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"Testing and Analysis for Mechanical Properties of Human Femur Bone at Head Portion"

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Abstract: As we all know, Bone plays an important part in our body, basically being strong enough to support our body, help us to form our shape, as well as protecting organs. Among these, femur bone is one of the most important parts since it is responsible for weight bearing and stability of gait. In normal day to day activities, our body is subjected to numerous complicated loads exerted by different loading conditions. The loading modes on the femur bones includes compressive, tensile, bending and torsional forces applied to the joint head part of bone. In this project we have perform FEA Analysis on different material such as PLA and ABS. Furthermore, after analysis we had developed artificial bone with 3D Printing technology. Then we compared the characteristics and properties of the FEA Analysis for this certain dimension of bone based on the above-mentioned materials to the standard values of specimens generally used for testing. The aim of this study is to analyze the property of different materials which can be used to manufacture the head portion of human femur bone using Additive Manufacturing.

Index Terms **- Analysis of Human Femur bone, 3D Printing, Artificial human femur bone, Human Femur Bone at Head Portion, Additive Manufacturing.**

1.INTRODUCTION

Femur bone, otherwise called thigh bone is the longest, heaviest and most grounded bone in the human body. The length of this bone is right around 26% of the stature of an individual. Femur bone is isolated in three sections: furthest points, body and lower limit. Upper part consists of the head, neck and the two trochanters. Body is the long and relatively tube-shaped fit as a fiddle. It is marginally curved. Lower furthest point is greater than furthest point. As the only bone in the thigh, it serves as an attachment point for all the muscles that exert their force over the hip and knee joints. Some muscles – which cross two joints, like the gastrocnemius and plantar is muscles – also originate from the femur. Overall. 23 individual muscles stem from or insert onto the femur. Under cross-section, the thigh part is divided into three separate fascial compartments divided by fascia, each contain with muscles. Using femur as an axis these compartments are separated by tough connective tissue membranes also known as septa. Each individual of these compartments is known to have their own blood and nerve supply, also containing a different group of muscles. These compartments are named the anterior, medial and posterior fascial compartments. Femur bone contrasts from human to human in the two terms of bone geometry and furthermore in the mechanical properties which make it difficult to separate the exploratory outcomes to be replicated. So, to break down the human femur a substitute approach is to utilize a manufactured femur of indistinguishable geometry which has roughly the same material properties as human bone. This standard geometric model may be used to perform investigations to acquire helpful outcomes. Furthermore, utilization of current procedures decreases this entanglement. Most recent methods of 3D analysis could be utilized in building PC helped plan (CAD) model of femur bone.

1.1 Area of interests: -

For our project we are focusing on the upper end of the femoral bone which includes the head, neck, the greater trochanter, the lesser trochanter, intertrochanteric lines and crest. Among these the head portion is the significant part on which we would perform the testing of certain mechanical properties.

Our main requirement is raw material. Some of the raw materials would be bought from hardware shops while the design of synthetic femur bone would be completed as per our requirement using modelling and analyzing software's and the finished product will be fabricated using Additive Manufacturing at our respective college lab.

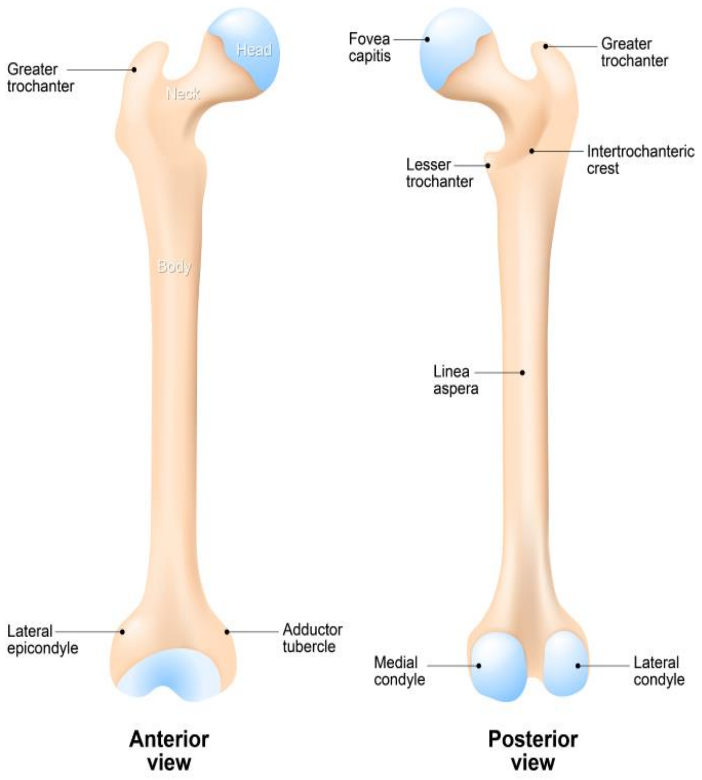


Fig. Anatomy of Femur bone [1]

