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ANALYSIS OF HUMAN HUMER BONE BY USING RAPID PROTOTYPING TECHNIQUE

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ABSTRACT

The Bones are living tissues, consists of minerals like calcium and phosphorus. The living tissues are grown rapidly during one's early years and renew themselves. The Bone is considered as homogeneous, isotropic and linear-elastic material. In human Skelton bones are essential part. The major cause of death and disability is Trauma (physical injury). Most of the Bone fractures in daily life occur within the Humer Bone and Femur Bones. To implant humer bone in body find out stress concentration and unsustainable pain. This paper describes to find best suitable material for Human Bone implant by evaluating specific properties of material. The Material properties are determined by using Ansys Workbench software and the prototype model is created by using Rapid Prototyping technique. The objective of this paper is to study Humer Bone under various loading conditions, such as Tensile Load, compressive Load, Shear Load, and Point Load and Analysis on different materials (Steel 304, Ti-6Al-4V, Calcium Phosphate, Strontium, PLA) has found out the best material based on the stresses, strains, total deformation, shear stress in static analysis and the deformations at different frequencies in modal analysis. Finally, the results shows that TI-6AL-4V is selected as humerus bone material due to less density and nearer other property values to the existing stainless steel 304.
Ky words: Humer bone, Rapid prototyping technique, Design, Ansys & Analysis.

1. Introduction:

Bones are the most essential parts of the body. There are 206 bones in the Human skeleton and the Humer bone is the longest bone in upper part of skeleton. The main function of the human bones is to provide support. Collagen is a protein, which is framed to form a Bone with a mineral called calcium phosphate that makes the framework hard and strong. Bones store calcium and release the same into the bloodstream when it's needed by other parts of the body. The longest bone in the human body is named as humer, located in the thigh. Many muscles and ligaments are attached by the humer and is the site of origin for attachment of muscles and ligaments. The Humer is Long, Strong, and Heavy.

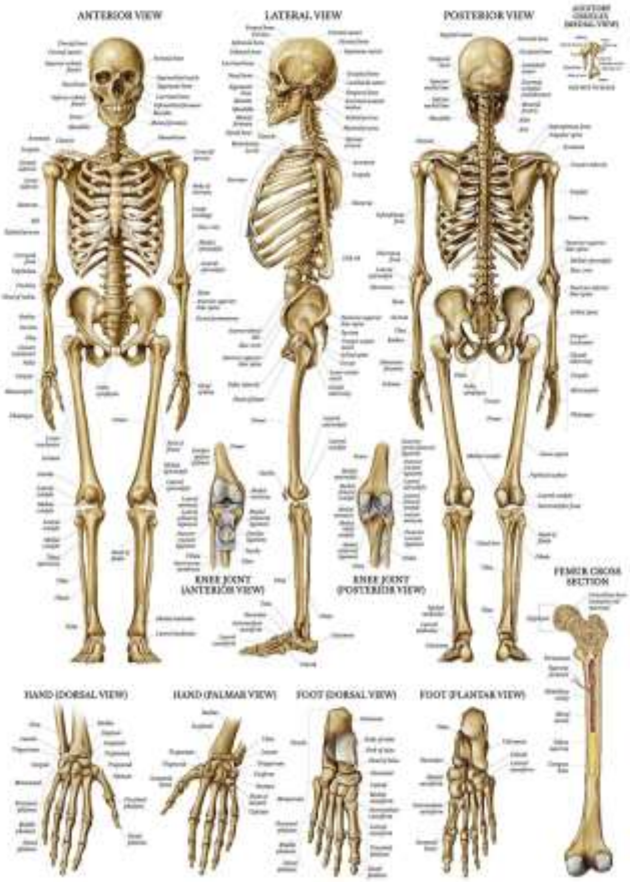

Fig. 1: Bones of Human skeleton system

The skeleton of the arm is formed by humerus which is the longest and thickest bone of the extremity and connects the shoulder and elbow joints each other, Hence the forensic and anthropological studies are carried out on Humerus bone [1, 2].

In morphometric examinations, involving all around saved bones of the human body as far as anthropological data is vital. Other than the bone design of the pelvis and noggin, humerus, tibia, femur, sternum, ulna, bone, calcaneus, span bones are additionally utilized in anthropological examinations. Because of the bone distortions framed because of substance and mechanical variables, the utilization of strong bones, for example, humerus has become extremely normal for the sex assurance. In this way, humerus has been oftentimes involved by specialists in criminological and anthropological examinations. In accordance with this information, the point of our review is to perform morphological estimations of humerus segments [3].

Huiskes R et al. conducted a survey of finite element analysis in orthopedic biomechanics and investigated on the relationships between load carrying functions and morphology of the tissues and optimize designs and fixation techniques of implants [4].

Swapnil S. et al. conducted experiments on the torsion Value Assessment of Human Humerus Bone and revealed that the skeleton system subjected to system of complex loading (tensile, compressive, bending, and torsional forces) by the application of force of gravity to investigate correlation between HU, STRENGTH &

BMD of humerus bone and evolution of humerus by torsion testing setup [5].

Rushali Pant et al. (2021), worked on Modal Analysis of Humerus Bone Using FEA", used to determine how vibration affects the human hand. The humerus bone, which joins the elbow and shoulder, is the longest bone in the arm. To simulate the humerus bone, finite element approach is employed. The natural frequencies of the bone under various boundary conditions are determined by simulation findings. The mode shape results for six modes are produced using the natural frequencies. A profile of the humerus bone is created using the FEA programmed Solid Edge, and ANSYS 14.5 is used for the simulation [6].

S. Adewusi, et al. (2014), conducted experiments on Modal parameters of the human hand-arm using finite element and operational modal analysis to determine natural frequencies and mode shapes, a finite element (FE) model of the human hand-arm system is created. By taking into account modal characteristics discovered through experimental vibration analysis, the FE model is calibrated [7].

M M Rashid, et al. (2017), investigated on Geometrical Model Creation Methods for Human Humerus Bone and Modified Cloverleaf Plate in the field of orthopaedic surgery, external and internal fixing methods, or a mix of these two techniques, are used to repair bone fractures. Different computer-based techniques and technological elements are being used to construct geometric 3D models of internal fixation implants and human bones. The use of computer visualisation techniques such as medical imaging, computer-aided design, finite element analysis, etc. is one of these strategies. This paper offers recently created techniques for the surface model of the human humerus. This paper offers recently created techniques for the surface model of the human humerus [8].

