Analysis of Human Bone, Implants & Design, Develop Artificial Bone by Rapid prototyping (3D Printing) Technology

Salim Mulla[1], Dr. Subim Khan[2]

[1] *PG Student, Department of Mechanical Engineering, JSPM's Rajarshi Shahu College of Engineering Tathawade (Pune), Maharashtra, India*

[2] *Professors, Department of Mechanical Engineering, JSPM's Rajarshi Shahu College of Engineering Tathawade (Pune), Maharashtra, India*

ABSTRACT

In Human body Bone plays important role in body. Which support & protect body parts. Bones comes in a variety of shapes and sizes and has complex internal and external structure. During daily activities, the skeletal system is subjected to a complicated loading exerted by the different loading conditions. Such loading modes for femur bones are include tensile, compressive, bending, and torsional forces applied to the bones of the skeletal system. In this project we have done FEA Analysis with different materials like Stainless steel, Titanium, ABS, PLA and develop artificial bone by 3D printing technology. The aim of this work is analysis & manufacture femur bone which can replace the damaged bone. Replacement of bone is done by design of bone then analysing its properties and its characteristics. Then it is to be printed by 3D Printer as prototype model.

Keyword : - *Analysis Femur Bone, 3D Printing, Artificial Human Bone etc….*

1. INTRODUCTION

It is important in body to distribution of load. Bone structure is such that it is rigid, which will sustain the static or dynamic load during daily activities. The femur bone is the longest bone in a human body and is of utmost important as most loaded bone. This bone always under stress and the stress is axial. Internally connected with hip bone, where the ball of femur fits in the socket of pelvis bone with the help of muscles. Secondly it is externally connected through cortical bone. Connected to the shank bones or the tibia and fibula and the patellar ligament or the Kneebone it present in the front to protect the joint.

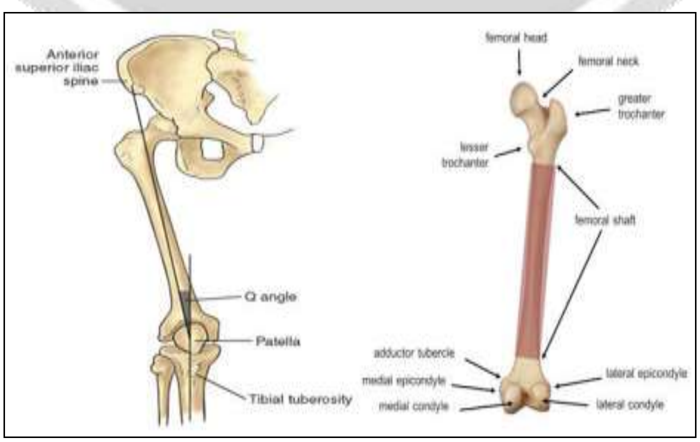

Fig -1: Femur Bone and its actual position in human body.

The entire structure of bone is made by cortical and trabacular bone. Where cortical bone is covered external part of bone. It is a stiff bone and porosity of about 5 to 10%.The porosity of the bone is measured. The porosity is defined as the measure of the void (i.e. empty) spaces in a material, is afraction of the volume, between 0-1, or as a percentage between 0-100percent. The term is used in multiple fields including pharmaceutics,materials, manufacturing, earth, sciences, soil mechanics and engineering. The cortical bone is much denser, stiffer and stronger than the trabecular bones. On the other hand, the trabecular bone has a higher surface area and is known to be extremely porous. Spongy bone is called highly vascular and it is responsible for blood cell production. cancellous bone is one of two types of osseous tissue that form bones. If compared with cortical bone, which is other type of osseous tissue, it has a higher surface area but is less dense, softer, weaker, and less stiff. This found at the ends of long bones, proximal to joints and within the interior of vertebrae. Cancellous bone is highly vascular and frequently contains red bone marrow where hematopoietic, the production of blood cells, occurs. The primary anatomical and functional unit of cancellous bone is the trabecular so it is important to analysis of the failure behavior of bones under all of these loading Conditions. Also important to develop artificial bones which can easy manufacture with less time and can be replace instead of damaged bone.

2. PROCESS FLOW FOR MANUFACTURING ARTIFICIAL BONE

Design of human bone in 3D cad software & analysis by FEM method in analysis software. Using this cad model and import into Rapid prototyping (3D printing) machine. This will create artificial bone. In order to fabricate artificial bone, the AM technique is applied to the bio-fabrication process, this process is known as Bio-Additive Manufacturing (BAM). Different from previous construction methods, BAM uses computer aided design technology to realize the customized manufacture of the bone defect, with an internal 3D-structure that is also similar to the human bone.

