FABRICATION AND ANALYSIS OF HUMAN PROSTHETIC ANKLE JOINT BY USING 3D PRINTING MACHINE

[1]VARANASI MANI KUMAR, [2]BHOOMIREDDY VAMSIDHAR REDDY,
[1]M.Tech student, [2]Asstiant professor,
[1]Department of mechanical engineering,
[1]JNTUA College of Engineering, Pulivendula, Andhra Pradesh, India.

Abstract— presently days, many persons are facing problems with ankle pain Because of foot injury, bursitis, fracture of stress and wear in the ankle. Doctors choose to exchange the initial ankle with an artificial ankle to decrease the ankle pain. During the selection of the artificial ankle, the trial and error method is adopted by the doctors, which is almost similar to the original ankle. Various sets of artificial ankles of distinct dimensions that suit the patient are preferred by physicians, which expands the price of surgery as well as the time to execute the surgery. In some cases, walking comfortably is difficult for the patient because the artificial ankle is not exactly similar to the original ankle.

In this work an attempt has been made to manufacture artificial ankle joint by 3D printing technique. 3D printing offers the original potential to fabricate organized tissue constructs to repair, replaced, damaged or diseased human tissue and organs. MRI scan digital images of ankle are taken and these images are converted to 3D printing language using 3D Slicer software. Dimensions of the artificial ankle, which are suitable for the patient are identified by using 3D slicer software and print the suitable ankle for the patient using 3D printing machine with PLA filament. If the 3D printed ankle is suitable for replacement, artificial ankle with Ti-6Al-4V material can be manufactured as per the dimensions of 3D printed model. By doing these the ordering cost as well as processing time can be reduced, further time consuming to replace artificial ankles and total operation cost can be reduced, so that the patient can walk comfortably as compared to traditional method.

Keywords: Human Leg, 3D Printing machine. 3D Slicer Software, 3D Tool, CATIA V5 Software, Ansys software.

I. INTRODUCTION

Additive Manufacturing is a system of joining materials to make items from 3-D model data, generally layer upon layer. The fundamental precept of this technology is that a version, initially generated using a three-D CAD version, may be fabricated without delay without the need for system planning. Now a day's RP performs a crucial position in manufacturing area, to lower the cost and time of the product to be produce.

The 3D printing method is an additive manufacturing method. From here on, the method of printing varies with the use of development, starting from industrial printers that break down a plastic cloth and place it on the printing stage to large modern machines that use a laser to specially condense steel powder at an excessive temperature.

II. LITERATURE SURVEY

Ankle replacement or ankle replacement surgery is used to substitute the damaged joint surfaces of the human ankle with prosthetic sections. This method is transformed into decision-making therapy for patients, supplanting frequent use of arthrodesis, e.g. bone combinations. The restoration of the range of motion is a main component for the replacement of the ankles as well as for arthrodesis.

The historical background of total ankle arthroplasties go back to the 1970s with a rise in importance of total hip and total knee replacement. A total ankle replacement was felt to be a simple thing and a few different structures were discharged. These were solidified prostheses, all in all two-section segments that were very non-anatomic. With present moment follow-up a portion of these ankles progressed nicely yet in halfway follow-up of even four or five years they started to come up short. By the mid-1980s total ankle replacement in the United States was not being finished. A significant number of these ankles were later intertwined as a rescue strategy. Along these lines over a fifteen to multi-year time span, ankle combination was extremely the main decision for patients with serious joint inflammation of the ankle.

Stefancatalin. P.et.al [1] has created an effort to build orthopaedic prosthetic ankles by rapid prototyping. This article described the benefits of rapid prototyping for orthopaedic prosthesis compared to the present manufacturing method. Explained the dimensional reconstruction and anatomical ankle system modeling technique based on the analysis and processing of images, graphic representations using 3D anatomical ankle model and using this model for the implementation of ankle prostheses 3D printing technique. The use of rapid prototyping in orthopaedic prostheses has resulted in an advantage for the quality of work, reducing costs. Of execution and in terms of meeting needs of each patient.