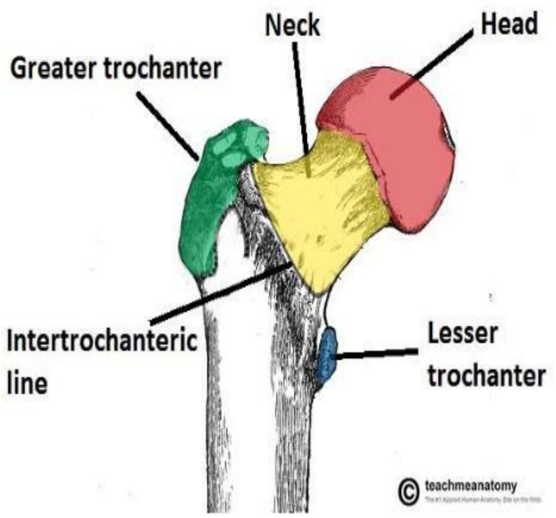


Fig. Head of Femur bone [2]

1.2 Problem Statement: -

Designing and Analyzing the Synthetic Femur bone at head portion and comparing its properties with other synthetic materials. Also manufacturing synthetic bone using additive manufacturing process (3D printing) using materials such as Acrylonitrile Butadiene Styrene (ABS) & Polylactic Acid (PLA).

1.3 Objective: -

- Study of various properties of human femur bone at head portion.
- Manufacturing of synthetic bone with the help of live bone.
- Analysis of human femur bone at head using CAD software.
- Comparing mechanical properties of standard specimen made up of synthetic materials.

2. METHODOLOGY

2.1 Properties of Human Femur Bone: -

Bone is a natural bio-composite material therefore it shows a complex behavior involving mechanical properties which are heterogeneous and anisotropic. Femur bone is the longest and strongest bone of human body. Femur bone is divided into three parts Epiphysis, Metaphysis and Diaphysis based on shape and material density.

2.2 Mechanical Properties of Human Femur Bone: -

2.2.1 Ultimate Strength of the Femur: The maximum stress experience by bone or any other material before it begins to form a fracture or rupture is called ultimate strength. Notice that material strength is defined in terms of stress, not force, so that we are analyzing the material itself, without including the effect of how much material is present. For certain materials the ultimate strength is vastly different when stress acts to crush the material (compression) vs when forces act to stretch the material under tension, we refer to ultimate tensile strength or ultimate compressive strength.

2.2.2 Transverse Ultimate Strength: Basically, transverse ultimate strength could mean as the maximum stress that a given material can withstand under an applied force. Few materials like bone, wood have different ultimate strengths along different axes. The ultimate compressive strength for bone along the smaller axis (transverse direction) is 131 **MPa**, or about 36**%** less than the 205 **MPa** longitudinal value. Materials having different properties along different axes are known as anisotropic. Materials that are known to behave same in all directions are known as isotropic. Interestingly when a person stands the femur experiences compressive and tensile stresses on different sides of the bone. The reason for this being the structure of hip socket applies the load of the body to the side rather than directly along the axis of the bone.

3. MANUFACTURING

We will be using an additive manufacturing process to manufacture synthetic bone. The technology is enabling synthetic manufacturers to create bones with enhanced functionality and more personalized to specific patient needs. Furthermore, 3D printing opens the door to personalized which can be created at the point of care. In addition to established medical device manufacturers, medical start-ups have also emerged over the last decade, developing proprietary approaches to 3D-printed orthopedic. 3D printing is basically an additive manufacturing process which builds up an object in layers. It is basically a process of making three dimensional solid objects from a digital life. Following are the types of latest 3D printing systems currently being use in the industry: -

- **Sintering:** is a technology where the material is heated, but not to the point of melting, to create high resolution items. For Direct metal laser sintering metallic powders are used while thermoplastic powders are preferred for selective laser sintering.
- **Melting:** methods of 3D printing consists of powder bed fusion, electron beam melting and direct energy deposition. These use lasers, electric arcs or electron beams to print objects by melting the materials at a very high temperature.
- **Stereolithographic:** utilises photo polymerization to create parts. This technology uses the optimum light source for interacting with different materials in a selective manner to cure and solidify a cross section of the object in precise thin layers.

Fig. 3D printed human femur bone ABS (left) & PLA (right)

<u>3.1 Material to be considered for Additive Manufacturing: -</u>

In addition to titanium and other biocompatible metals, 3D printing can be coupled with polymers like ABS (Acrylonitrile, Butadiene and Styrene Polymers) and PLA (Polylactic Acid-thermoplastic polymer) to produce model. These thermoplastics are known for their high strength and biocompatibility, and also offer a few benefits over metal like lower costs and radiolucency.

Currently most common materials on the market are ABS (Acrylonitrile, Butadiene and Styrene Polymers), PLA (Polylactic acid-thermoplastic polymer) as well as PCL (Polycaprolactone) are some materials. Below is a simple tabular form representing these materials and comparing them along with an actual human femur bone.