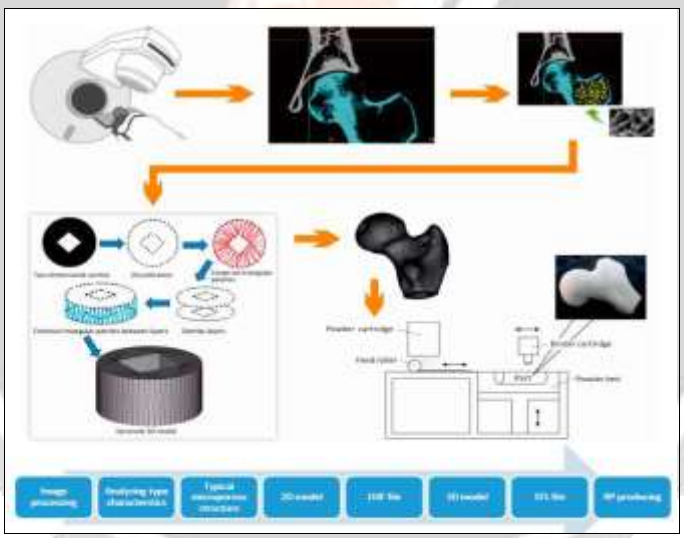

Fig -2: Bionic design and manufacturing process of the inner microstructure of artificial bone scaffold.

2.1. Bionic Design Performance:

The performance of bone, after being implanted into human body, can be assessed based on both mechanical performance and biological performance and mechanical performance refers the structural support of bones and matching the stress caused in the host.

2.2. Bionic Design of Mechanical Performance:

Multiple studies have shown that the response of the host to the implant is largely determined by the mechanical properties of the scaffold. Biomechanical requirements include adequate static strength (e.g., bending, compression, tensile, shear, etc.), appropriate elastic modulus and hardness, resistance to fatigue, friction, wear, and so on. The bone model used in diagnosis and approximation of bionic design in mechanical properties influences the preparation and planning of the implants. The bonic bone model is closer to the real bone in both structure and texture. To match the mechanical and biological performance with original bone, the importance of functionally graded scaffold (FGS), made of porous biomaterials, has been increasingly realized in recent years. This possesses the characteristics of complex gradient porosity and function and could mimic the shape, morphology, and overall physiology fully. In the architecture of FGS, porosity, pore size, and pore interconnectivity is of critical importance.

2.3. Bionic Design of Biological Performance:

For achieving good biological performance, bionic bone scaffolds in vivo will produce no harmful degradation products, be resistant to body fluid erosion, and experience no water absorption, swelling, softening, or deterioration. Also the ideal bionic bone material should have good bioactivity, biodegradability, and osteogenesis. As previously mentioned, bioactive materials can exchange substances with human bones, biodegradable materials can be gradually replaced by human bones, and osteogenic materials can transfer the force of bones and act as a mechanical support to avoid stress concentration, caused by the high mechanical strength of the material.

2.4. Bone Replacement:

Replacement of bone is sometimes required when a section of bone is missing and the gap needs to be filled in, for example following an accident or after the removal of a tumor. There are many options for this type of bone replacement: autografts involve using material from the same patient, but from a different site (such as the pelvis). Although this reduces the chances of rejection, there is a limited amount of material available, and two surgical procedures are needed, leading to more pain and a higher risk of infection. Synthetic materials are gradually becoming more popular. The Hydroxyapatite will be prepared easily in a laboratory, but since it is a ceramic, it’s too brittle to be used on its own for large-scale applications. Composites of hydroxyapatite with degradable polymers are also used, which resorb over time and allow bone to regrow and fill the space. [4]

3. BLOCK DIAGRAM OF PROCESS

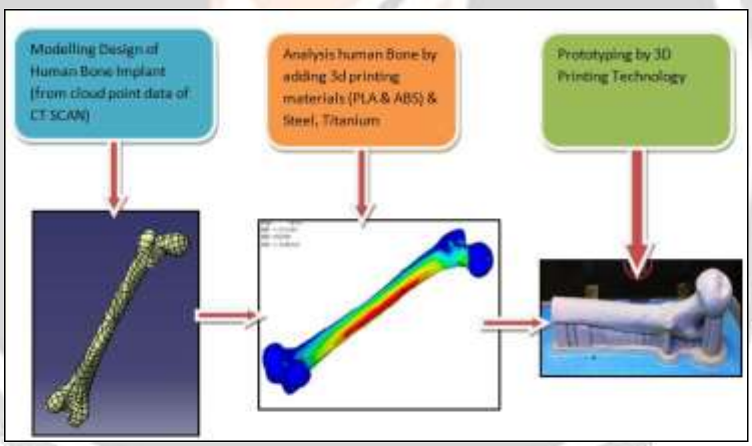

Fig -3: Block Diagram of Process.

3.1. Point data:

The point cloud is a set of data points in some coordinate system. In 3D coordinate system, these points are defined by X, Y, and Z coordinates, and often is intended to represent the external surface of an object. Point clouds may be created by 3D scanners. Which measure in an automatic way a large number of points on the surface of an object, and often output a point cloud as a data file. These points are represents the set of points that the device has measured. As the result of a 3D scanning process point clouds are used for many purposes, including creating 3D CAD models for manufactured parts, metrology/quality inspection, and a multitude of visualization applications. The point clouds are not directly usable in 3D applications due to this they converted to polygon or triangle mesh models or CAD models through a process commonly referred to as surface modeling reconstruction. There are many options for converting a point cloud to a 3D surface. Some examples Delaunay triangulation, ball pivoting and alpha shapes build a network of triangles over the existing vertices of point cloud. The another option to convert the point cloud into a volumetric distance field and reconstruct the implicit surface so defined through a marching cubes algorithm. While the point clouds will also used to represent volumetric data for example in medical imaging. The point clouds multi-sampling and data compression are achieved.

