of various human organs, tissue engineering, stents used in cardiovascular, designing of biomedical micro-systems, various materials which are used in AM and their application in biomedical science by using different AM techniques.

Keywords:

Additive Manufacturing (AM), Biomedical, Computer Aided Design (CAD), Stress, Surgery

1. Introduction:

AM is the process in which the required object is obtained by joining the material, layer upon layer by using 3D data or images of the model and it is widely used for the manufacturing of Tissue engineering (TE) scaffolds by applying various techniques like stereolithography, fused deposition modeling etc.[1]. Accurate three-dimensional structures with porous characteristics are obtained using these techniques with an interlinked network. The 3D models are obtained using CT scan or MRI which are processed by CAD and CAM software [2]. Basic steps in AM are shown in Fig. 1. AM are classified into four type for scaffold fabrication of TE. These are as follows: a) three-dimensional printing (3DP) b) stereolithography (SLA) c) fused deposition modelling (FDM) and d) selective laser sintering (SLS) [3]. However, many other industrial techniques are introduced to meet the requirements which are under observation. The different types of AM are as shown in Fig. 2. AM technology helps the clinician to plan for surgeries due to the advancement of materials, services and equipment that are related to 3D printing technology. Mechanical properties like stiffness, shear stress, Young's modulus etc. can be determined easily without compromising the biocompatibility of the materials used in TM [4]. Material wastage is less in AM, and multiple materials can be used which results in less cost and lead time with high degree of design freedom. AM is the combination of flexibility and automation in design according to an individual's needs which makes it flexible and the treatment process is enhanced [5].

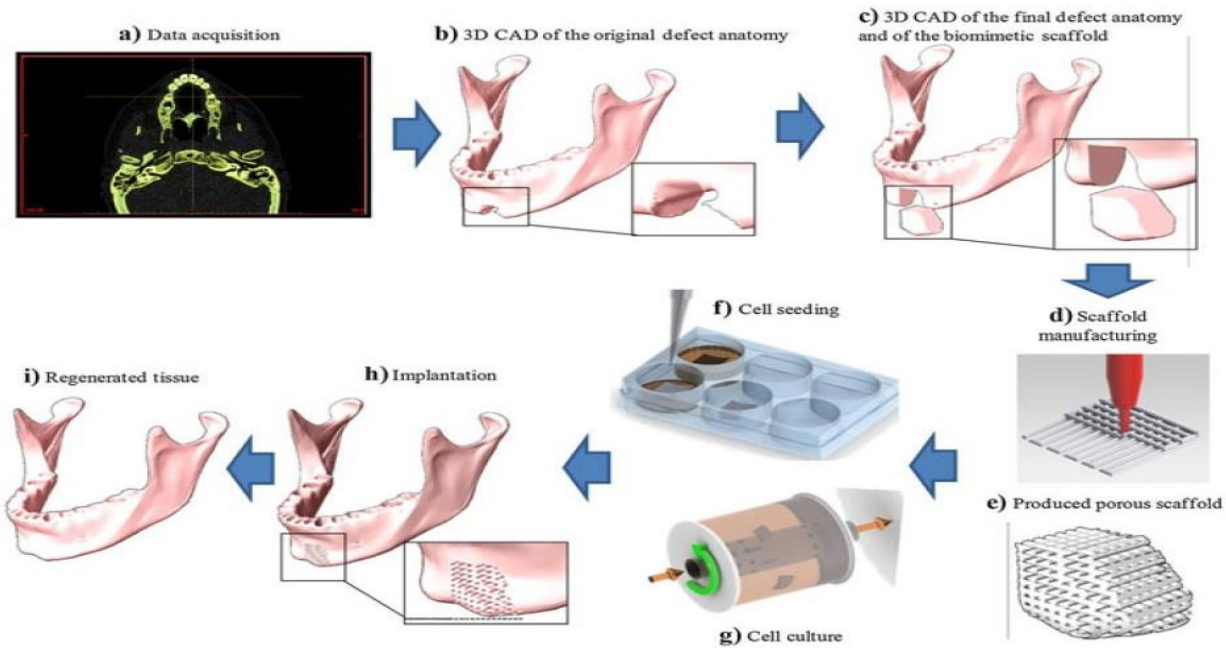


Fig. 1.- Steps in AM of regenerative tissue process [4]