Vaishali Chaudhry, et al. (2020) carried an experiment on Static structural analysis of humerus bone to find out the load at which fracture occurs and predict suitable alternative materials for bone implants, Biomechanics is the science to study the mechanical properties of biological objects. The humerus bone is the upper body's longest bone. In this investigation, various loads are applied on the humerus bone by fixing the proximal (upper end) and altering the distal (lower end), the displacement and maximum stress values are obtained at different weights for different materials. The maximum stress is calculated at which the bone fails for various loading conditions [9].

Ligon, S.C, et al. (2017) investigated on the Polymers for 3D Printing and Customized Additive Manufacturing, and revealed that the medical industry has been transformed by 3D printing, which is still growing quickly. Manufacturing patient-specific implants and prostheses, building scaffolds for tissue regeneration and bioartificial organs, individualised drug delivery systems, and anatomical modelling for perioperative simulations are all common clinical applications. Because of its possibilities, including the personalization of medicine, cost effectiveness, speed, and increased productivity, 3D printing is increasingly being used in the medical industry [10, 11].

2. SYSTEMATIC APPROACH FOR THE MANUFACTURING OF ARTIFICIAL BONE:

Human bone design in 3D CAD software & analysis by FEM method in analysis software. By using this cad model and import into Rapid prototyping (3D printing) machine. It will create artificial bone. To fabricate artificial bone, the AM technique is applied to the bio-fabrication process, this process is known as Bio-

Additive Manufacturing (BAM). Bio-Additive Manufacturing (BAM) uses computer-aided design technology to realize the customized manufacture of the bone defect, with an internal 3D structure that is also like the human bone.

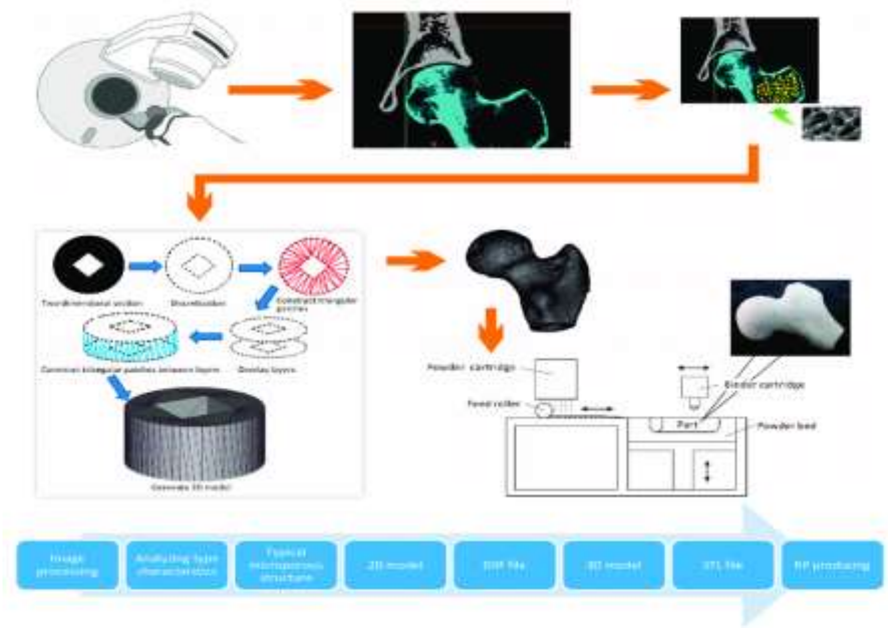

Fig. 2: Bionic design and manufacturing process of the inner microstructure of artificial bone scaffold.

2.1 Performance on Bionic Design:

After being implanted into a human body, bone performance is defined and can be assessed based on both mechanical and biological performance. Mechanical performance refers to the structural support of bones and matching the stress caused in the host.

2.2 Mechanical Performance on Bionic Design:

Different 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 the diagnosis and approximation of bionic design in mechanical properties influences the preparation and planning of the implants. The bionic bone model is closer to the real bone in both structure and texture. To match the mechanical and biological performance of 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 are of critical importance.

2.3. Biological Performance on Bionic Design:

By 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. Using the ideal bionic bone material should have good bioactivity, biodegradability, and osteogenesis. As of 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 mechanical support to avoid stress concentration, caused by the high mechanical strength of the material.

2.4. Replacement of Bone:

Bone replacement 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). Now a days the available materials for the replacement of humer bone is limited and may leads to infection with pain and high risk. 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 the bone to regrow and fill the space.

3. SQUENTIAL OPERATIONS FOR THE DESIGN OF HUMER BONE:

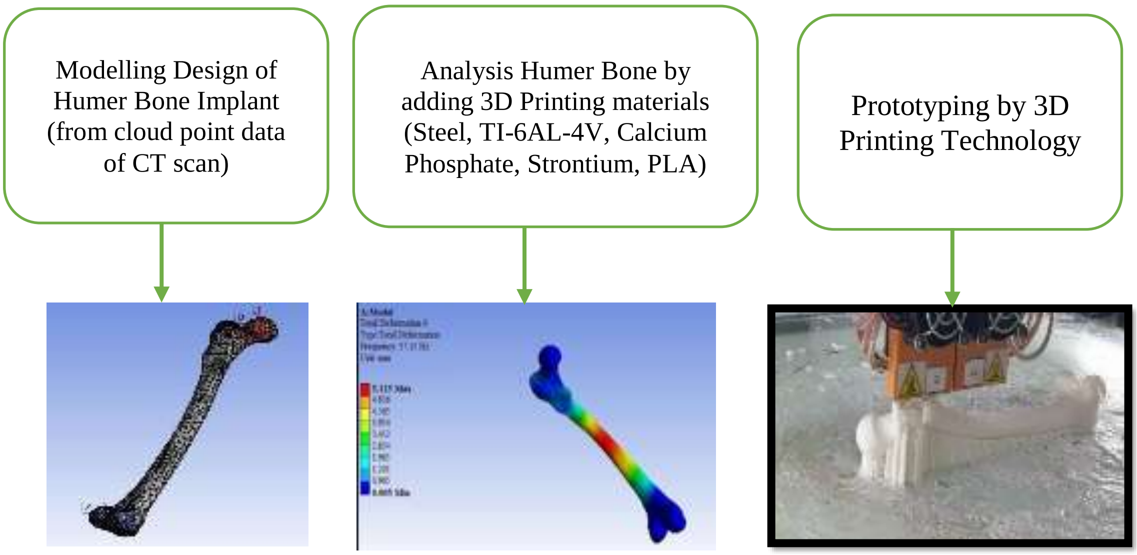

Fig. 3: Humer bone process of block diagram

3.1 DESIGN PROCEDURE OF HUMER BONE:

Modelling methods and processes the modelling process mainly includes image processing, information extraction, surface reconstruction and entity reconstruction. Firstly, the original information of Humer is obtained from the gray-scale image of CT image through the processing of CT image acquisition, threshold segmentation, region growth and mask editing, and triangular mesh surface is obtained by rapid pre-modeling. If there are no noise points, the surface is reconstructed by reverse engineering, and the data in reverse engineering modeling are divided into blocks. The three-dimensional solid model of Humer is completed by surface fitting and entity generation.