	ABS	PLA	PCL
Density (g/cm^3)	1.0-1.05	1.25	1.145
Ultimate Tensile Strength (MPA)	22.1-74.0	48	10.5-16.1
Poisson ratio	0.35	0.33	0.3 (+1,-1)
Young's Modulus/ Flexural strength (MPA)	2200	3500	343-364

Table.3.1 Different properties of synthetic materials [3], [4], [5]

4. MECHANICAL TESTING

There are few mechanical tests that will be performed with the additive manufactured synthetic bone are mentioned below: -

- Compression test
- Bending test
- Torsional test
- Shear test
- Fatigue test

The major modes of loading seen by the femur are axial compression, bending, and torsion. The rigidity or stiffness of the bone in these loading modes is the greatest factor contributing to the load sharing characteristics, for example, in the proportion of total load taken by bone compared to an intramedullary nail in a bone/nail system. Thus, axial and torsional stiffness were chosen as measures on which to base comparisons. Given below the tests which are traditionally performed: -

- **Compression test**- A very common testing method used to determine the compressive forces or crush resistance of a material and its ability to recover after a specified compressive force is applied or even held over a period of time.
- **Bending test**- Bending test is also known as bend test, is used to determine the strength of a material by applying force to the sample in question and seeing how it reacts under pressure. Generally, bend test measures ductility which means the ability of material to change its form under pressure and keep that form permanent. In certain cases, the bending test can determine tensile strength.
- **Torsional test**- A torsion test measures the strength of any material against maximum twisting forces. Considered a common, torsional test is used in material mechanics to measure how much twist a certain material can withstand before cracking or breaking. This applied twisting pressure is known as torque.
- **Shear test**- This test is designed to apply stress to a certain test sample so that it experiences a sliding failure along a plane which is parallel to the applied forces. Usually, due to shear forces one surface of material moves in opposite direction to the other surface so that the material is stressed in a sliding motion. Shear tests differ from torsional and compression tests in that the forces applied are parallel to the two-contact surface, on the other hand, in tension and compression they are perpendicular to the contact surfaces.
- **Fatigue test**- Fatigue is a progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The maximum stress limit values are lesser than ultimate tensile stress limit, moreover they may even be below the yield stress limit of material. It is known as one of the failures that occur in materials. Fatigue occurs when a material is subjected to certain alternating stresses, over long periods of time.

5. MODELLING AND ANALYSIS BY SOFTWARE:

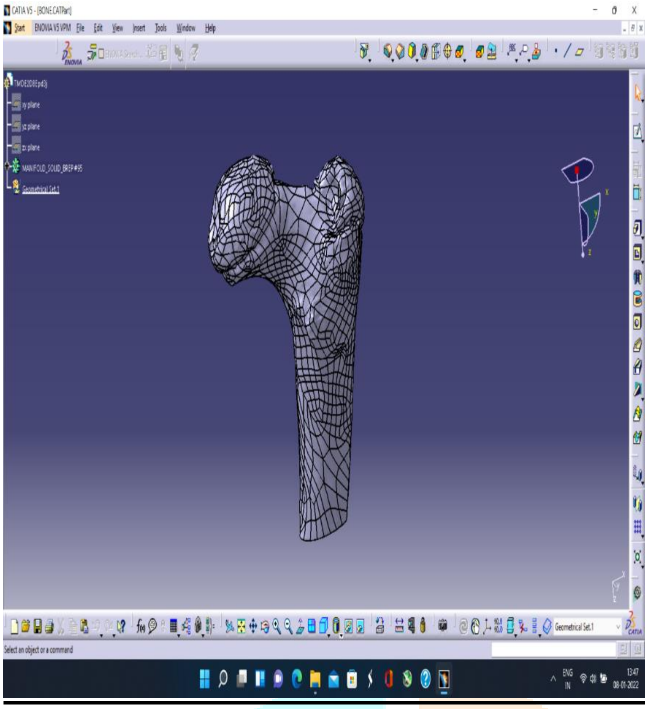
5.1 Parametric CAD of 3D scanned data: -

Sometimes we don't have access to a part's original design documentation from its original production. Here Reverse engineering basically empowers us to analyze certain physical parts/aspects and explore how it was originally built to replicate, create variations, or to improve certain aspects of the design. The goal is to ultimately create a new CAD model for use in manufacturing and analysis purpose. We can use it to replicate the part or create a new design based on the original. 3D scan data serves as a visual guide for sketching the CAD drawing. It could be pretty much considered tracing on top of the scan data. We would begin our CAD drawing with tracing basic 2D sketches along with creating standard relationships and constraints so as to maximize control over how our design is developed. 2D sketches are then converted into 3D features.

