Review Article
Mishra & Sharma, 8(Spec. Issue), 2017:136-140]
ISSN: 0976-7126
Int. J. of P. & Life Sci. (Special Issue Engg. Tech.)
Engg. Tech

A Review-Design and development of bio- compatible scaffold with CAD tool and FEA for Additive manufacturing

Ashutosh Mishra and Prof. P. K. Sharma
Department of Mechanical Engineering, NIIST, Bhopal, (M.P.), India

Abstract

In tissue engineering it is deals with all possible alternatives to recover damaged tissue or bone by applying bio-compatible scaffold on the damaged part. The bio- compatible scaffold of cellular structure were build with various traditional process like solvent casting, fiber etching etc., But it has various limitations like less range of material available, less accurate parts and a lot of time taken for preparation. with the advent of additive manufacturing, it becomes possible to fabricate complex parts with greater accuracy and with in shortest lead time. Additive manufacturing may also be used to fabricate parts specially targeted to medical industry but it only limited to creative capability of designer who design the 3D part by using CAD. The design through CAD is used further in form of .STL file to export into Additive manufacturing machine for fabrication of object. But designing of complex shape scaffold is tough task, and takes a lot of time and effort. So in this project an unique CAD tool will developed which will simplify the design and modeling of complex shape scaffold. CATIA V5 software with Virtual Basics Macros will be used to develop the desired CAD tool. The author appreciate that this CAD tool will be very useful for modeling of complex software and it will reduce the lead time to manufacture of it.

Key words: Additive manufacturing, Bio- scaffold, CAD, Tissue engineering, Unit block, SLS machine.

Introduction

In bio- environment, scaffolds are used as artificial supporting structure which bears the load of original part and the same time it transfers the nutrients to the cells. Scaffolds support the proliferation of tissue due to bio- active phenomena in place of damaged tissue. Scaffolds are of complex shape structures just like the bone, which is to be replaced by scaffold due to damage condition. Design and development of these scaffold are very tough job due to its complex shape, and irregular internal structure.

Additive manufacturing is the novel technique of manufacturing of 3D objects, which advances the fabrication of complex structures with more accuracy, and in shortest possible lead time.

Additive manufacturing build the parts in form of layer by layer and finally required object is obtained ,unlike the subtractive process of manufacturing which starts the process by considering a stock material, and machining process is done to give it desired shape. The additive manufacturing process starts from the generation of design by using CAD, this 3D model is then converted into .STL file (Triangulated data), which is accepted by all AM machines. There are various types of AM machines available and based on part build, level of complexity of object, choice of material to fabricate the part we have to select specific type of AM machine.

The material used to fabricate scaffold must be bio- compatible and non- toxic in nature to the human body. The material should have enough strength so that it can sustain the load of original body parts. Unit block is the architectural building block of the scaffold. Porosity is the important parameter for scaffold because it reduces the weight of the scaffold, but on the same time mechanical strength of the scaffold should be balanced. So finite element analysis has to be done to find mesh density of particular unit block, and porosity has to be determined. Based on porosity and high effective stiffness we will select one of the unit block structure for fabrication of scaffold.

ISSN: 0976-7126

The scope of this project is to select best unit block structure for fabrication of unit block, based upon FEA analysis made for various types of unit blocks. And to develop unique CAD tool for better modeling of scaffold for better design of complex scaffold.

Literature review

To starts with, several literature's regarding fabrication methodology, porosity range, strut size, material selection were reviewed in order to develop unique CAD tool for modeling of complex scaffold.

Jayanthi parthasarathy et. al. (2011) - They discussed the design process for creation of periodic cellular structure made by porous titanium Ti6Al4V in form of metal powder to fabricate parts by using electron beam melting machine. They use finite element analysis for assessing the performance of final part by calculating effective young's modulus and shear modulus by utilizing representative volume element (RVE) method, i.e. By considering an RVE to represent porous structure of implant due to geometrical complexity.