Kranthi nagaraju.K.et.al [2] made an attempt to modeling and structural analysis on artificial ankle joint under various loading conditions. SS316L are used presently. This paper proposed co-cr-mo alloy,Ti-6Al-4v alloys are used as implant material in ankle replacement surgery.Ti based alloys are used in many applications of biomaterials due to their excellent mechanical, physical and biological performance.by considering a finite element model of the implant will be developed to study the model developed by CATIAV5 software. The analysis of fe using ANSYS software of the implant. This paper proved that Ti-13NB-13ZR-produce less stress compared to other 2 material by applying the static and model analysis, because of low young's modulus.

III. PROBLEM STATEMENT

The ankle is a weight-bearing joint and carries the complete weight of the body, so it is very essential to treat a painful ankle. Severe ankle pain may be debilitating, and this is where ankle replacement surgery comes in. Ankle replacement is an solution to arthrodesis for chosen patients (Figure). It is an appropriate pain relief alternative and is only used when conservative techniques of pain relief or ankle deformities are ineffective. The benefit of replacing the ankle is the maintenance of motion and function. This may also lead to changes in gait, including the decrease of limp and the preservation of other joints. Multiple methods that are used for ankle replacement surgery to relieve pain and restore stability are discussed in the following chapter.

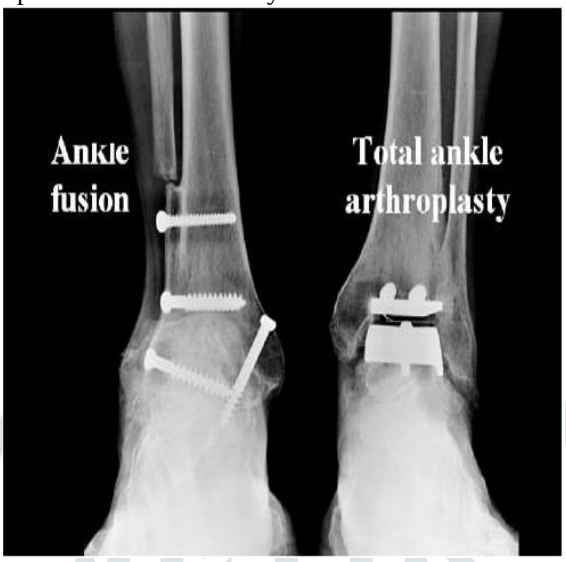


Fig:1 Human ankle joint

IV.PROBLEM SOLUTION

Additive Manufacturing is the process in which material will lay up layer by layer to produce the required part. Additive Manufacturing is also called as 3D printing. 3D printing is aid for prototyping industry. 3D printing has new and growing specialized social and monetary effect especially in prototyping. 3D printing permits mass customization in industries like car, health care's aviation, training, customized blessings and shopper parts. Prototyping is the main one which utilizes 3D printing. 3D printing machines produces physical items layer by layer to fabricate the required 3D model. It can make physical model as per structure, model might be made in Modeling software's CATIA, PRO-E, SOLIDWORKS, AUTOCAD and so on. 3D model is converted into .STL format. As indicated by the .STL file 3D printing machine going to print the part.

V.EXPERMENTAL PROCEDURE

A.3D SLICER:

3D slicer is a free software package which is open source. It is a modular visualization and analysis platform for images. 3D Slicer can be expanded to allow interactive and batch processing tools to be designed for a wide variety of tasks. In the medical industry, 3D slicer plays an major role; especially in orthopedics, and recognizes cracks and bone defects. For physicians, 3D slicer is very helpful to conduct surgery and decreases the time of surgery.

1)3D Slicer Work Bench:

• Using FILE–IMORT–DICOM–OK, DICOM information is transmitted into 3D slicer software.
• Importing the DICOM file into 3D slicer software displays 2D images.