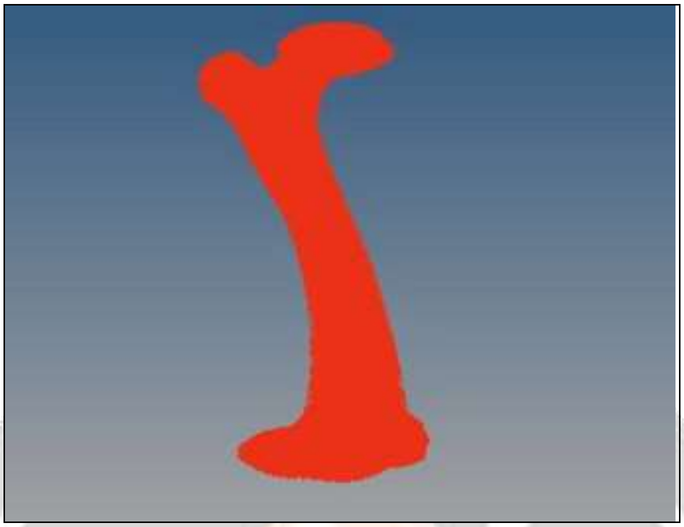

Fig -4: Cloud point data model.

3.2. Surface and Solid Modeling:

Once we get the data in the form of cloud points, the next step is to make a surface model out of it. The surfacing is done with the help of CATIA software. We used the CATIA V5 R20 version of software to get the surfacing done. We open the cloud point data in IMAGEWARE software to create the surface modeling in IMAGEWARE, we took multi sections for generating the smooth multi curves. By using these curves we generate the (NURBS-Non Uniform Rational B-Splines) surfaces that are surface modeling. After that surfaces are exported in IGES format from imageware. This surfaced model is the connecting link between the steps of scanning and the solid modeling. The data we get by scanning cannot directly be used for analysis. For that sec we need to generate the surfaced model of the part in the appropriate software. Save drawing as cad part file and IGS file format, for analysis purpose. [9] [10] [4]

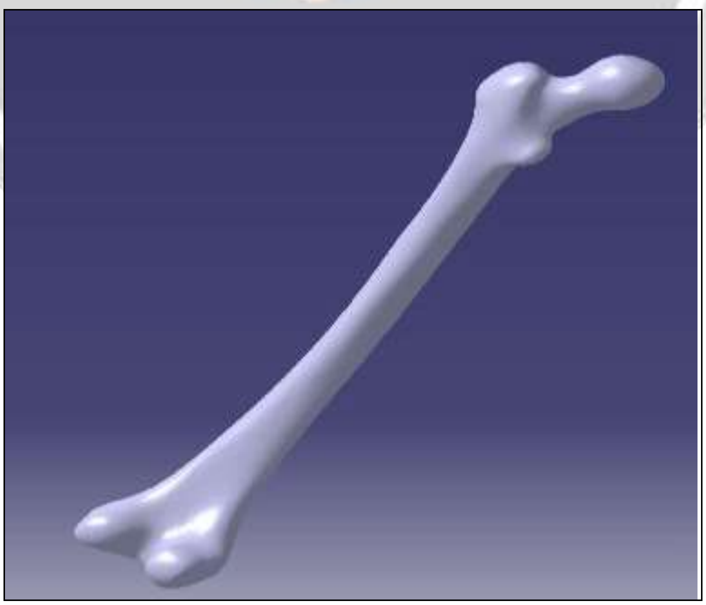

Fig -5: Modeling of Human Femur Bone.

3.3. Analysis of Bone Implant by FEA:

The Finite Element Analysis (FEA) is the simulation of any given physical component using the numerical technique is called Finite Element Method (FEM). It uses to cut back the quantity of physical prototypes and experiments and optimize elements in their style part to develop good products, faster. Finite Element Analysis (FEA) is technique for calculating the strength and behavior of engineering structures. This will be used to calculate deflection, stress, and vibration, buckling behavior etc. this method uses to analyze different scale of deflection under various loading or applied displacement and should analyze elastic deformation, or "permanently bent out of shape" plastic. Deformation The computer is required because the astronomical number of calculations needed to analyze a large structure. The power and low cost of modern computers has made Finite Element Analysis available to many discipline and companies. [8] In the Finite Element Method, a structure is divided into many small simple blocks or elements. Then the behavior of an individual element can be described with a relatively simple set of equations. The set of elements would be joined together to build the whole structure, the equations describing the behaviours of the individual elements are joined into an extremely large set of equations. By this solution, the computer extracts the behavior of the individual elements. From this, it can get the stress and deflection of all the parts of the structure.