We have approached a doctor for the necessary data required for 3D printing of the human femur bone and manufactured it using additive manufacturing process. Later onwards to model and analysis of the bone we have done reverse engineering, basically we have 3D scanned the bone specimen and by using that data we will be modelling the bone in the CAD software and further complete the analysis in the ANSYS software.

5.2 CAD Model: -

The Femur CAD model will be developed in CAD software using the technique of transforming 2D geometry into 3D using the cloud data obtained earlier. The CAD model of the Femur bone is shown in Figure. At this stage CAD model was obtained based on external geometric features of femur bone however, the internal detail (e.g. marrow cavity) in CAD was approximated. The dimensions of the marrow cavity are hard to know considering it is a hollow imprint within the bone. The dimensions of the marrow cavity were approximated in this work with a hallow.



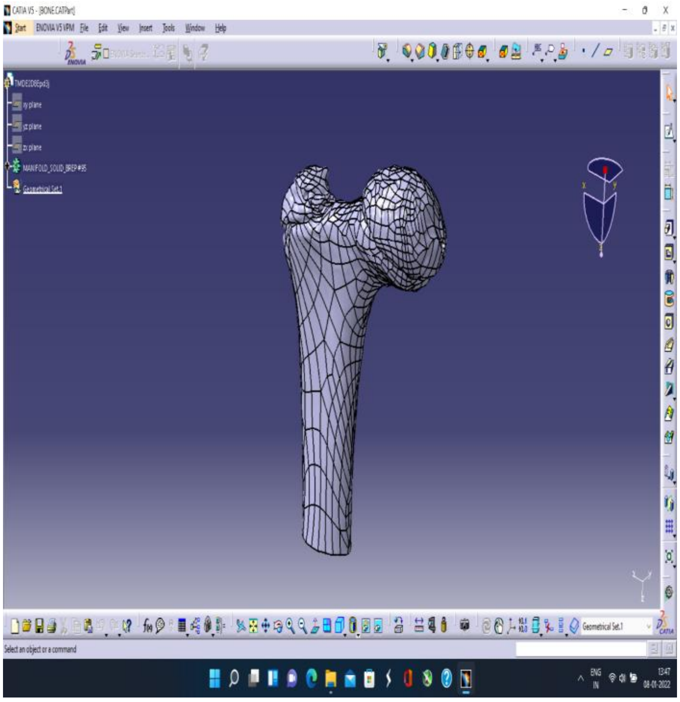


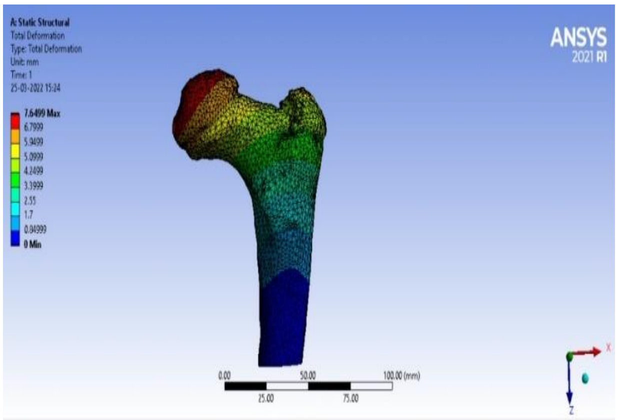
Fig: - Left & Right views of CAD modelled Femur bone head portion

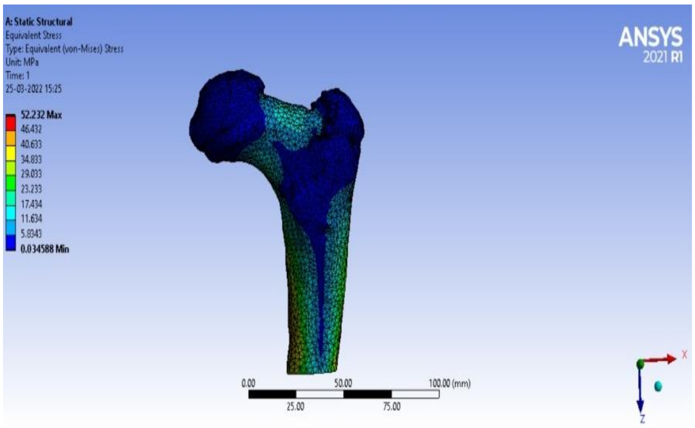
5.3 Finite Element Analysis (Analysis by software's): -

In this work, FEA mesh will be generated on 3D CAD model of femur bone. Tetrahedral nodded Structural Solid elements were used to build the FEA mesh. The stated element type is chosen since it has higher accuracy compared to its equivalent lesser node element. FEA mesh will be generated using the auto-mesh generation algorithm in FEA software ANSYS. Mesh refinement will be performed in desired segments of the bone to avoid unrealistic stress concentration points. Furthermore, mesh will be refined in regions of higher gradients to magnify the accuracy of results. Mesh sensitivity analysis is also carried out to ensure the quality of results. Following is the step-by-step method of how we are having to perform the analysis of 3D scanned human femur bone's CAD model.