2) Rendering volume:

• Digital 2D information can be converted to 3D information in the first step by clicking the rendering volume. On the correct side of the screen, 3D information is visible.
• Click this option and select CT MIP again, then display the bones in 3D image.

3) Crop quantity:

• Select the human ankle joint part of this job by clicking on the crop icon again.

4) Creating label and building model:

•After cropping is done labels should be generated by using the editor tool to create 3D model. The 3D model should be saved in a .STL (Standard Tessellation) format.

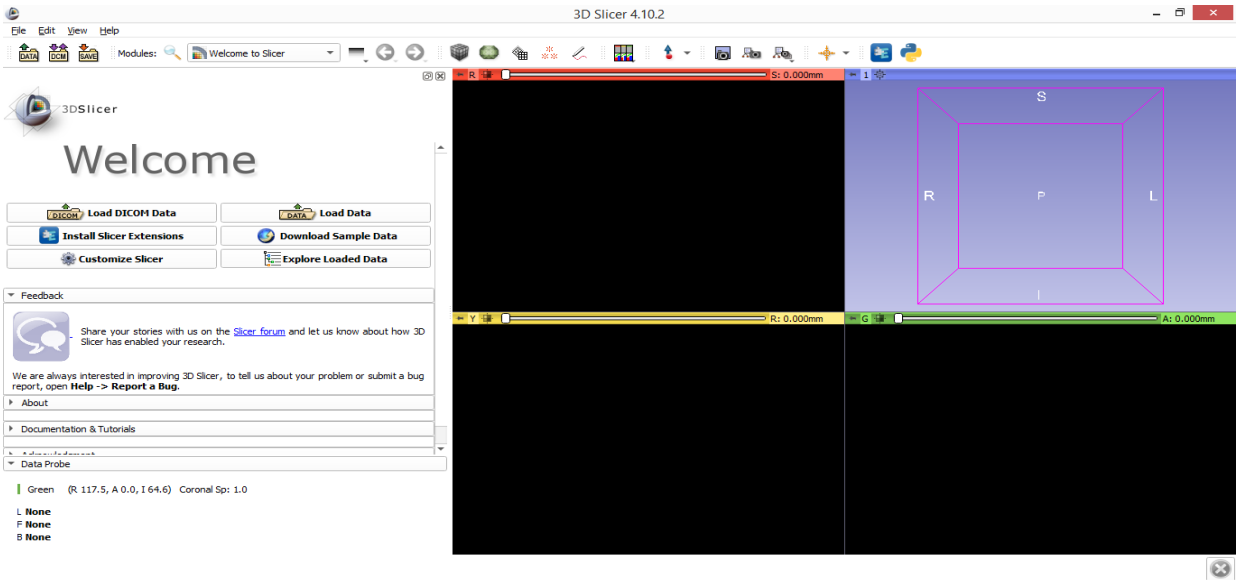


Fig: 2 3D Slicer home window

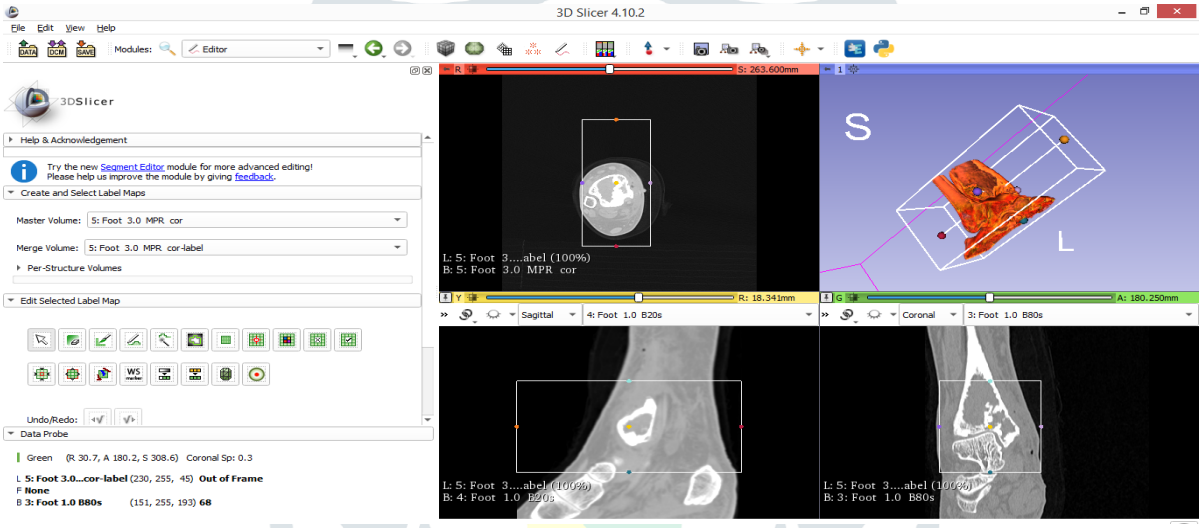


Fig 3: Loading and saving condition in 3D slicer software.

3D-tool

The 3D-Tool Free Viewer bolsters the 3D-Tool EXE and DDD document arrange and the .STL design. It isn't conceivable to stack in excess of one model at any given moment.

3D-Tool is an expert CAD-Viewer for 3D-models and 2D-illustrations. To gauge separations, edges, radii and divider thicknesses and also to make cross areas and detonated sees

Load .STL file Begin :3D-Tool, and utilize Open capacity in the Data file tab or snap Open in the Quick Access Toolbar. At that point choose the files with the File open exchange, and snap Open. .

.**Distance**: Measure the partition or the edge among two references dependent on the sort and area of the references.

Measure and Mark up: Utilize the Measure/Mark up device to include 3D measurements and stamp ups to the parts, and pictures and content to the foundation. The Measure/Mark up instrument is situated in the Tools gathering of the 3D-Mode tab.

Measure Angle, Edge, Distance, Wall Thickness and Clearance: Measure separations, edges, edges, limit boxes, divider thickness, and clearances. Tap the Measure/Mark up instrument in the Tools gathering. Tap the Angle catch to gauge separations and points or tap the small dark bolt in the catch to choose some other measure work