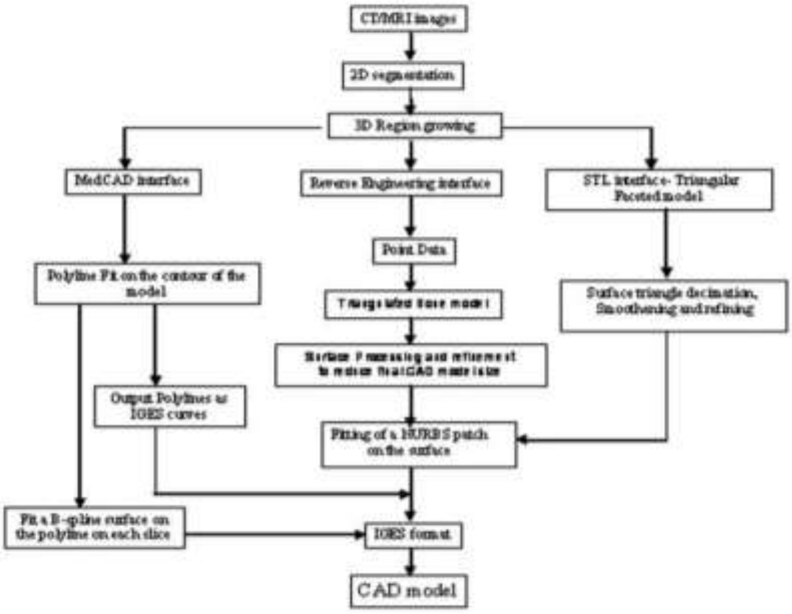

Fig. 4: Flow chart for CAD Model

The Image acquisition and processing of CT after CT image in the DICOM format is imported into Mimics, the image information with different gray characteristics, including bone tissue, muscle, cartilage and so on, is obtained. When acquiring CT scanned image, it will be obtained due to interference of external factors. Images are affected by noise, resulting in local blurring and ambiguity of the image. These interference factors will have a great impact on subsequent image processing and analysis. Therefore, the imported image must be processed by threshold segmentation, region growth and mask editing. The import of the CT image shows that the untreated CT image information of Humer is highly integrated with surrounding tissues and other structures and cannot directly extract the image information of Humer.

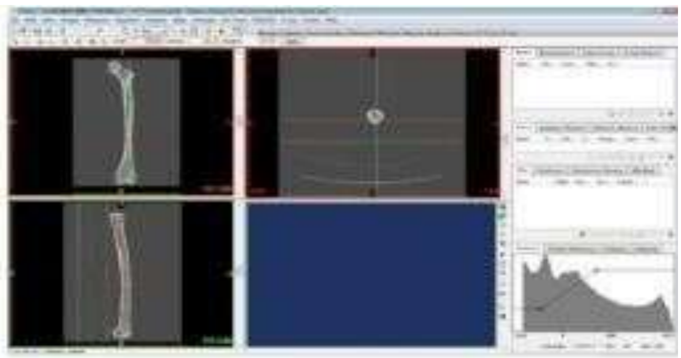

Fig. 5: CT scan image

3.2 Entity Model

After the transition between pavement and adjacent surfaces is completed, some closed polygonal holes will be produced, which can be filled with appropriate curved surfaces and be continuous with the surrounding curvature or tangent. After the above process, although the external contour of Humer has been formed and there is a continuous relationship between them, it is not a whole. Surface stitching should be used to merge them into one. Firstly, the middle Humer is designed, then the upper Humer is designed, and finally the lower Humer is modeled, and the three parts are connected by the above transition surface and filling surface. As shown in Fig. 11, for the process of creating the whole femoral surface, comparison between the effect of the three-dimensional model of the whole femoral entity and the triangular mesh surface introduced. From the 12 drawings, the reconstructed three-dimensional entity model has a high coincidence with the triangular mesh surface.

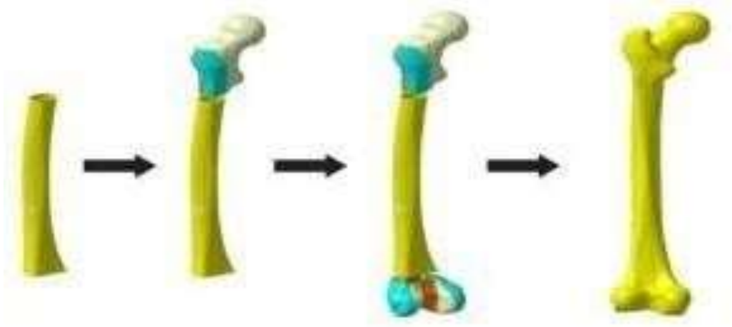

Fig. 6: Reconstruction of the humeral surface

Fig. 7: CAD Final object

The errors of reconstructed surface mostly come from the discrete errors of points cloud and the errors in the process of reconstructing reverse surface. The distance between the original points cloud and the reconstructed surface is analyzed by the method of distance measurement. If the maximum distance error between the reconstructed surface and the original point cloud is less than 0.5mm, it can meet the design requirements.