5.4 Final results: -

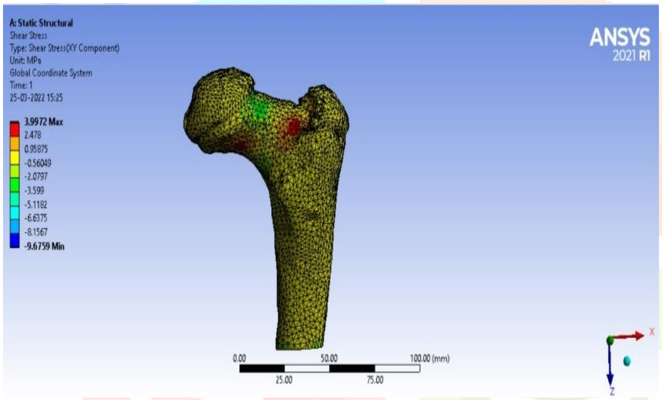
Ansys at 70 Kgs for ABS

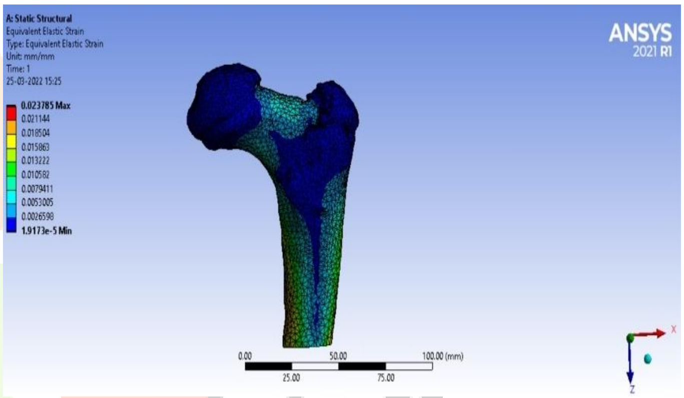




Max. Total Deformation 7.6499mm

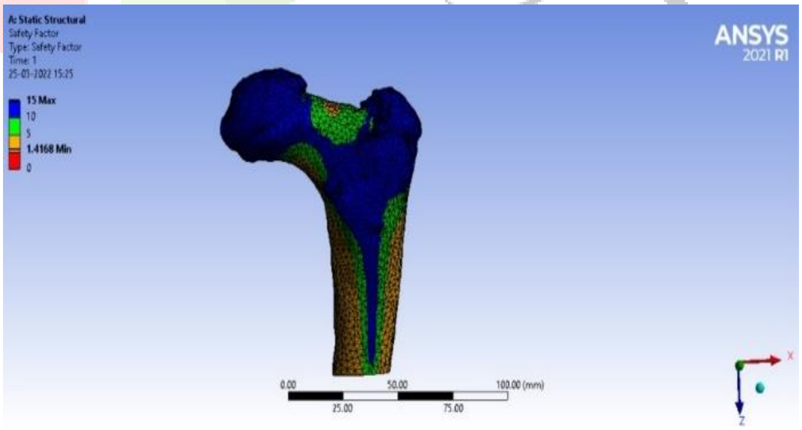
Max. Equivalent Stress 52.232 MPa





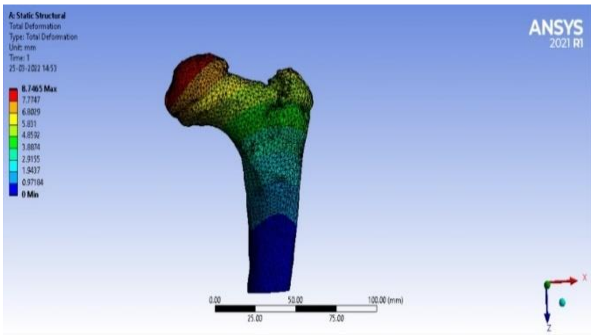
Max. Shear Stress 3.9972 MPa

Max. Equivalent Elastic Strain 0.023758

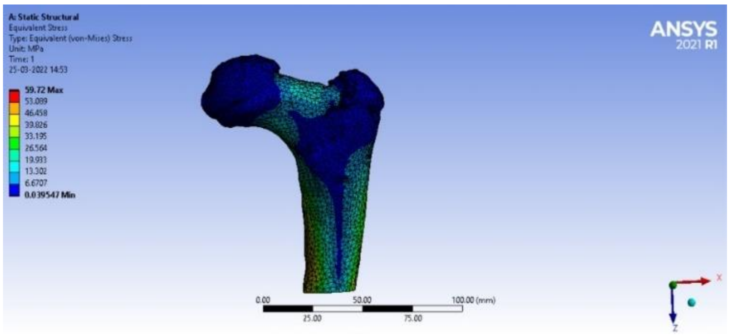


Min. Factor of Safety 1.4168

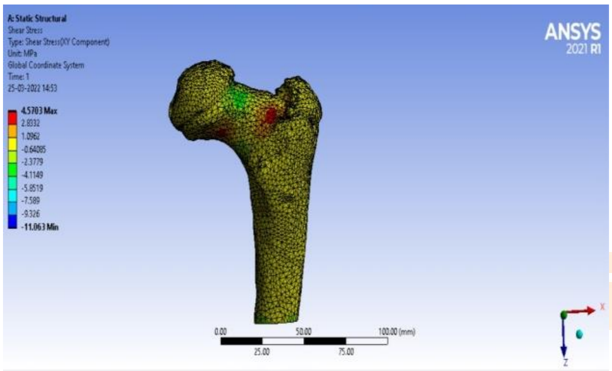
For 80 Kgs



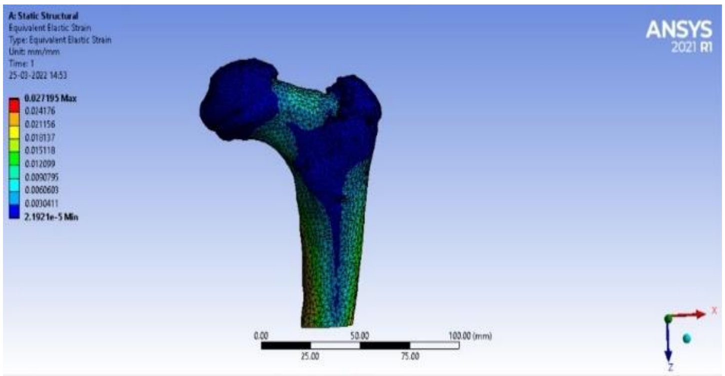
Max. Total Deformation 8.7465mm



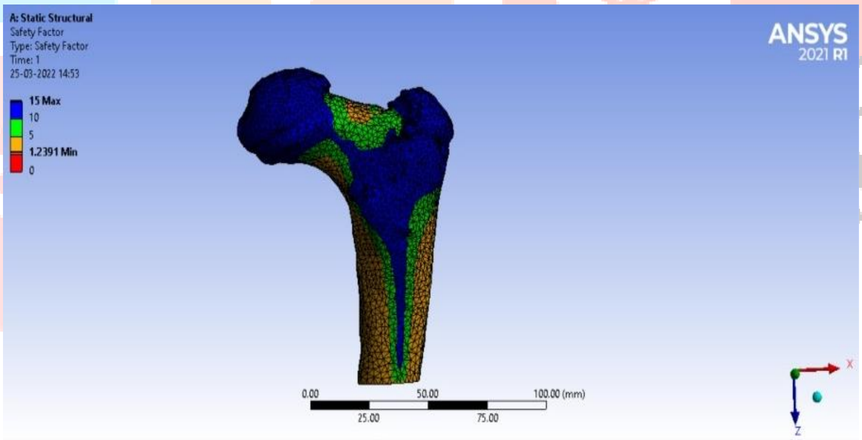
Min. Factor of Safety 1.4168



Max. Shear Stress 4.5703 MPa

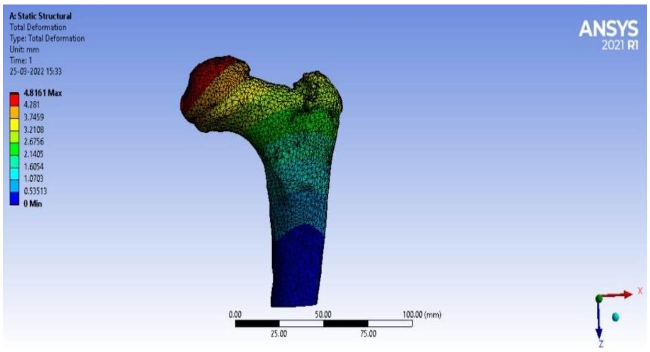