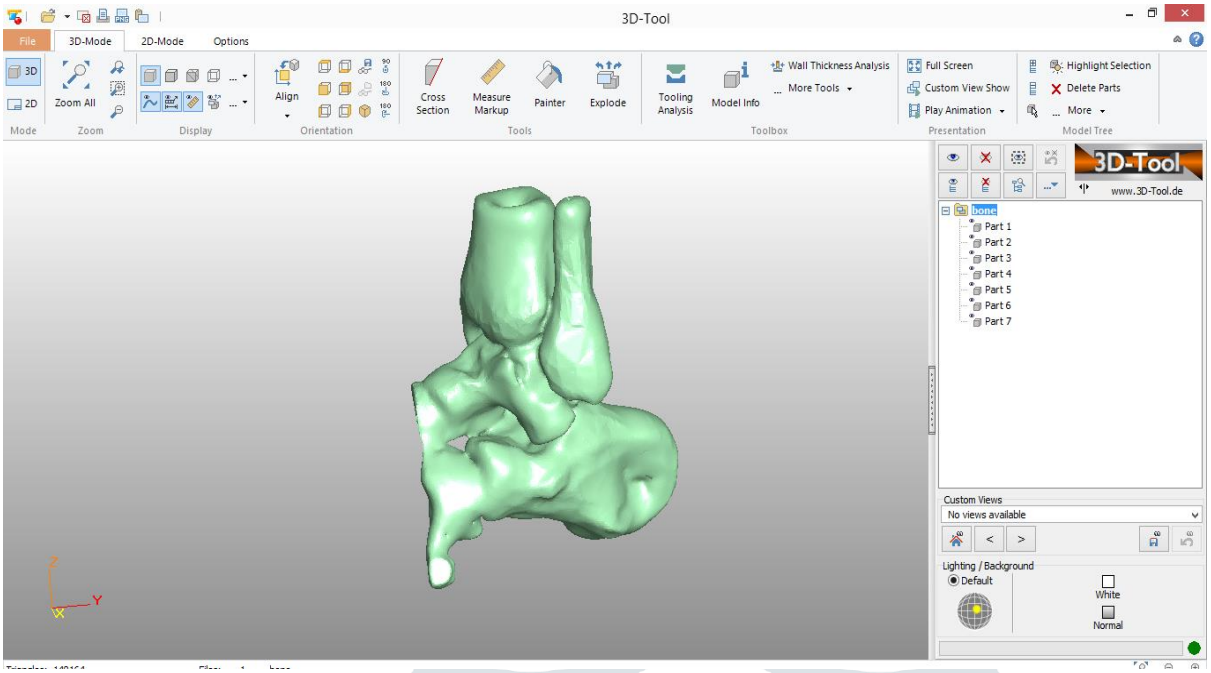


Fig.4 loading ankle joint .stl file in 3D tool software

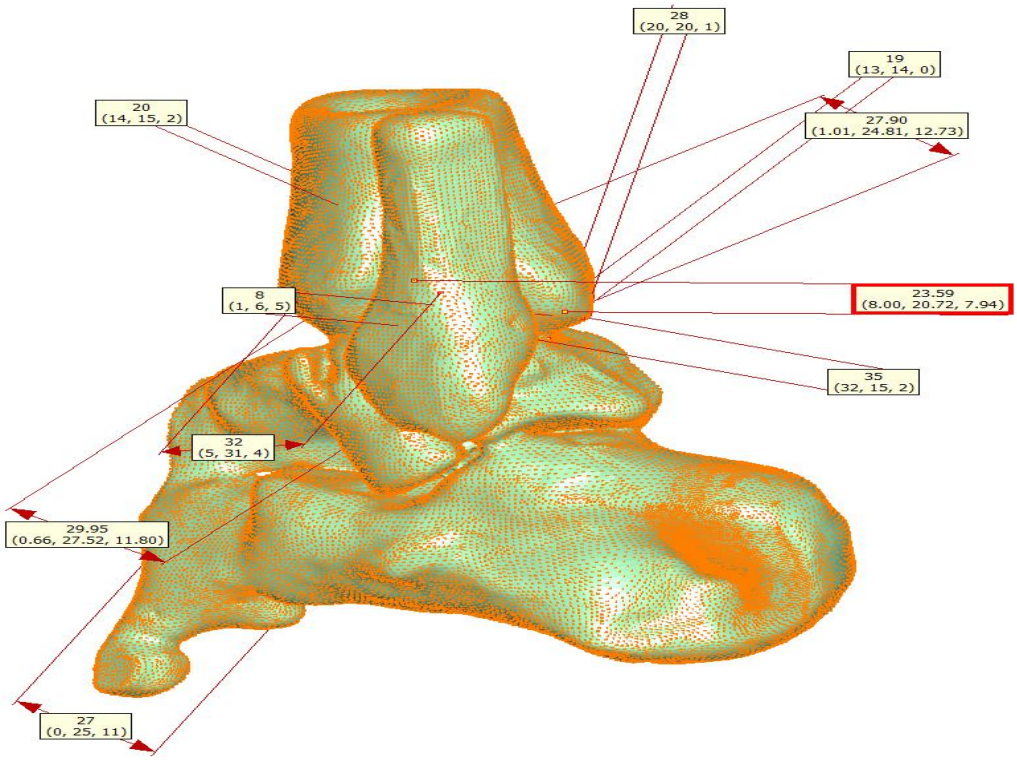


Fig.4 measurements of ankle joint in 3D tool software

1) CATIA

CATIA is an abbreviation for a computer-aided three-dimensional interactive application. It is the most capable, ground-breaking and highly-famous CAD, e.g. the PC-supported programming plan. It is produced, generated and claimed by Dassault Systems of France. IBM was CATIA's primary advertiser until 2010. In view of its elevated level of comfort, CATIA's assertion is one of the most prominent and desired confirmation on the market.