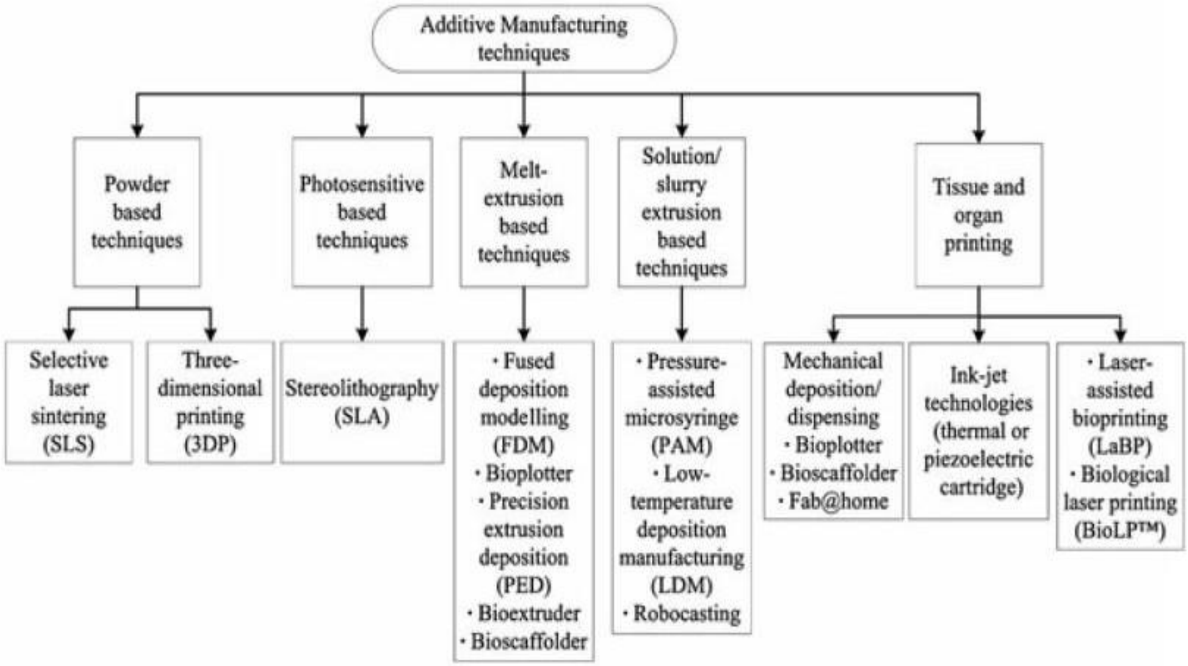


Fig.2- Classification of Additive Manufacturing [4]

2. Novel design for Bone replacement

Parthasarathy *et al.* [6] have modelled bone and dental implant by using titanium craniofacial by considering both functional and design i.e. esthetic requirement. Bone structure is quite complex comprising of dense cortical region at outer and spongy region at inner having the modulus of elasticity of 20 and 0.5 Gpa respectively. Titanium is known for its biocompatible characteristic which gives high strength to weight ratio, with a density of 4.43 g/cm^3 results in increasing the implant's weight twice than that of the original bone part need to be replaced. Mechanical properties such as Young's modulus, shear modulus, porosity, elastic modulus, stiffness are calculated and varying pore size and strut thickness, these properties can be varied. Once these values are found, the performance can be checked using finite element analysis of final part. Next step to give CAD design as a input file for abrasive manufacturing. The CAD file contains the no. of parts, strut size which are to be fabricated which are generally cubes. The parts were designed using commercial software package like Pro Engineer and then the