Max. Equivalent Elastic Strain 0.027195

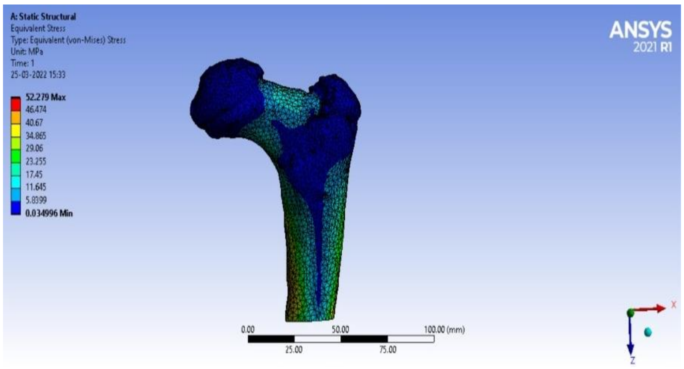


Min. Factor of Safety 1.2391

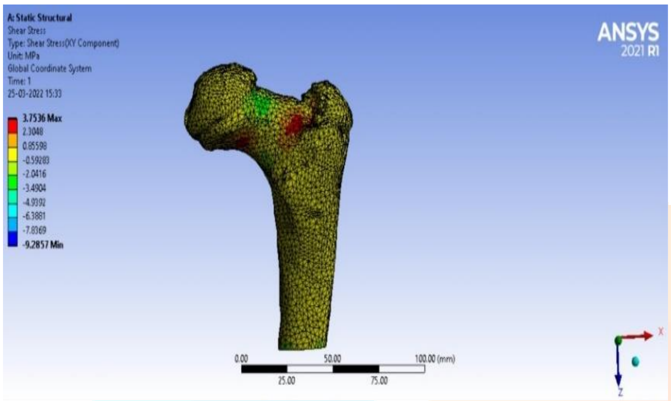
Ansys at 70 Kgs for PLA



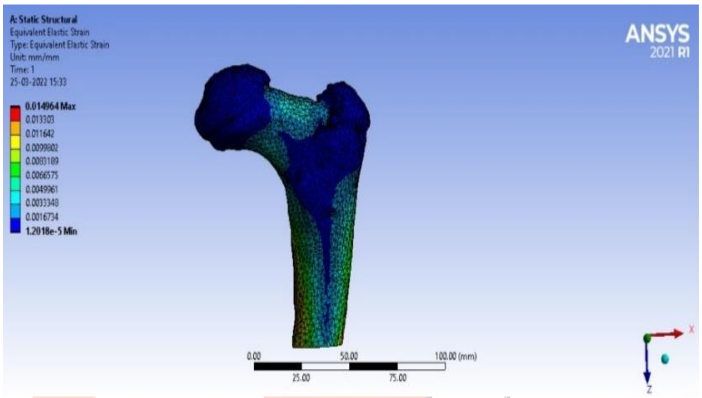
Max. Total Deformation 4.8161mm



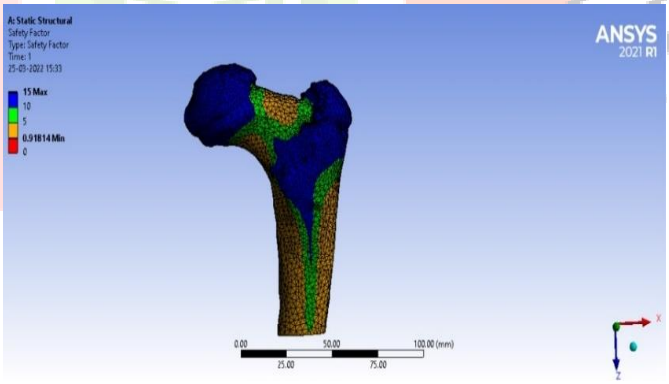
Max. Equivalent Stress 52.279 MPa



Max. Shear Stress 3.7536 MPa

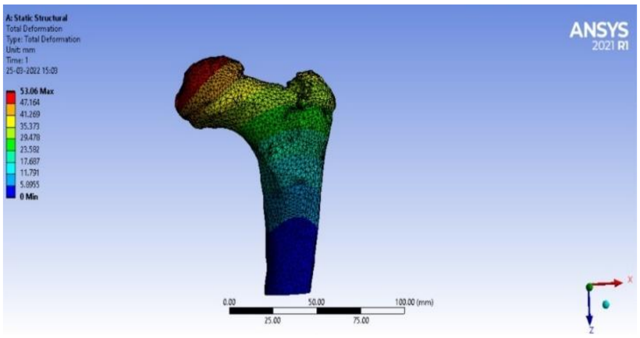


Max Equivalent Elastic Strain 0.014964

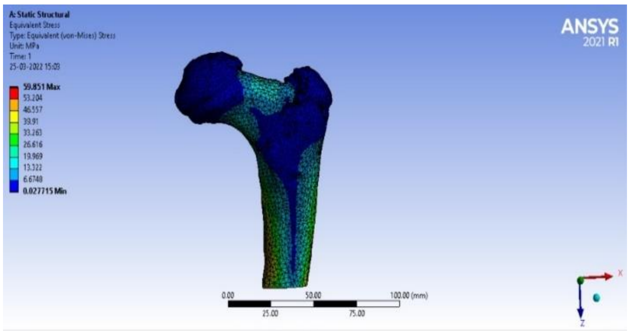


Min. Factor of Safety 0.91814

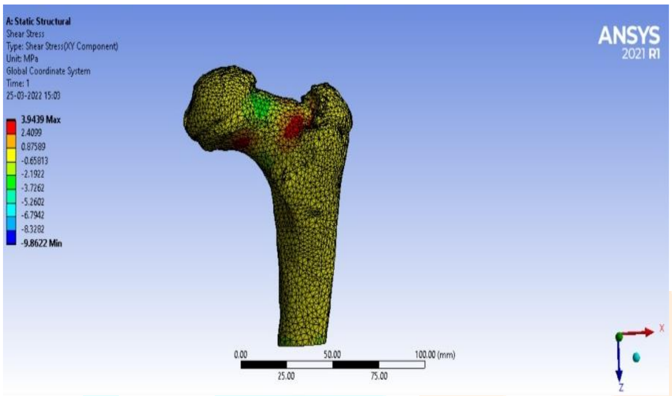
For 80 Kgs PLA



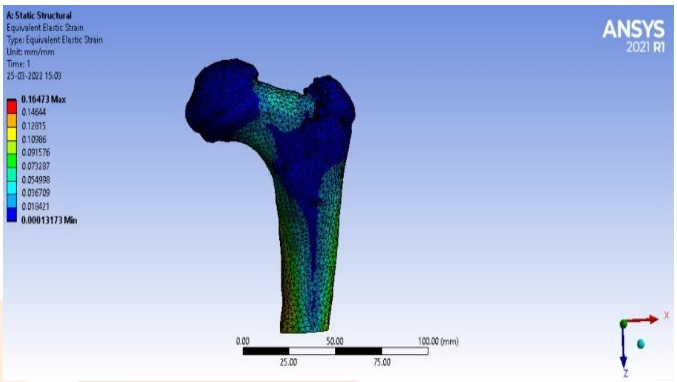
Max. Total Deformation 5.306 mm