Fig. 8: Multiple views of Humer bone

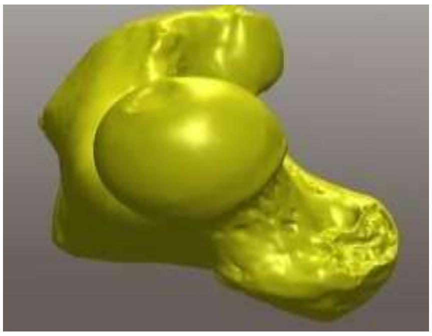

Fig. 9: Top view of Humer bone

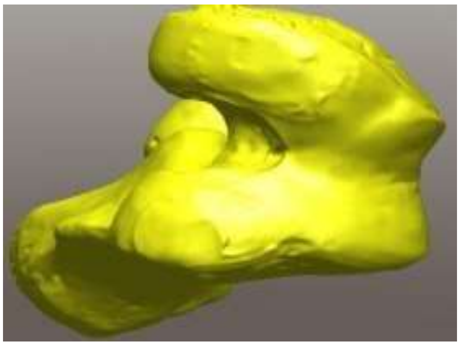

Fig. 10: Bottom view of Humer bone

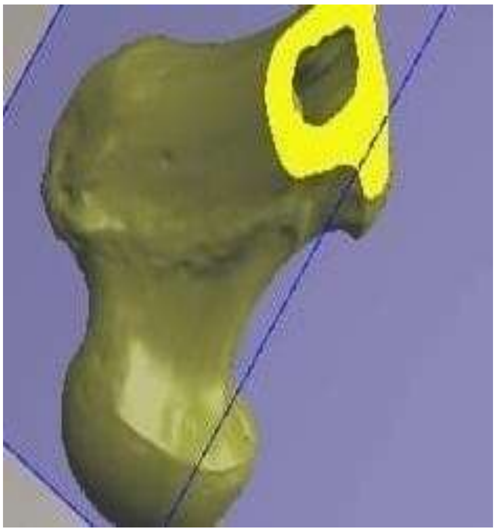

Fig. 11: YZ Sectional view of Humer bone

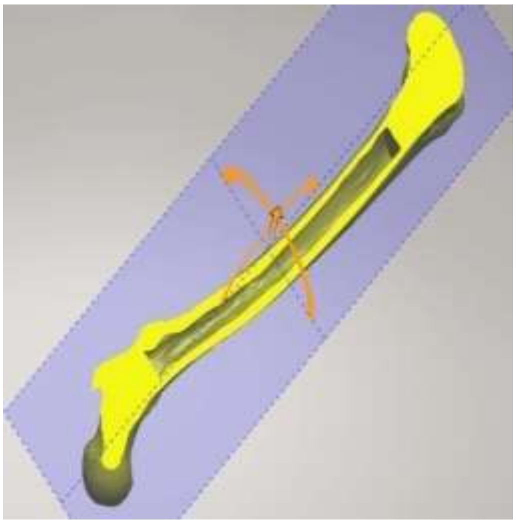

Fig. 12: XY Sectional view of Humer bone

3.3 Bone Implant Analysis by FEA:

Finite Element Analysis (FEA) is the simulation tool in which, any physical component can be analyzed by using a numerical technique. It reduces the number of physical prototypes and experiments and optimizes various elements in their style to develop good products within short interval. Finite Element Analysis (FEA) is an advanced technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, and also the bending behavior etc. This method can be used effectively to analyze deflections at various points under different loads or displacements and to analyze elastic and plastic deformations. The software is required to analyze large structures, which includes an astronomical number of calculations. To access this software in many disciplines, the power and low cost of modern computers have made finite element analysis in a better manner. In the elementary method, the structure is divided into several small simple blocks or elements, then the behavior of the individual element can be described by a relatively simple set of equations. A set of elements are combined together to build the whole structure, the equations describing the behavior of the individual elements are combined into a very large set of equations. The computer controls the behavior of individual elements to obtain the required solution. The stress and deflection at various points can be analyzed effectively to know the mechanical behavior of various structures.

3.4 Analysis of Bone Implant by FEA:

The analysis of bone implant is follows

- The file related to humer bone is imported into the ANSYS software
- Click generate option
- Now the model is ready for analysis.

  The imported geometry in ANSYS is shown in the figure. The analysis of the humer bone is carried out by assuming it as isotropic, linearly elastic and cortical material properties.

3.5 Humer bone Mesh formation:

In order to get accurate results, it is required to have smaller aspect ratios and hence tetrahedron meshing is used for outer cylinder as it provides aspect ratio close to unity. The total number of Nodes and elements are to be considered for meshing were 20179 and 11104.

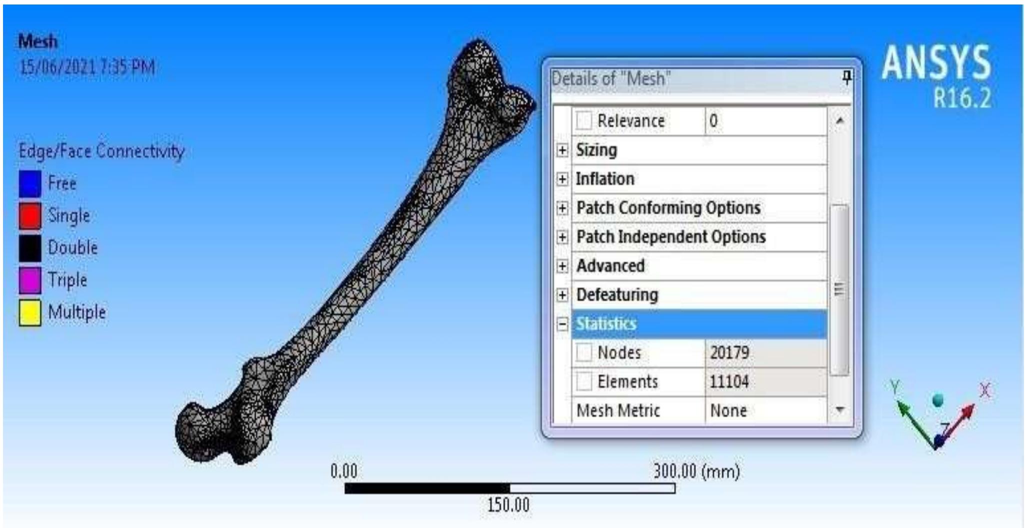

Fig. 13: Humer bone meshing

3.6 Boundary Conditions:

The geometric model of the humer bone is inflexible and the analysis is subjected to eccentric and concentrated load at 390N. In this, the boundary condition for the analysis of humer bone is carried out at a load of 390N and is applied on the lower surface of skull and fixed support.