3.4. Analysis Procedure:

The file is imported to the ANSYS software Then generate option is clicked. Now the model is ready for analysis. The imported geometry in ANSYS is shown in Fig. 6. Femur was assumed to be isotropic and linearly elastic and the material properties for the cortical bone. [13]

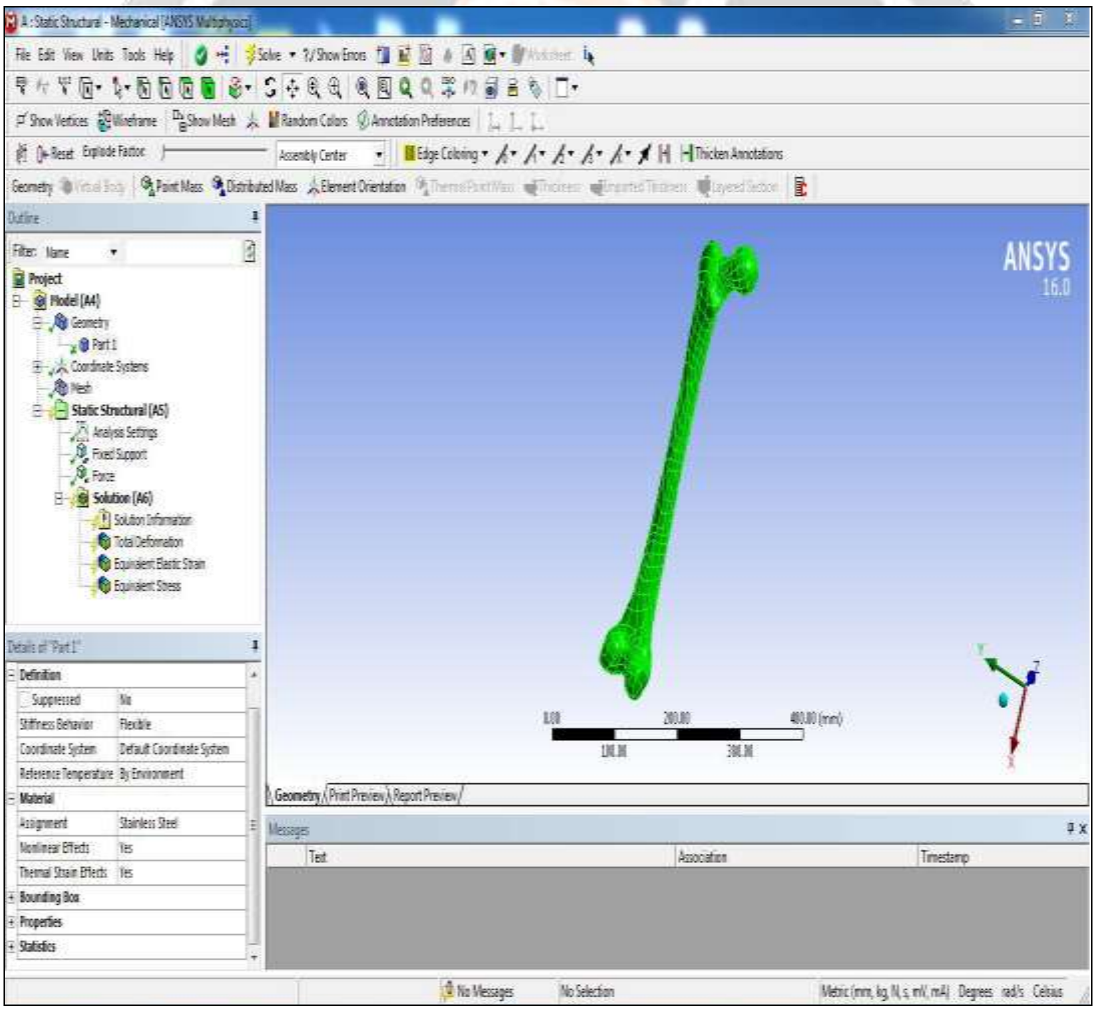

Fig -6: Imported geometry in Ansys.

3.5. Mesh formation of Bone:

The bone was meshed with Nodes-4604 and Elements 2415.

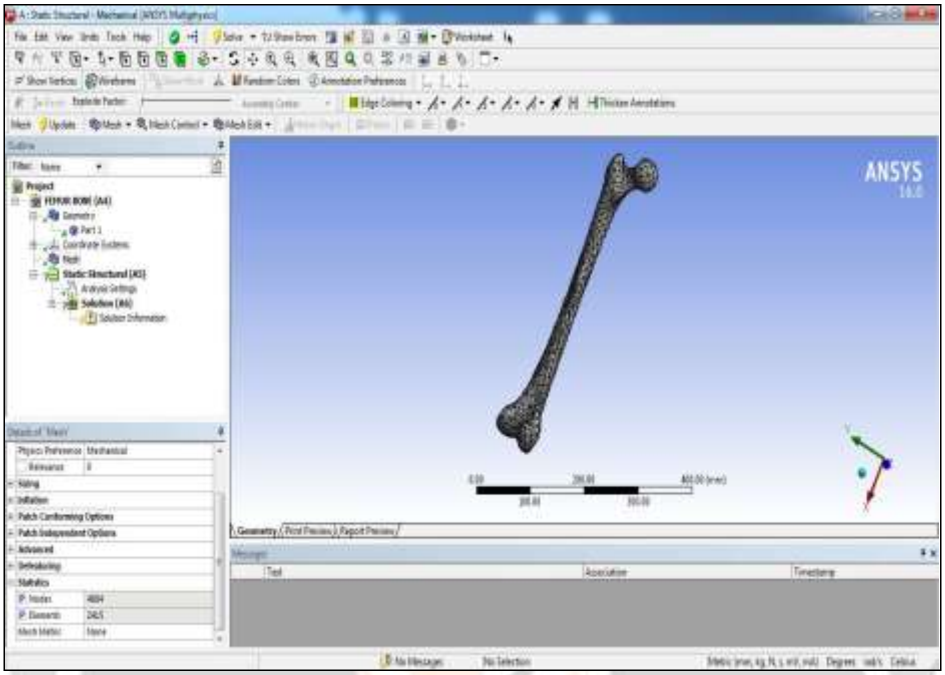

Fig -7: Meshing of Femur Bone.