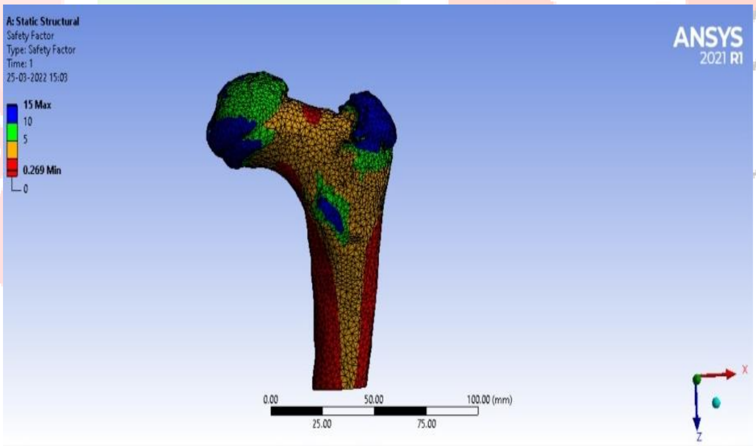
Max. Equivalent Stress 59.851 MPa



Max. Shear Stress 3.9439 MPa



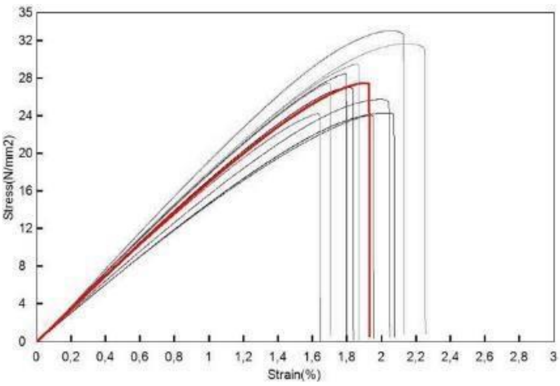
Max Equivalent Elastic Strain 0.16473



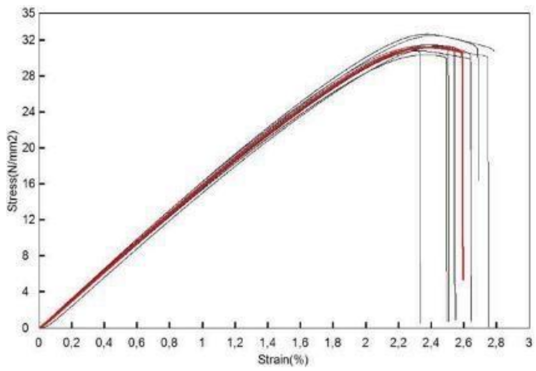
Min. Factor of Safety 0.269

5.5 Mechanical properties of PLA and ABS material: - [6] [7]

We have referred some research papers regarding the mechanical properties of PLA and ABS materials we have got some data of the different testing that they have carried out on the standard dimensional specimens of the materials. We came to know about the graphs given below for the test results of materials. In the fig 22 and fig 23 the graph is of stress vs strain properties of the material PLA and ABS.



Stress vs Strain graph of PLA



Stress vs strain graph of ABS

6. ACKNOWLEDGEMENT

Analysis can be clearly stated that the stresses or strains on a bone can be evaluated virtually with great accuracy. For modelling the patient's unaffected bone can be done by scanning it through 3D scanning as a source and then designing and analyzing it three dimensionally by using Catia and ANSYS software. In this project femur bone is modelled and analyzed with two different materials. Out of these materials used PLA have been found to have low material equivalent stress, corrosion resistance and wear resistance.

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