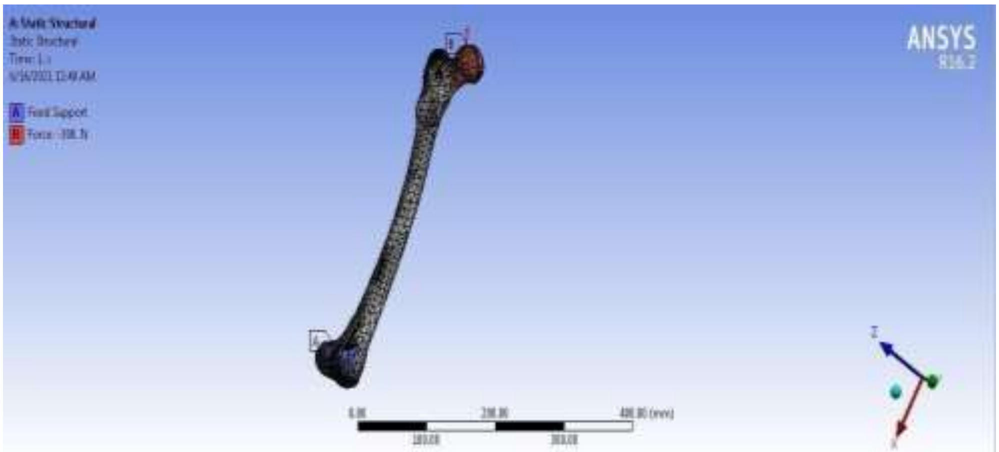

Fig. 14: Boundary condition of the humer bone

3.8. Analysis Results:

The analysis of humer bone is carried out on various materials like Steel 304, TI-6AL-4V, Calcium Phosphate, Strontium, and PLA with same boundary condition & loads.