3.6. Boundary Condition:

Femur bone is inflexible condition and the analysis of geometrical model is subjected to eccentric and concentrates loading conditions. In this boundary condition applied load of 250N, 500N and 1000N applied on the head bone and fixed support is provided at lower surface. [13]

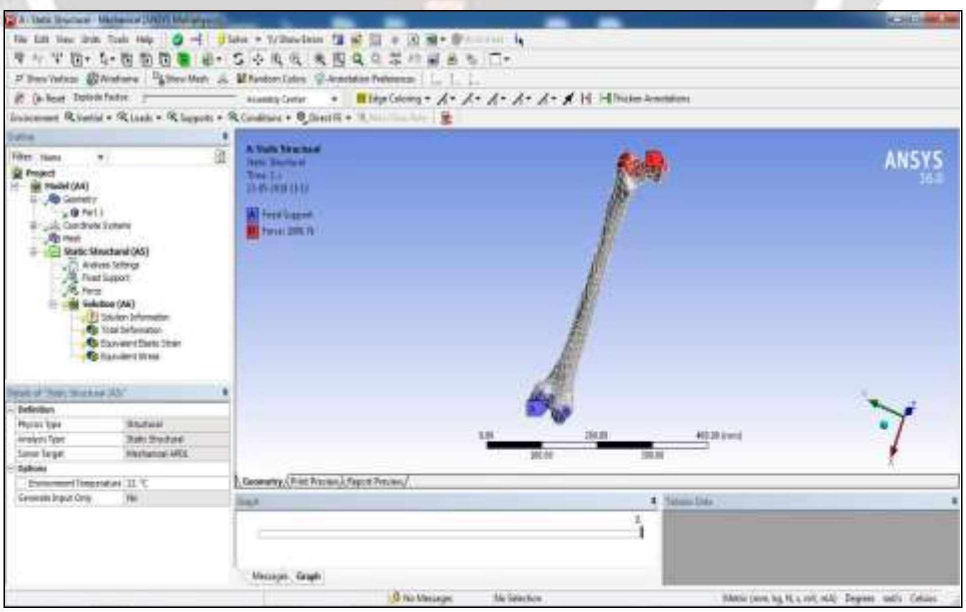

Fig -8: Fixed Supports in the Lower Surface and Load at the Head Surface of Femur Bone.

3.7. Analysis Results:

In this analysis we applied for materials like Stainless Steel, Titanium, ABS and PLA with same boundary condition & loads.

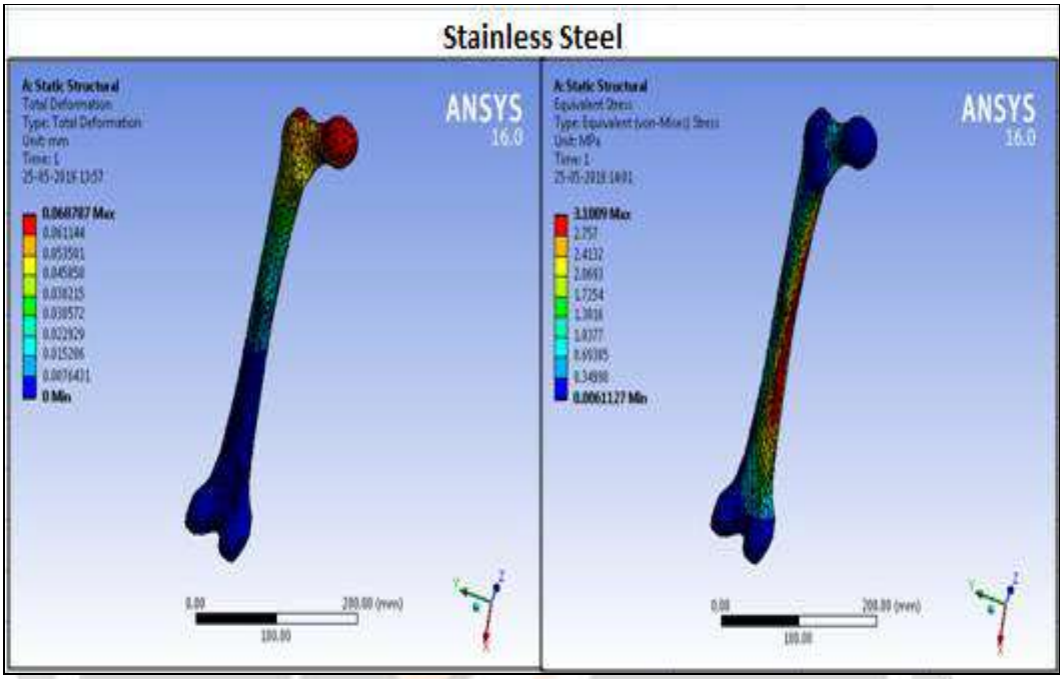

Fig -9: Stainless Steel Result.