.STL file given as input to ARCAM- EBM machine. Electron Beam Melting is a process in which the porous and dense parts of metal are formed directly from CAD files. This is also known as computer-aided design to metal rapid prototyping. The solid dense metal part are formed by melting the powder of Ti6Al4V , layer by layer using a beam of electron. The information of layer is then supplied to machine and each layer are hardened or solidified and mounded one over the other untill they are solidified resulting in forming complete part. The mechanical and structural properties were evaluated by performing compression test, low-pressure pycnometers etc. and analysing the structure with the help of scanning electron microscope. The steps in manufacturing are shown in Fig. 3.

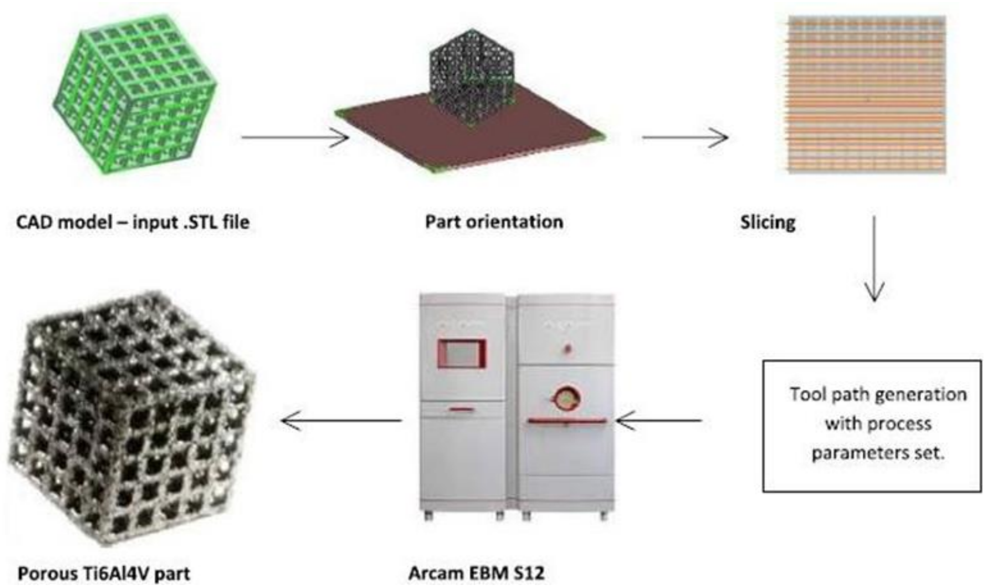


Fig. 3- steps in EBM part manufacturing [6]

They used two CAD model, hip and mandible implant for bio-mechanical consideration as shown in Fig. 4. The structural properties were determined and are as shown in Fig. 5. Compressive strength were calculated which is as shown in Table 1. From Table 2, it can be seen that for almost same value of porosity i.e- 49.75 and 50.75, compressive strength and stiffness significantly decreases with the reduction in the size of strut. It is clearly observed that strut size is mainly responsible for change in mechanical properties like strength rather than overall porosity. Shear strength is as shown in Fig. 6. Clean shear was not observed in any layer of produce by EBM. Mandible and hip implant performance were calculated and found to be in line with the real values. Finally they have concluded that bone remodeling and shielding of stress can be ensured for cancellous bone which can be replaced with the help of thinner struts.