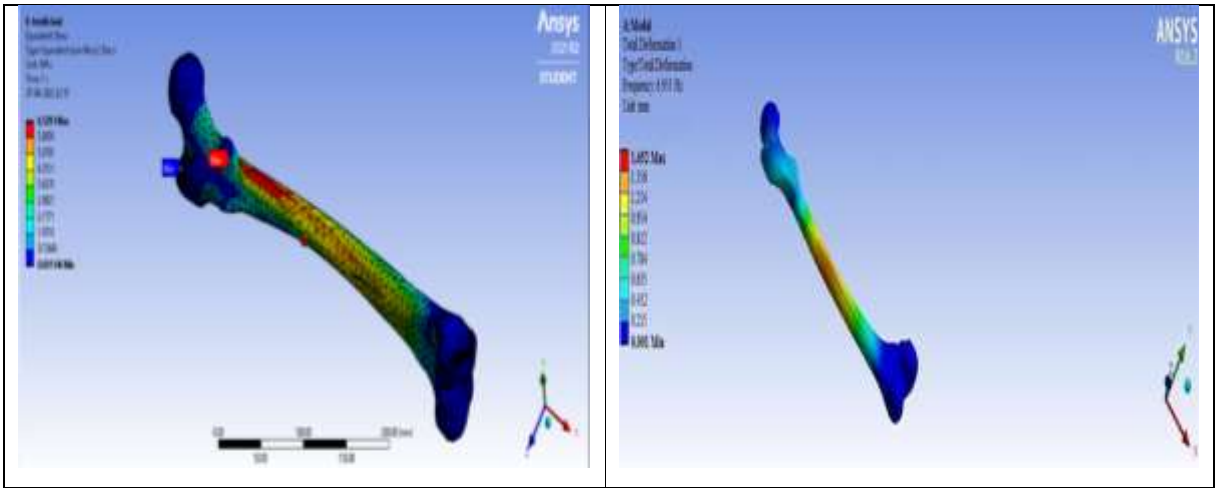

Fig. 15: Static and modal analysis on Steel 304

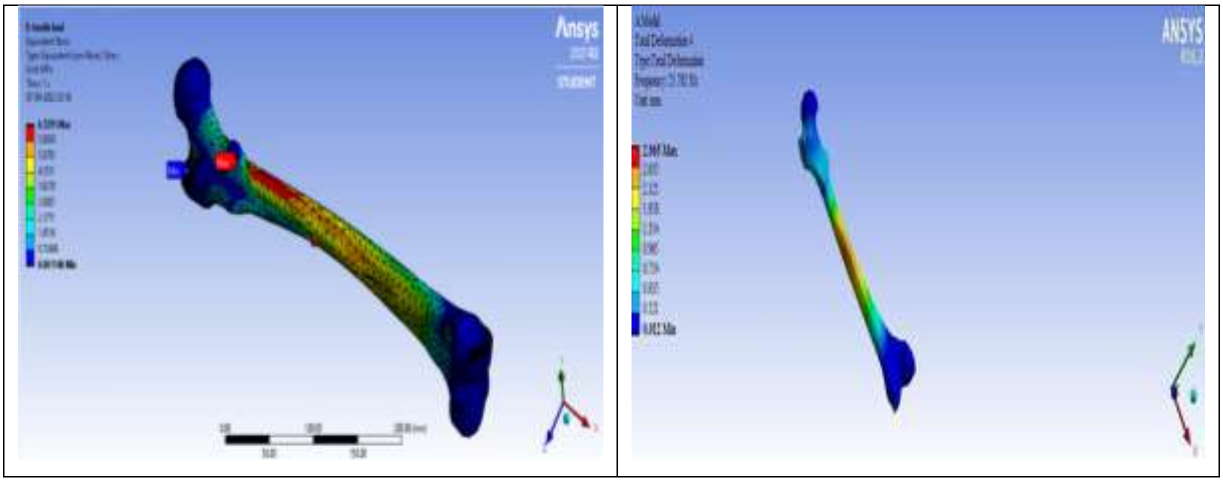

Fig. 16: Static and modal analysis on TI-6AL-4V

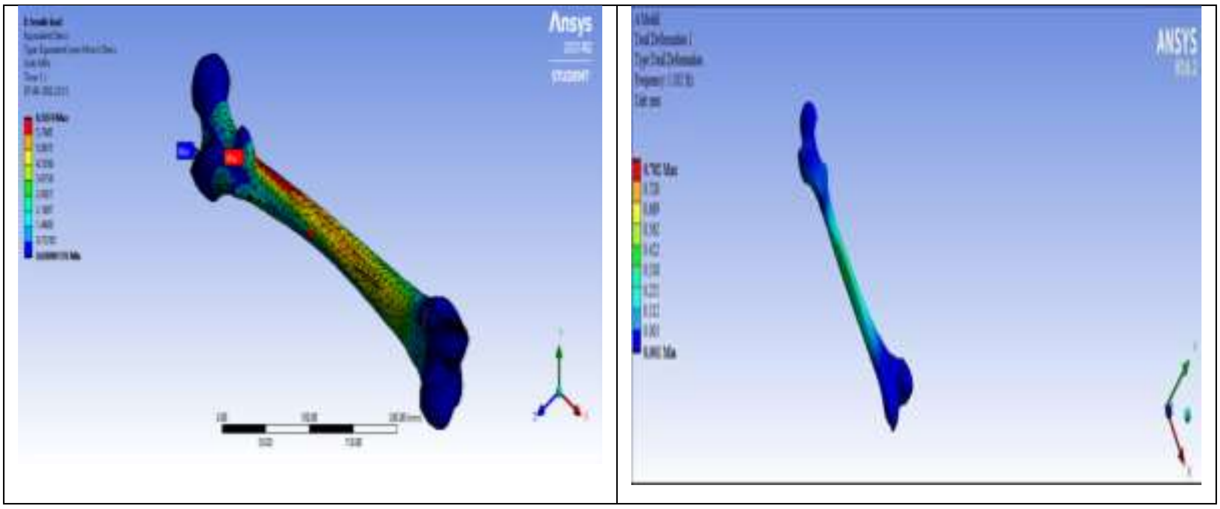

Fig. 17: Static and modal analysis on Calcium Phosphate

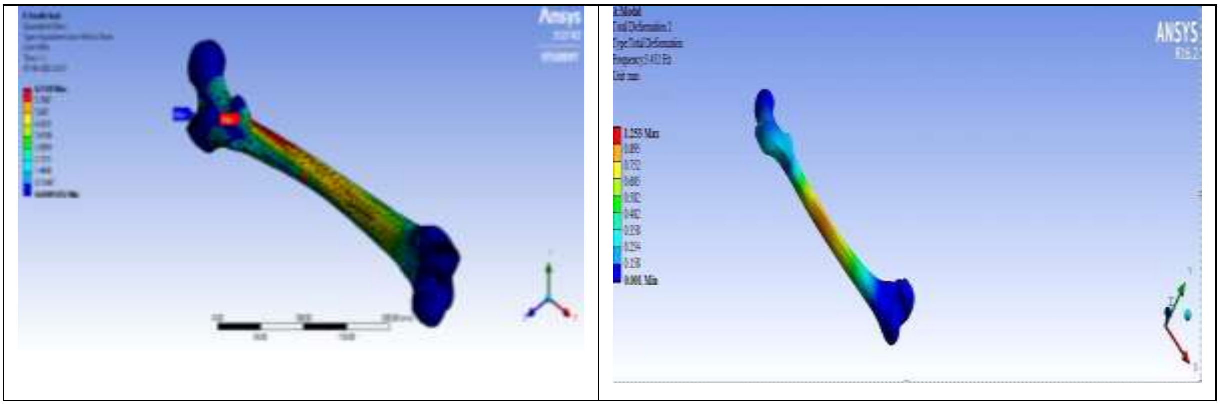

Fig. 18: Static and modal analysis on Strontium

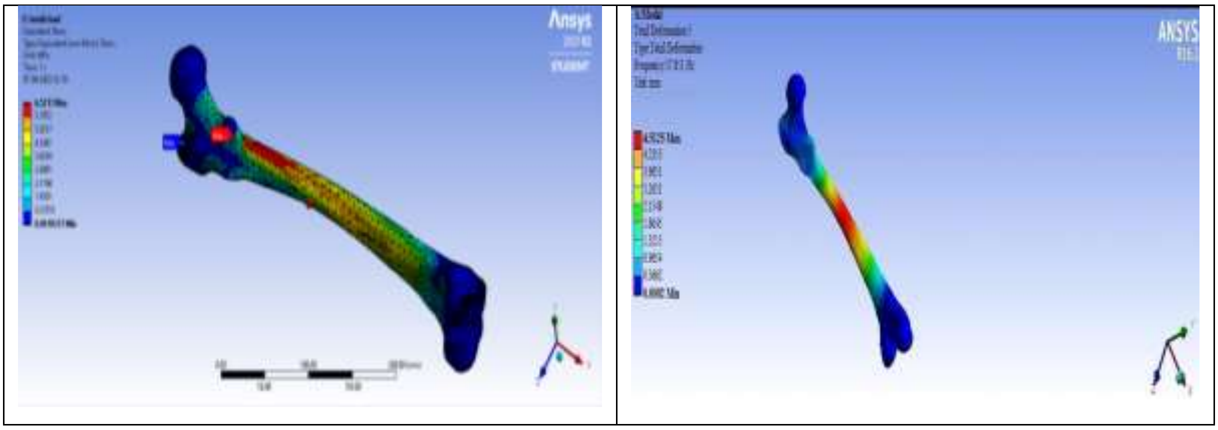

Fig. 19: Static and modal analysis on PLA

4. Results and Discussions

Modal analysis is a technique to study the dynamic characteristics of a Humer bone by fixing the two ends and the observations are taken under vibration excitation. The model analysis for all the materials is conducted at a load of 390 N.

Dynamic Analysis:

Natural frequencies, mode shapes and mode vectors of a structure can be determined by using modal analysis on **Steel 304, TI-6AL-4V, Calcium Phosphate, Strontium, and PLA**. Graphical variations of the number of modes vs frequency are obtained from ANSYS Workbench. The dynamic analysis is also conducted for all these materials at a load of 390 N.

Table-1: Model analysis at a load of 390N

Materials/ Modes	**Frequency in HZ**				
	Steel 304	TI-6AL-4V	Calcium Phosphate	Strontium	PLA
Mode-1	1.235	1.152	1.102	1.123	0.965
Mode-2	3.653	3.532	3.321	3.542	3.125
Mode-3	6.951	6.698	6.251	6.352	6.123
Mode-4	26.128	25.782	23.62	24.68	23.654
Mode-5	48.628	47.965	37.965	39.21	37.851
Mode-6	78.63	61.621	58.45	59.36	57.15

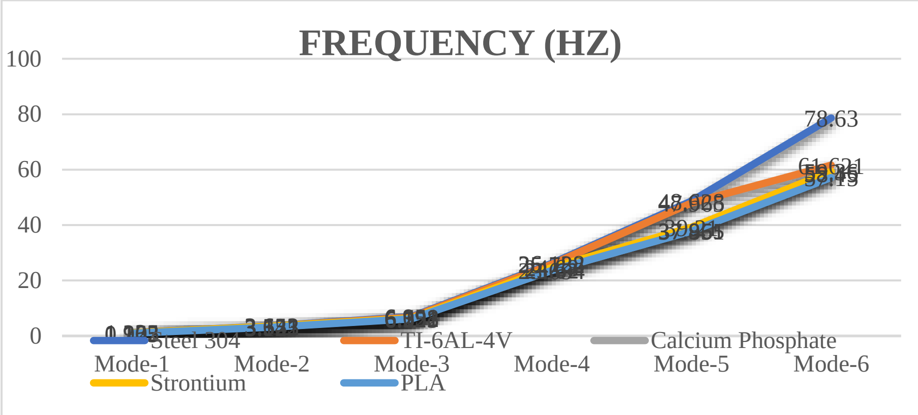

Fig. 20: Mode vs frequency graph

Table-2: Total deformation at a load of 390N

Materials/ Modes	Total Deformation in mm				
	Steel 304	TI-6AL-4V	Calcium Phosphate	Strontium	PLA
Mode-1	0.235	0.355	0.782	0.632	0.793
Mode-2	0.965	0.998	1.362	1.235	1.456
Mode-3	1.625	1.692	2.361	1.965	2.536
Mode-4	2.635	2.965	3.351	3.154	3.568
Mode-5	3.784	3.965	4.365	4.261	4.5125
Mode-6	4.235	4.352	4.998	4.965	5.125