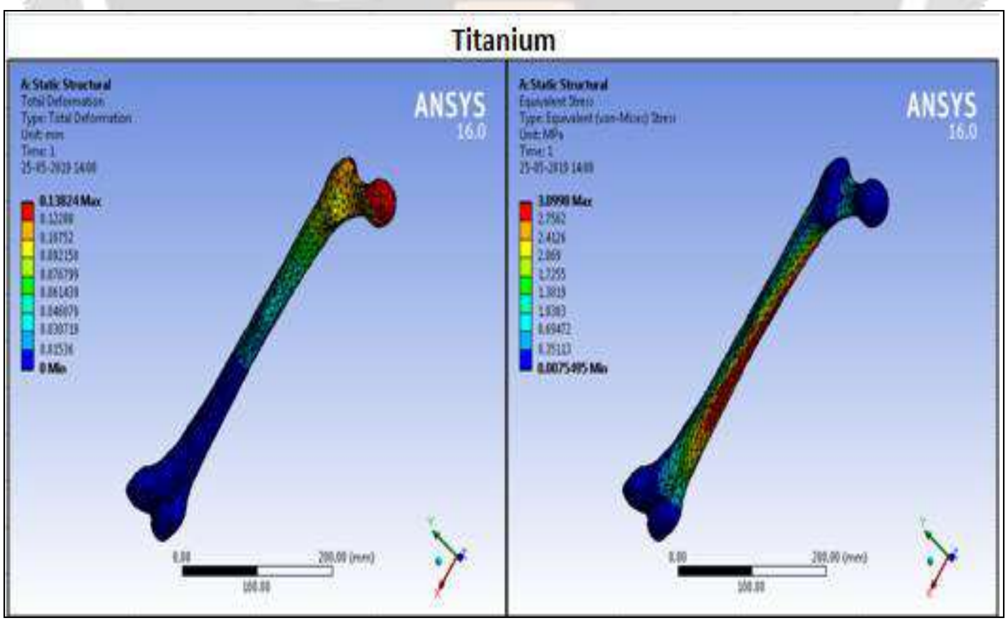

Fig -10: Titanium Result.

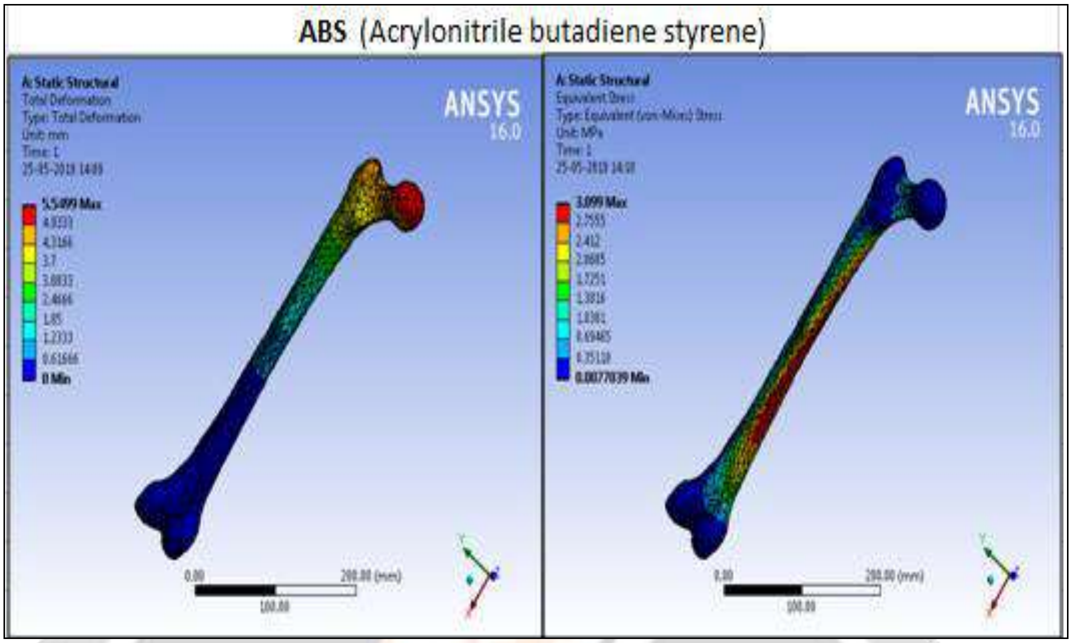

Fig -11: ABS Result.