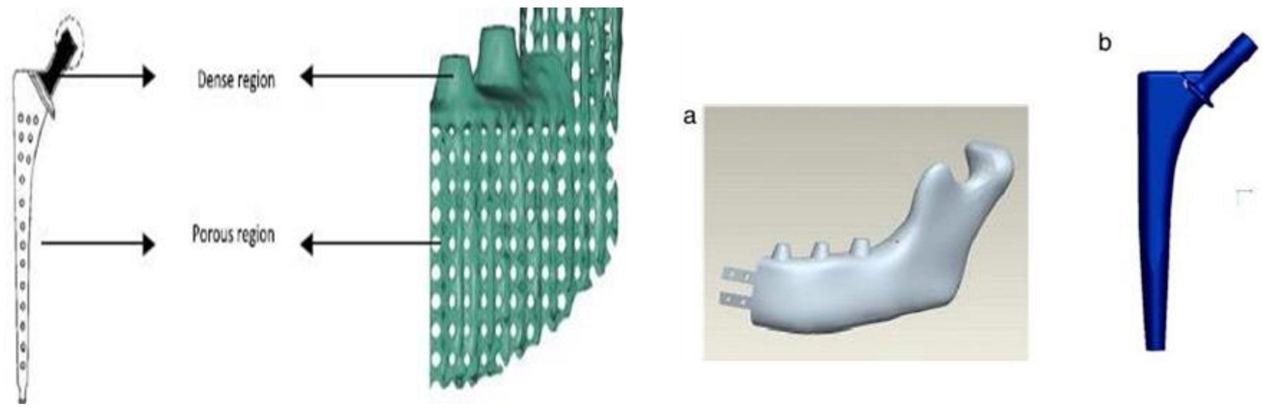


Fig. 4- Hip implant with porous and dense region (left) a)Mandible b)Hip implant [6]

Table 1- Compressive strength and stiffness [6]

Set	Porosity (%)	Compressive stiffness (GPa)	Compressive yield strength (MPa)
1	50.75 (±0.69)	2.92 (±0.17)	163.02 (±11.98)
2	60.41 (±0.81)	2.68 (±0.12)	117.05 (±5.54)
3	70.32 (+0.63)	2.13 (±0.21)	83.13 (±10.25)
4	49.75 (±1.00)	0.57 (±0.05)	7.28 (±0.93)

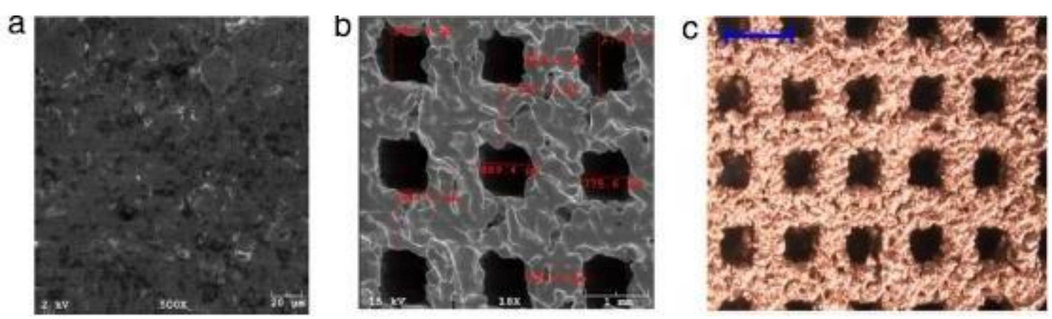
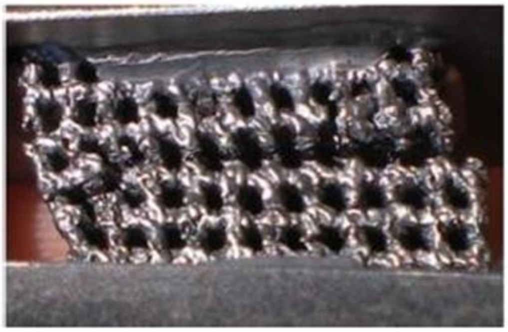


Fig. 5-a.SEM image of melting of powder particle-microstructure image b. SEM image showing strut size, pore size and deformation c. Surface deformation using optical microscope [6]