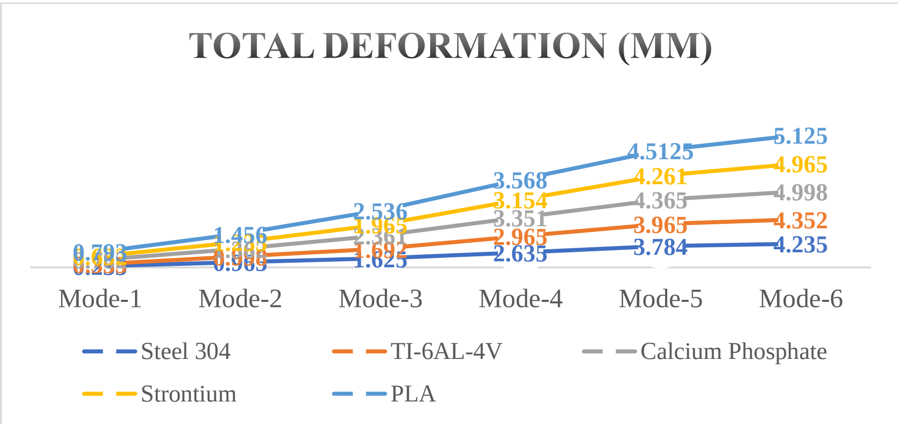

Fig. 21: Mode vs total deformation graph

Static Analysis:

The effect of steady (or static) loading on a structure is determined via static structural simulation. The stress, strain, and deformation are examined under a variety of loading circumstances. This aids in identifying weak spots with low strength and durability during the design stage and to avoid failures during its application. The static analysis on **Steel 304, TI-6AL-4V, Calcium Phosphate, Strontium, and PLA** is conducted at a load of 390 N.

Von-misses stress:

The von-misses stress is obtained by using static structural analysis on various materials (Steel 304, TI-

6AL-4V, Calcium Phosphate, Strontium, and PLA). A Graphical representation of various load conditions vs von-misses stress is obtained by fixing humer bone at the shoulder area and a load of 390 N is applied at humer ball.

Table-3: Von-misses stress at a load of 390N

Materials/ Loads	**Von-misses stress (Mpa)**				
	Steel 304	TI-6AL-4V	Calcium Phosphate	Strontium	PLA
Point	14.02	14.02	14.07	14.13	14.18
Tensile	15.186	15.71	15.82	16.577	20.9
Compressive	7.89	7.69	8.571	8.561	8.55
Shear	2.14	2.14	2.145	2.15	2.141

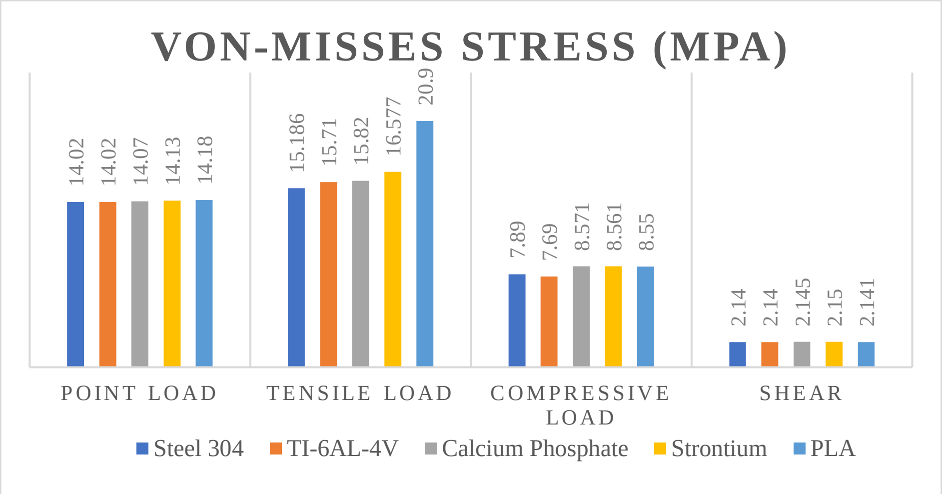

Fig. 22: Load vs von-misses stress graph

Total Deformation:

The total deformation is obtained by using static structural analysis on various materials (Steel 304, TI-6AL-4V, Calcium Phosphate, Strontium, and PLA). A Graphical representation of various load conditions vs von-misses stress is obtained by fixing humer bone at the shoulder area and a load of 390 N is applied at humer ball.

Table-4: Total deformation stress at a load of 390N

Materials/ Loads	**Total Deformation in mm**				
	Steel 304	TI-6AL-4V	Calcium Phosphate	Strontium	PLA
Point	10.83	11.2	19.86	13.29	12.02
Tensile	92.071	110.5	160.17	113.6	170.7
Compressive	109.1	130.9	200.83	134.31	6.8
Shear	1.1	1.08	2.12	1.42	1.19