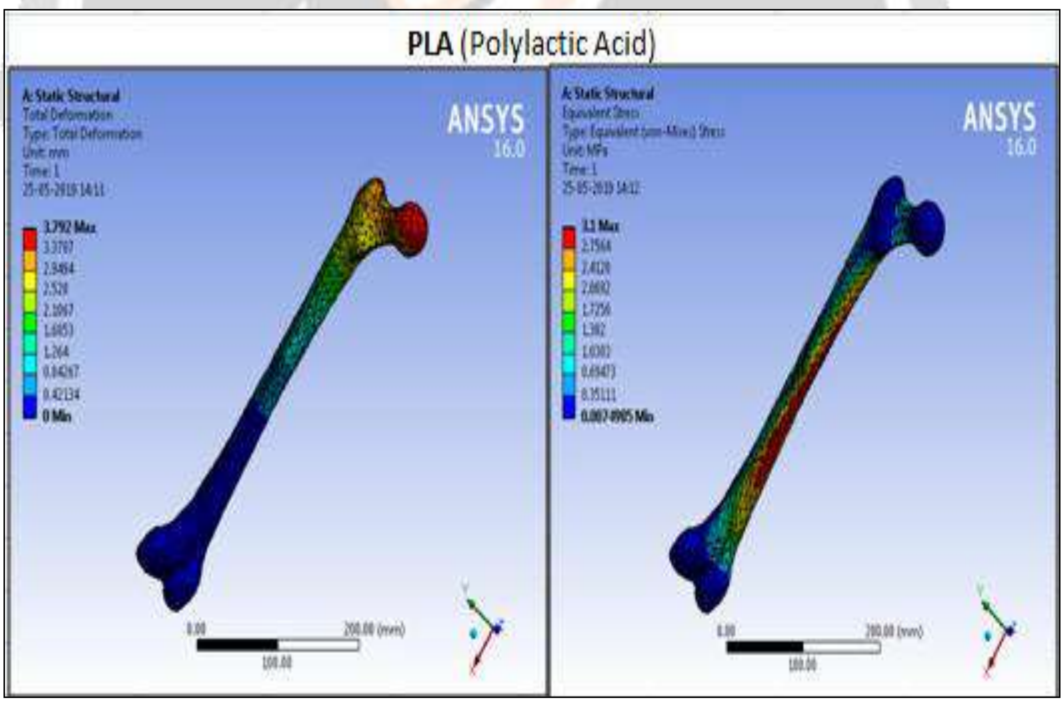

Fig -12: PLA Result.

3.8. Results with different load & materials:

Table -1: Analysis Result with Different loads & Material.

Material	Load (N)	Von-Misses Stress (Mpa)	Deformation (mm)
Stainless Steel	250	3.1009	0.068787
	500	6.2018	0.13757
	1000	12.404	0.27515
Titanium	250	3.0998	0.13824
	500	6.1996	0.27648
	1000	12.399	0.55295
ABS (Acrylonitrile, Butadiene and Styrene polymers)	250	3.099	5.5499
	500	6.1979	11.1
	1000	12.396	22.2
PLA (Polylactic Acid-thermoplastic polymer)	250	3.1	3.792
	500	6.2001	7.584
	1000	12.4	15.16

4. Rapid prototyping Technology (3D PRINTING):

The technology is additionally called Additive Manufacturing Technology (AM), refers to processes used to create a three-dimensional object in which the layers of material are formed under computer control to create an object. Any shape of object or geometry and they are produced using digital model data from a 3D model or another electronic data source such as an Additive Manufacturing File (AMF) file. Stereo Lithography (STL) is one of the most common file types that 3D printers can read. 3D printing or AM builds a three-dimensional object from computer-aided design (CAD) model or AMF file by successively adding material layer by layer.

4.1. 3D printing stages:

In the process of rapid prototyping 3D Printing type, the following steps are to be followed: [2]

A. 3D geometric modeling-

In this stage we used the computer aided design program Catia to geometrically describe the sections obtained by tomography with computer tomography, achieving a large number of electronic cross sections. In this case it is necessary to make several shapes with NURBS curves in separate planes which fallow the bone contour of each section. To obtain cross sections in bones it was used AURA PHILIPS CT tomography device installed in the Emergency Clinical County Hospital of Craiova. CT imaging device allows achieving images in DICOM works format, specialized software for obtaining images and their management. To be able to process images, they were converted from DICOM format in Windows Bitmap format. Newly designed components, implants or prosthesis were designed as 3D virtual models using Solid works CAD software through original design or based on existing models on the medical market and continuing to optimize them.

B. The transfer of CAD model for sectioning processor
C. The 3D printing process
D. The extraction of the prototypes from the Z-Corp printer and the removal of the additional powder.
E. The infiltration process.

4.2. Material Extrusion:

Commonly used technology for 3D printing is Fused Deposition Modeling (FDM). In Fused deposition modelling (FDM) is method of rapid prototyping: [1] [11]

1. Nozzle ejecting molten material (plastic).
2. Deposited material (modeled part).
3. Controlled movable table.

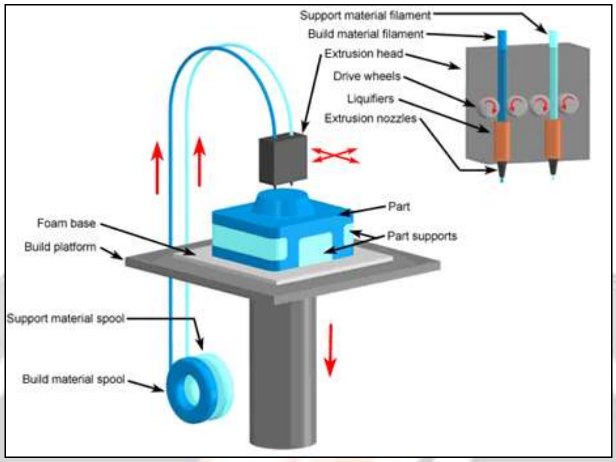

Fig -13: Fused Deposition Modelling (FDM).