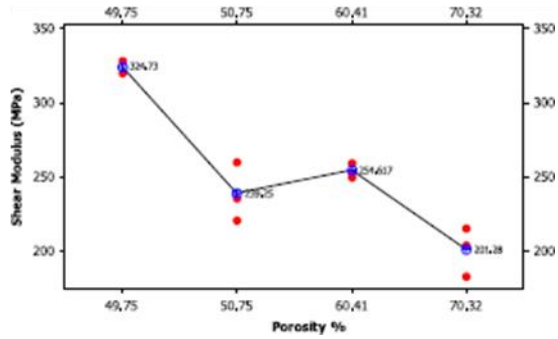


Fig.6- Sheared part and graph of porosity Vs shear modulus [6]

3. Cardiovascular stent by SLM

Manufacturing of Cardiovascular stent by using powder alloy of CoCr by using selective laser melting (SLM) was investigated by Demir and Previtali [7]. The SLM system uses modulation of high power emitted by pulsed wave laser, empowering control over various process parameters. The stent produced by SLM is an alternate technique to the traditional manufacturing process mainly depends on consecutive laser micro cutting and micro tube production. Considering the design rule a viable prototype design was proposed. The SLM procedure was researched with a modern framework that wave emission generated from pulse. Various strategies related with scan were used mainly concentric and hatching scanning. Further analysis was carried out like measurement of microhardness and micro X- ray computer tomography. Surface finishing was carried out using electro-chemical polishing. Prototype stents with satisfactory geometrical precision were accomplished and enhanced surface quality was obtained by using an electrochemical cleaning process. It was also observed that with minor increments in the oxide, the chemical composition does not vary. The stent image and SEM analysis result is as shown in Fig. 7.

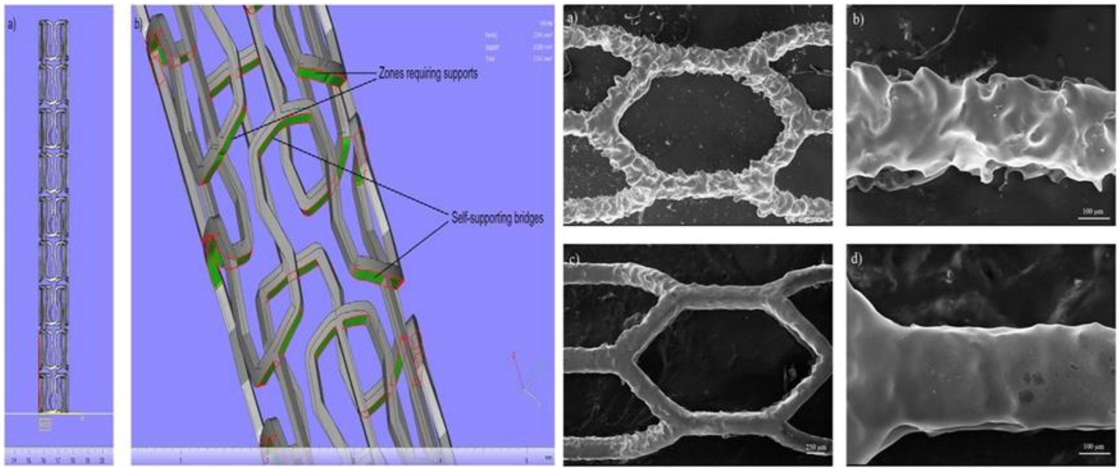


Fig. 7- Stent Image & SEM result after electrochemical polishing [7]