They find the porosity by using following equation.

$$P = \frac{V_1 - V_2}{V_1}$$

Where,

V_1 is the bounding volume and V_2 is the volume of material.

They calculated effective elastic modulus of the RVE for the porosities ranging from 28.18 % to 78.14%, and found that effective elastic modulus decreases with increase in porosity values.

They use PRO-E for designing of part, and further convert into .STL file into ARCAM- EBM to fabricate the parts. they use optical microscope to determine strut and pore size,and calculate compressive strength which were from 0.57 (±0.05) to 2.92 (±0.17) GPa and from 7.28 (±0.93) to 163.02 (±11.98) MPa respectively. They design novel strategy of fabrication of porous titanium structure for bio- medical application. As per author, the future scope of this work is to optimize design process to simplify modeling process.

Lev podshivalov et. al.(2013)- They discus about a novel approach to fabricate micro- scale scaffold by using patient specific micro CT images. First of all they cleaned the micro CT images by means of curvature, bilateral and gaussian filters to distinguish between bone tissue and another tissue, after that 3D volumetric model is reconstructed.the volumetric model is further converted into octree data structure which allows adaptive coarsening of model. they used multi-scale FEA to verifying mechanical properties of the structure. They used commercially 3D printer to fabricate the micro- scale scaffold by using bio- compatible material polymethylmetacrylate PEMA/ PMMA. For verification of scaffold they again scan the manufactured scaffold by micro CT technology ,and compared it with initial scans. As per Lev, in future research may be focused to improve the design to allow easy removal of excessive material from manufactured scaffold.

J. C. Dinis et.al. (2014) - They discussed about design of customized scaffold of macro and micro architectures for tissue engineering, and develop an open source software for design of scaffold. They used triple periodic minimal surface lyotropic liquid crystals, diblock polymers, hyperbolic membranes for geometric database modeling. They compared five parametric hyperbolic surfaces to select the best structure for designing. The open source software were developed in python, an high level programming language, which is also object- oriented, functional and strong typing. As per his software when an user opens the library, then he have options to choose type of surface in which he want to build the scaffold with defined size, and porosity. they printed schwarz- D and gyroid 3D surfaces with porosity ranging from 68% - 81% for observing performance of model by visualization of pores.

S. M. Giannitelli et. al. (2014) - They discussed about the integration of the fabrication of scaffold through additive manufacturing and fabrication of scaffold through another methods to obtain hybrid structures with complementary structural features. They concluded that Computer aided tissue engineering (CATE) gives direction to scaffold based tissue engineering into multidisciplinary research field. They used experimental analysis and numerical simulations to give a better result so that a better procedure be followed for development of scaffold for tissue engineering. This method gives freedom to design novel design principles for scaffold which incorporates bio-mimetic features in the architecture of scaffold.

Problem formulation : As per jayanthi parthasarathi et.al., Fabrication of any complex shape structures like scaffold can be done through additive manufacturing process but it is only limited to creativity of CAD designer to design the complex structure of scaffold . So a better and accurate CAD design of scaffold eased to fabricate through any one of additive manufacturing process.

ISSN: 0976-7126

As per lev podshivalov et.al., in future research may be focused to improve the design to allow easy removal of excessive material from manufactured scaffold.
So, as per literature's opinion modeling of scaffold plays an important role for fabrication of scaffold for tissue engineering ,so in this project an a CAD tool has to be developed which will simplify the design process of complex scaffold structures. The points on which work has to be done in this project are-
Selection of material - earlier various material like metal, ceramics, polymers were used to fabricate scaffold with various traditional manufacturing systems. Various researchers uses natural bio- material like collagen, starch, chitosan to fabricate bio- scaffolds through solvent casting, fiber etching methods, but there are many limitations of these scaffolds like patient specific scaffold may not produced through it, the mechanical strength of these scaffolds were less, required porosity may not obtained etc. In modern era, additive manufacturing technique used for fabrication of scaffold where a wide range of material available for selection, but mostly polymer material like PA, PLA, PGA, PC, ABS etc used for fabrication of scaffold as per required strength and other properties. These materials are also bio- compatible, bio- degradable and non- toxic in nature. In this project we will select a material for fulfilling our criteria so that it having maximum mechanical strength, high heat resistant and also compatible with our selected AM machine for fabrication.
Selection of AM machine - Based on principle of operation there are various types of additive manufacturing machines used for fabrication of scaffold. The types of AM machines have different properties to built the part.