The FDM technology works using a plastic filament or metal wire which is unwound from a coil and supplying material to an extrusion nozzle which can turn the flow on and off. Nozzles square measure heated to melt material and can be stirred in every horizontal and vertical direction by a controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package. The components are produced by extruding melted material to form layers as the material hardens immediately after extrusion from the nozzle. This technology is most widely used with two plastic filament Materials types: ABS (Acrylonitrile Butadiene Styrene) and PLA (Polylactic acid). [1] [12]

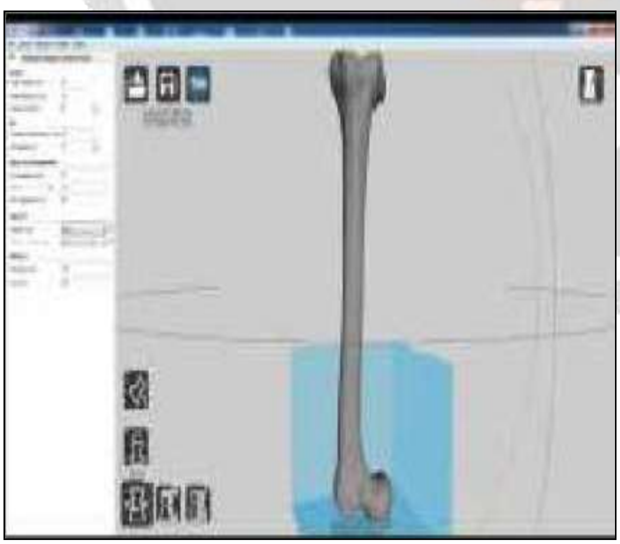

Fig -14: Imported cad model into FDM.

Fig -15: 3D Printed artificial bone.

5. CONCLUSIONS

1. Analysis can be clearly stated that the stresses or strains on a bone can be evaluated virtually with great accuracy.

2. Modelling the patient's unaffected bone by scanning it through CT scan as a source and then designing it three dimensionally by using ANSYS software.

3. Currently, there are only a limited number of biodegradable polymers available for 3D printing. Most of those 3D printing biomaterials are used for either drug delivery or space-filling implantation function purposes. Therefore, there is significant would like for analysis to fabricate novel biopolymers with tunable bio-properties which will restore practically at the positioning of application. Inexpensive, readily available lactic acid based polymers (such as PLA and PCL) are focused on, mainly due to their abilities to perform well in most types of 3D printing technologies. Additionally, they have excellent mechanical and biodegradable properties. These polymers are mixed with ancient biomaterials (such as HA, TCP) and used as composites to provide higher printability, mechanical stability, and greater tissue integration for orthopedic applications.

4. In this project femur bone is modeled and analyzed with four different materials. Out of these materials used titanium & PLA is found out to have less equivalent stress & corrosion and wear resistance of the materials.

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6. REFERENCES

[1]. Azem Yahamed, Pavel Ikonomov, and Paul D. Fleming, Application of 3D Printing for Human Bone Replacement.

[2]. K Michael Jai Kumar, N V S Shankar, BIO-MODELING AND BIOMECHANICS OF ILIUM AND FEMUR BONES.

[3]. Alkan, A., Celebi, N., Ozden, B., Bas, B., Inal, S., 2007. Biomechanical comparison of various plating techniques in repair of articulator angle fractures. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology & Endodontics 104, 752 756.

[4]. Leonardo Frizziero, Giampiero Donnici, New Methodology for Diagnosis of Orthopedic Diseases through Additive Manufacturing Models. 7 March 2019.

[5]. Auricchio, F.;Marconi, S. 3D printing: Clinical applications in orthopaedics and traumatology. EFORT Open Rev. 2016, 1, 121–127.

[6]. D.Amalraju, Dr.A.K.Shaik Dawood; Mechanical Strength Evaluation Analysis of Stainless Steel and Titanium Locking Plate for Femur Bone Fracture, Engineering Science and Technology: An International Journal (ESTIJ), ISSN: 2250-3498, Vol.2, No. 3, June 2012.

[7]. ZHAO Jun-hai, MA Shu-fang, WEI Xue-ying, Finite Element Analysis of Femur Stress under Bending Moment and Compression Load" IEEE 2009, e-ISSN: 4244-4134.

[8]. Sameer Jade , Kelli H. Tamvada , David S. Strait , Ian R. Grosse; FEA analysis of a femur to deconstruct the paradox of bone curvature, Journal of Theoretical Biology341(2014)53–63.

[9]. Yegireddi Shireesha, Dr S. V. Ramana, Modelling and static analysis of femur bone by using different implant materials (Jul. - Aug. 2013).

[10]. Sarah J. McIlwain, Finite Element Modelling of a Human Femur.

[11]. Karthik Tappa, Udayabhanu Jammalamadaka, Novel Biomaterials Used in Medical 3D Printing Techniques

[12] Fred Fischer, Stratasys, Thermoplastic strongest choice for 3D printing.

[13] Shahjad A. Sheikh, A. P. Ganorkar, Finite Element Analysis of Femoral Intramedullary Nailing in December 2016