4. Manufacturing of biomedical micro-system

Hengsbach and Lantada [8] investigation provides a unique method for manufacturing biomedical micro systems. They had combined two AM processes. The device structure is manufactured by using a conventional laser writer and the smallest details were obtained using direct laser writer which works on the principle of two-photon polymerization. Their main aim was to examine the effect on microstructure surface during movement of cell or cell motility. The design of matrix based micro textured channel was obtained by rapid prototyping using digital light processing and this resulted in the formation of cell cultures which are attached to textured channel. As mentioned earlier, their process is comprised of many different processes. Three dimensional CAD method was used to design the microchamber and microchannels. The file is then converted into .STL format which is the input to the 3D AM. Various technologies like selective laser sintering, conventional laser stereolithography, digital light processing and fused deposition process the information which were stored in .STL format and given as input for the same. The manufacturing process at the multi-scale level is as shown in Fig.8(a). The impact of surface texture is shown in Fig. 8(b). Heidelberg laser writer were used to obtain the outer surface and nano scribe systems were used to create textured channel. The micro texturing process and its accuracy is shown in Fig. 8(c). The surface topology is controlled in the microsystem can be validated by observing the resemblance between the final prototype and the initial design.

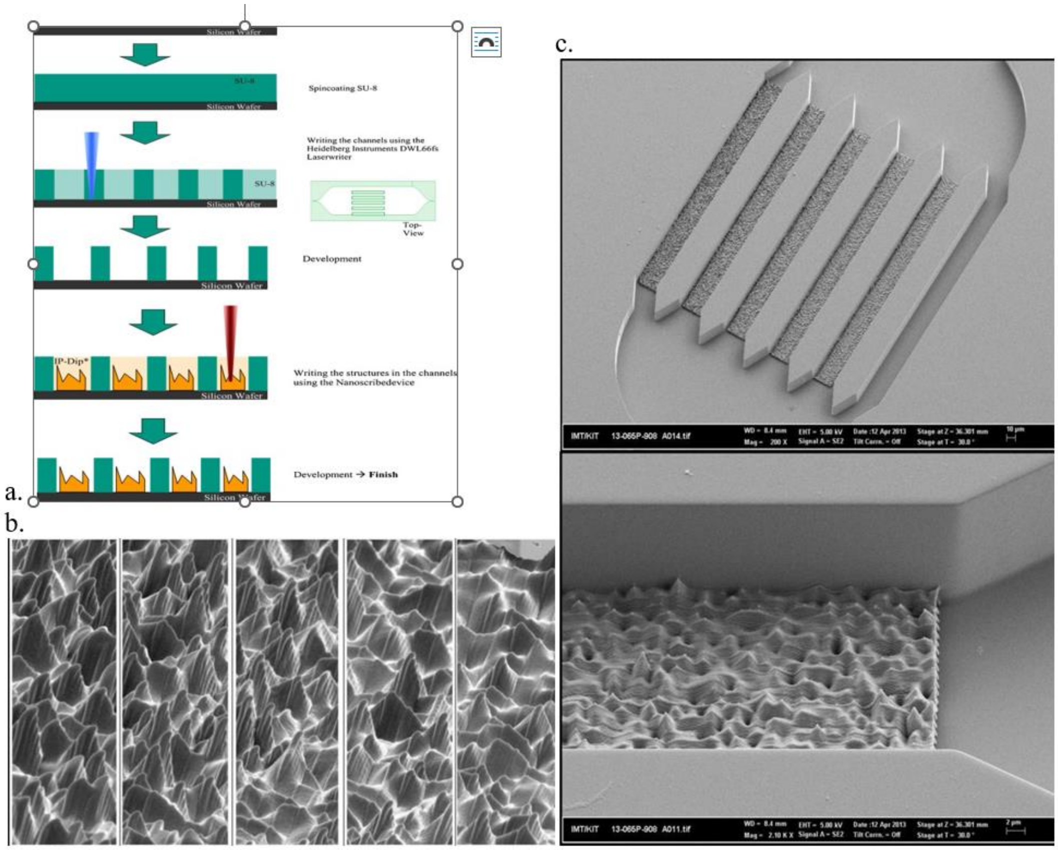


Fig. 8- a) Manufacturing at multiscale b) Impact of surface texture c)Micro texturing process [8]