Table 1. Comparison of AM machines

Machine	Principle of operation	Material	Pore size (μm)	Advantage	Limitation
3 DP	Powder with binder deposition	HA, DTPH	45- 100	Low heat effect, Wide range of material choice	Difficult to remove trapped materials.
SLA	Photo- polymerization process	PEG, PHOH	≥ 70	High resolution, Easy to remove trapped materials	Limited choice of photo- curable materials
SLS	Powder sintering	PLA, PCL, PA	≥ 500	Wide range of material choice.	Material may thermally degradable.
FDM	Extrusion& melting	ABS, PCL	250 -1000	Low cost, No trapped materials	Limited choice of materials,

Based on above advantages and pore size an suitable AM machine will have selected for fabrication of scaffold.
Modeling of scaffold with CAD - This is the main area on which our research is focused. An CAD tool will developed with the help of CATIA V5 software which will generate an equation as per input parameter given by the user, which will formalize the standard scaffold model into customized scaffold model with required porosity and tailored mechanical properties. We will also use VB macros Graphical user interface for development of CAD tool. This CAD tool will simply the design procedure and reduce the lead time.
Methodology : The process starts with design of standard scaffold with CAD tool, an ASTM standard scaffold will be designed by using CATIA V5 software, the designed scaffold model will be subjected to further analysis to find its mechanical properties with required porosity. Selection of unit block structure is also an important process, which is building block of any scaffold. Unit block will be selected based on porosity and effective stiffness from the library of unit blocks. After that unique CAD tool has to be developed with the help of CATIA V5 software and VB macros which will generate the required customized scaffold as per input parameters enters by the designer for patient specific scaffold. This customized scaffold will further subjected to Finite element analysis to find out mechanical properties and mesh density by convergence test, so that we a find the versatility of the tool. When the design fulfills our requirement as per numerical simulation then the design has to converted into .STL file and would exported into selected AM machine for further fabrication process, where it is fabricated by suitable selected material. The fabricated scaffold would further subjected to experimental compression test which will show its

experimental stress and strain value and finally the experimental effective stiffness value. The deviation in the values of experimental and numerical analysis values will proves the versatility of CAD tool.

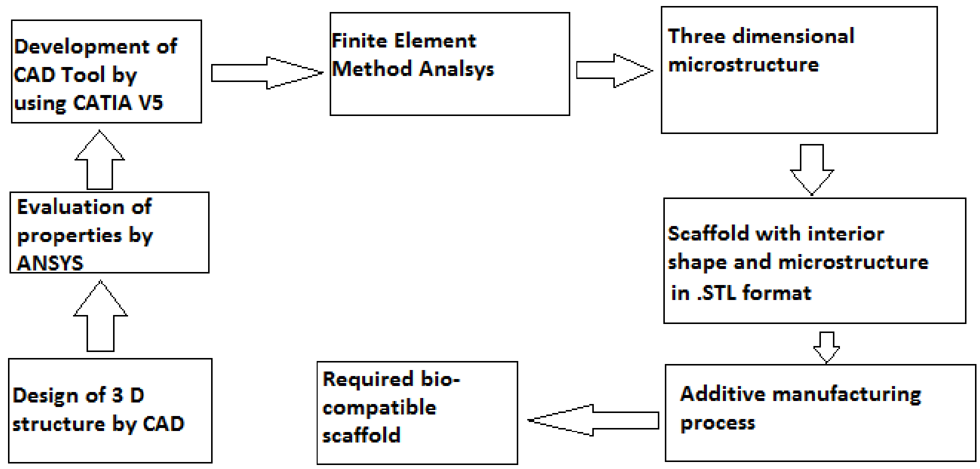

Fig. 1. Methodology

The customized scaffold will subjected to patient specific implantation, which is out of scope of this project.