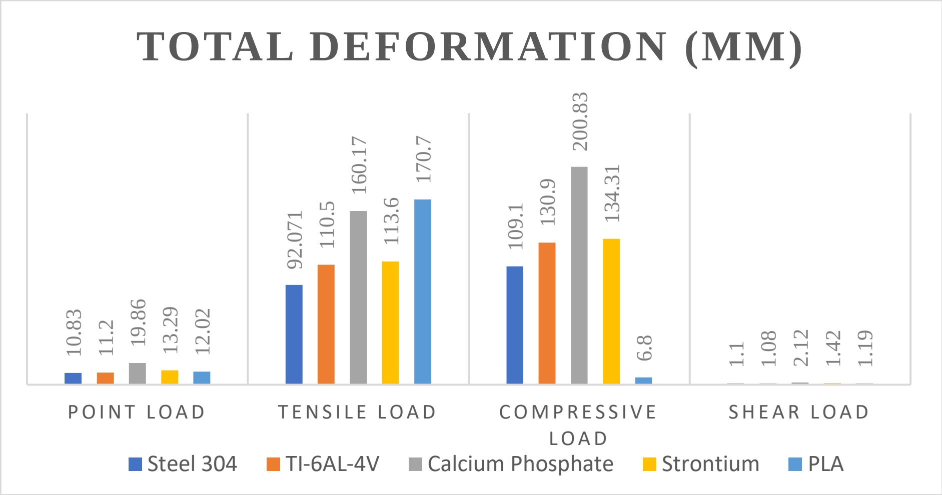

Fig. 23: Load vs total deformation graph

Strain:

The strain is obtained by using static structural analysis on various materials (Steel 304, TI-6AL-4V, Calcium Phosphate, Strontium, and PLA). A Graphical representation of various load conditions vs von-misses stress is obtained by fixing humer bone at the shoulder area and a load of 390 N is applied at humer ball.

Table-5: Strain at a load of 390N

Materials/ Loads	**Strain**				
	Steel 304	TI-6AL-4V	Calcium Phosphate	Strontium	PLA
Point	0.08	0.09	0.14	0.092	0.1
Tensile	0.0356	0.0421	0.0667	0.0443	0.0701
Compressive	0.044	0.064	0.081	0.054	0.002
Shear	0.01	0.011	0.02	0.021	0.022

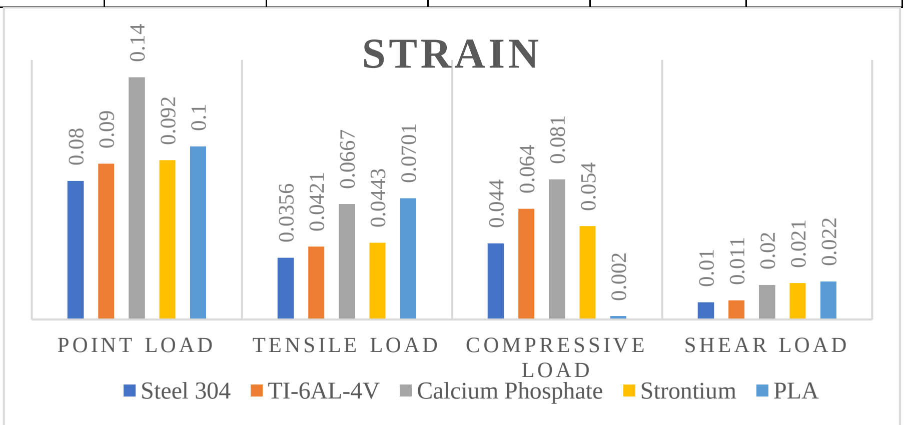

Fig. 24: Load vs strain graph

Shear stress:

The shear stress is obtained by using static structural analysis on various materials (Steel 304, TI-6AL-4V, Calcium Phosphate, Strontium, and PLA). A Graphical representation of various load conditions vs von-misses stress is obtained by fixing humer bone at the shoulder area and a load of 390 N is applied at humer ball.

Table-6: Shear stress at a load of 390N

Materials/ Loads	Shear Stress (Mpa)				
	Steel 304	TI-6AL-4V	Calcium Phosphate	Strontium	PLA
Point	4.12	4.11	4.18	4.13	4.16
Tensile	6.529	6.521	6.539	6.53	6.599
Compressive	1.1	0.96	1.17	1.16	1.169
Shear	1.104	1.105	1.114	1.11	1.106

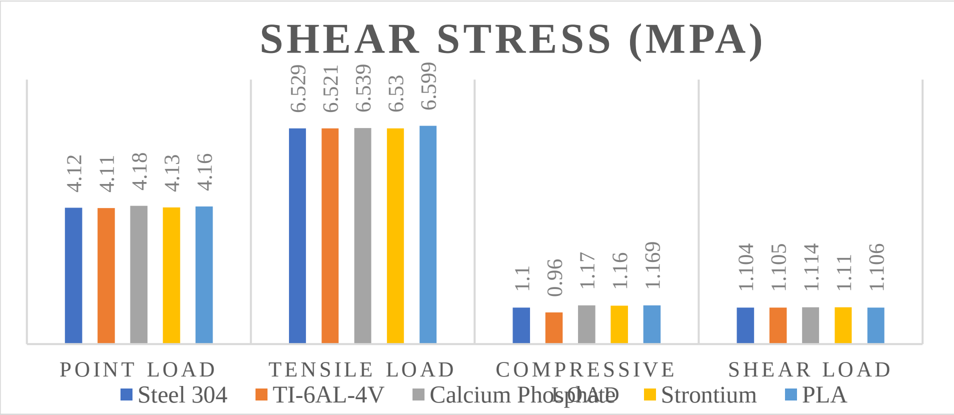

Fig. 25: Load vs shear stress graph

5.1. Rapid prototyping Technology (3D printing)

Additive Manufacturing Technology (AM) is used to produce a three-dimensional object, in which the layers of material are generated under computer control to create the required object. They can be in any shape or geometry and are to be created by using digital model data which are from 3D model or another electronic data source, such as an Additive Manufacturing File (AMF).

Stereo Lithography (STL) is one of the most common file type is to read 3D printers. 3D printing, also known as additive manufacturing (AM), creates a three-dimensional object from a computer-aided design (CAD) model or AMF by layering material.

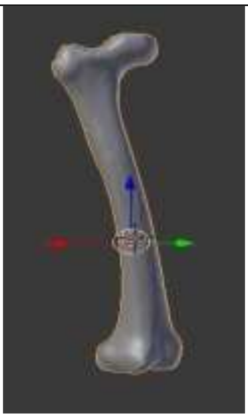	
Fig. 26: Imported cad model into FDM	**Fig. 27: 3D Printed artificial bone**

Conclusions:

1. In modal analysis, the obtained results (table-1 & 2) shows that the stainless steel 304 is the best existing material for humer bone but due to high density of steel, it can be replaced with composite material which is TI-6AL-4V having nearer frequency and total deformation values to the steel.
2. In the static analysis, the obtained results (table-3, 4, 5 & 6) shows that the stainless steel 304 is the best existing material but due to high density of steel, the composite material TI-6AL-4V is replaced and it can be used as a humer bone material.
3. Humor bone is successfully manufactured in PLA by using Rapid Prototyping Technique.

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