5. Materials used in Additive Manufacturing

A study done by Fischer et al. [9] found that Ti -27.5 (beta titanium alloys) can be considered as a suitable material for arthroplasty and implantology application. These materials are biocompatible and possesses unique mechanical properties. Their Young's modulus is low which help in reducing the stress shielding which generally takes place after surgery. In their study, they have used a powder-blown AM process which is also known as CLAD process which results in the manufacturing of patients-required implants. Thus, they investigated the mechanical biocompatibility, tensile tests, cytocompatibility etc. of the Ti-27.5 Nb alloys for various biomedical applications. SEM analysis image at different magnification is shown in Fig. 9. Various composite, ceramics and polymers material like polycaprolactone, acrylate poly etc. are used to manufacture Scaffold structure that are used as the implant was investigated by Ferry et al. [10]. Due to certain limitation like solvent, high temperature, water scarcity etc. it is not advisable to use these materials as they are not helpful in incorporating the cell. Due to this nowadays hydrogels are gaining interest in the manufacturing of patients implant. Hydrogels are a network of polymers that are insoluble but absorb H_2O thus retaining its 3D structure.

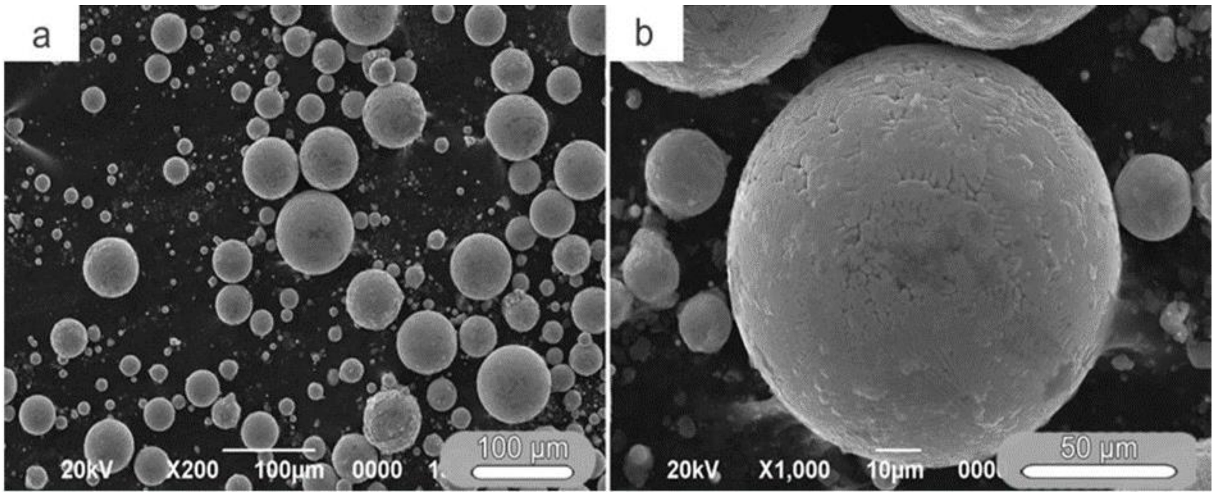


Fig.9- SEM micro graph at two different magnification of Ti-27.5 Nb powder [9]

6. Conclusion

Additive manufacturing is the best way to the production of various tissue organs by using computer-controlled methods. Although this technology has not been widely explored similar to various computational approaches like computational fluid dynamics [11] in the field of medical science. These technologies will definitely result in savings of high cost which are expensed in tissue and organ transplantation. Due to AM complex surgery, and diagnosis, implants are booming with high success rate with the same physical, chemical and mechanical characteristics of the patients. Obtaining the anatomical structure of a patient from the digital data or image with the help of AM has improved the accuracy rate in surgery. The interest in these technologies of manufacturing is increasing day by day due to accurate reproducibility, achieving the desired scaffold shape and microstructure which results in the development exact geometry, pore size, anatomical size, and shape of implants and tissue engineering. This will result in fulfilling the demand of surgical needs in a better way in the field of medical science and can be used as a clinical tool in the near future.

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