Conclusion

The author appreciating that, a better CAD tool will be developed in this project ,which will simplify the modeling process of bio- compatible scaffolds so that complex shape scaffolds can be designed in easier way and an accurate and patient specific scaffold will be developed with desired mechanical properties. This tool will reduces the time and extra effort to design the scaffold.

Acknowledgment

The author is grateful to department of mechanical engineering ,NIIST, Bhopal, India for technical support affording me to carryout this project.

References

[1] ASTM F2792-10. Standard terminology for additive manufacturing technologies, copyright ASTM international, 100 Barr Harbor Drive, West Conshohocken, PA 19428.
[2] Bin duan, Min wang, Wen you zhou, Yai Lam Cheung, Zhao Yang Li & William w. Lu 2010, ‘ Three-dimensional nano coposite scaffolds fabricated via selective laser sintering procedure for bone tissue engineering’, Acta Biomaterialia vol. 6 , pp. 4495- 4505.
[3] Cahill, S, Lohfeld ,YT McHugh, PE, 2009, ‘ Finite element predictions compared to experimental results for the effective modulus of bone tissue engineering scaffold fabricated by selective laser sintering, ’ Material science vol. 20, No. 6, pp. 1255- 1262.
[4] Deckard CR, 1988, ‘Selective laser sintering’, Mechanical engineering, Austin; University of Texas at Austin.
[5] Dinis J.C., Morais. T.F. ,Amorim P.H.J., Ruben. R.B., Almeida. H.A., Inforcati P.N., Bartolo P.J. & Silva J.V.L. 2014, ‘Open source software for the automatic design of scaffold structures for tissue engineering application’, Procedia Technology , vol. 16, pp. 1542-1547.
[6] Giantelli S.M., Accoto D.,Trombetta M. & Rainer A., 2014, ‘Current trends in the design of scaffolds for computer- aided tissue engineering’, Acta Biomaterialia, vol. 10, pp. 580- 594.
[7] Goodridge RD, Tuck CJ & Hague ggRJM, 2012, ‘Laser sintering of polyamides and other polymers’, Progress in material science, vol. 57, No. 2, pp. 229- 267.

ISSN: 0976-7126

[8] Jayanthy parthasarathy, Binil starly & shivakumar Raman, 2011, ‘ A design for the additive manufacturing of functionally graded porous structure with tailored mechanical properties for bio-medical application, ‘Journal of manufacturing process, vol. 13, pp. 160-170.
[9] Kajal Ghosal, Mahima santhakumar Latha & Sabu Thomas, 2014, ‘Poly (ester-amides)- scaffolds for tissue engineering applications’, Europian polymer journal, vol.60, pp. 58- 68.
[10] Leong K.F., Cheah, C.M. & Chua C.K., 2002, ‘Solid freeform fabrication of three- dimensional scaffold for engineering replacement of tissue and organs’, Biomaterial, vol. 24, pp. 2363- 2378.
[11] Lev Podishavalov, Cynthia M. Gomes, Andrea Zocca , Jens Guenster, Pinhas Bar- yoseph, Anath Fischer, 2013, ‘Design, analysis and additive manufacturing of porous structurs for bio- compatible micro- scaffolds’, Procedia, CIRP5, pp. 247- 252.
[12] Lin Liulan, Hu Qingxi, Huang Xianxu, & Xu Gaochun, 2007, ‘Design and fabrication of bone tissue engineering scaffolds via rapid prototyping and CAD’, Journal of Rare Earths , vol.25, pp. 379.