Application of CATIA

Apparatuses, Aviation, Engineering, Development, Car, Buyer Goods, Medicinal, Gadgets, Form and Die, Furniture, Apparatus Protection, Shipbuilding

1. Open the CATIA by double click on CATIA icon on desktop
2. Select start-- mechanical design -- part design -- in the new part dialogue box check “enable hybrid design”—enter the part name as part—click ok

•The 3D model should be saved in a .STL (Standard Tessellation) format

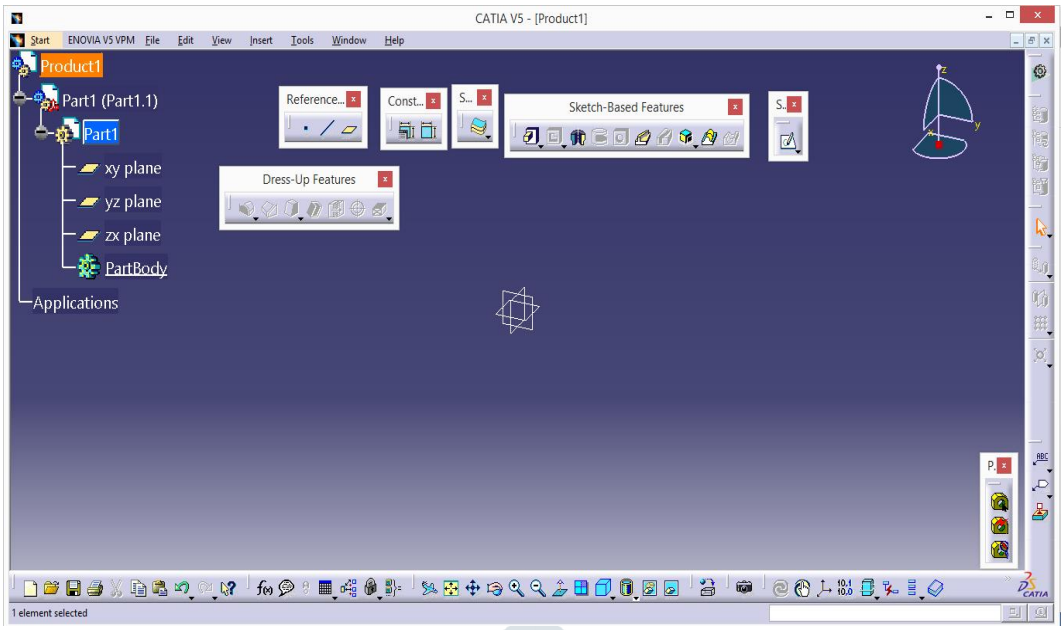


Fig: 5 Home window of CATIA V5 SOFTWARE

The S.T.A.R Ankle system includes three functional components. The three principal components of the prosthesis are:

1. A tibial component
2. A mobile bearing
3. A Talar component

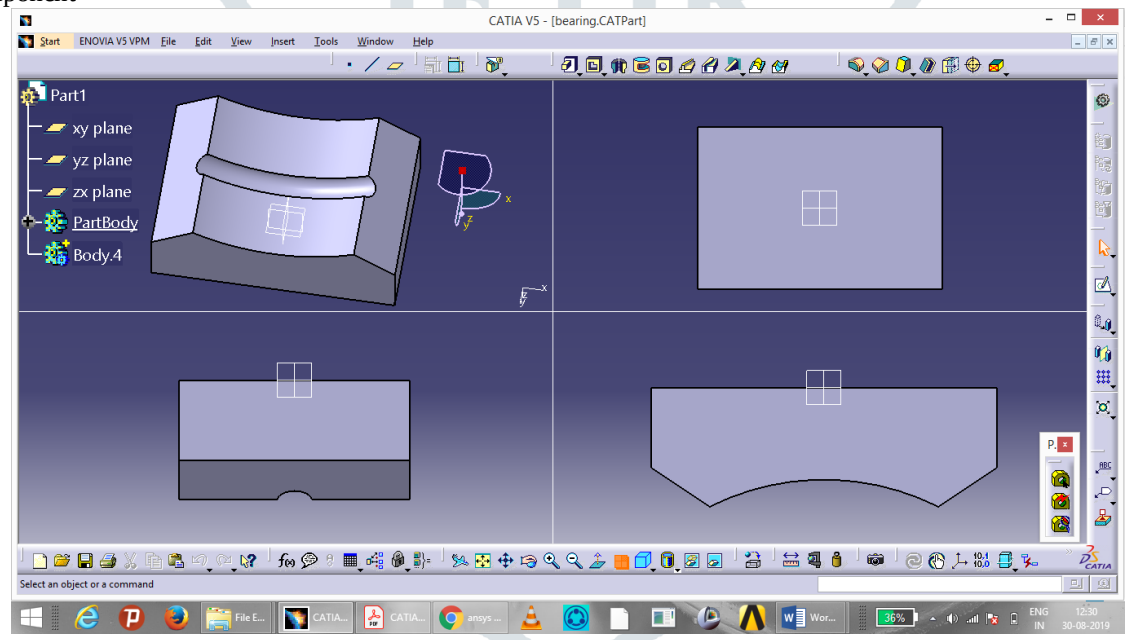


Fig: 6 A mobile bearing

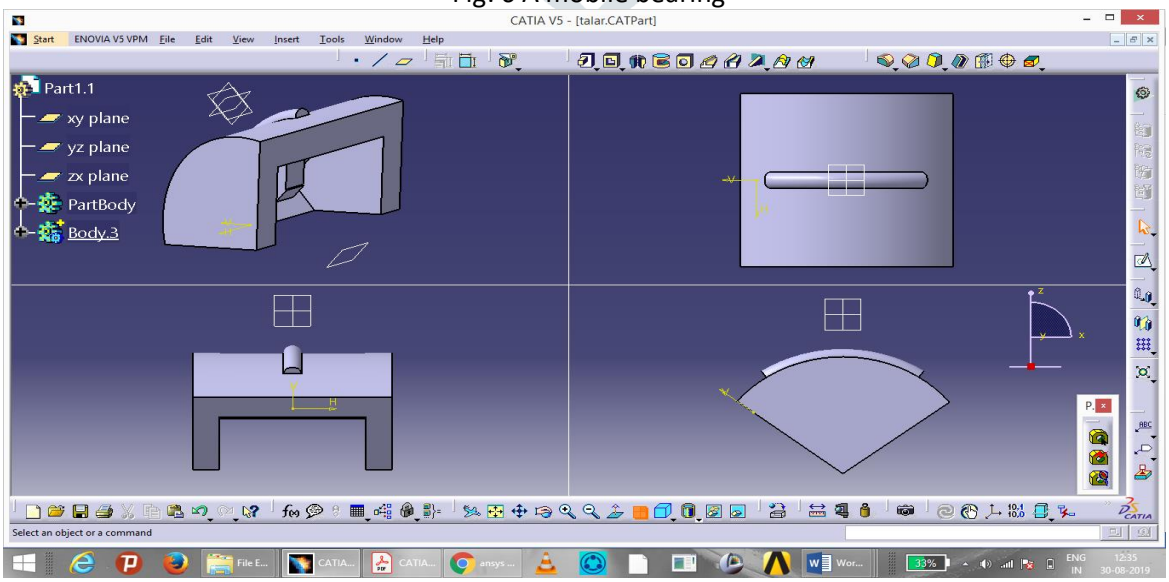


Fig:7 A Talar component

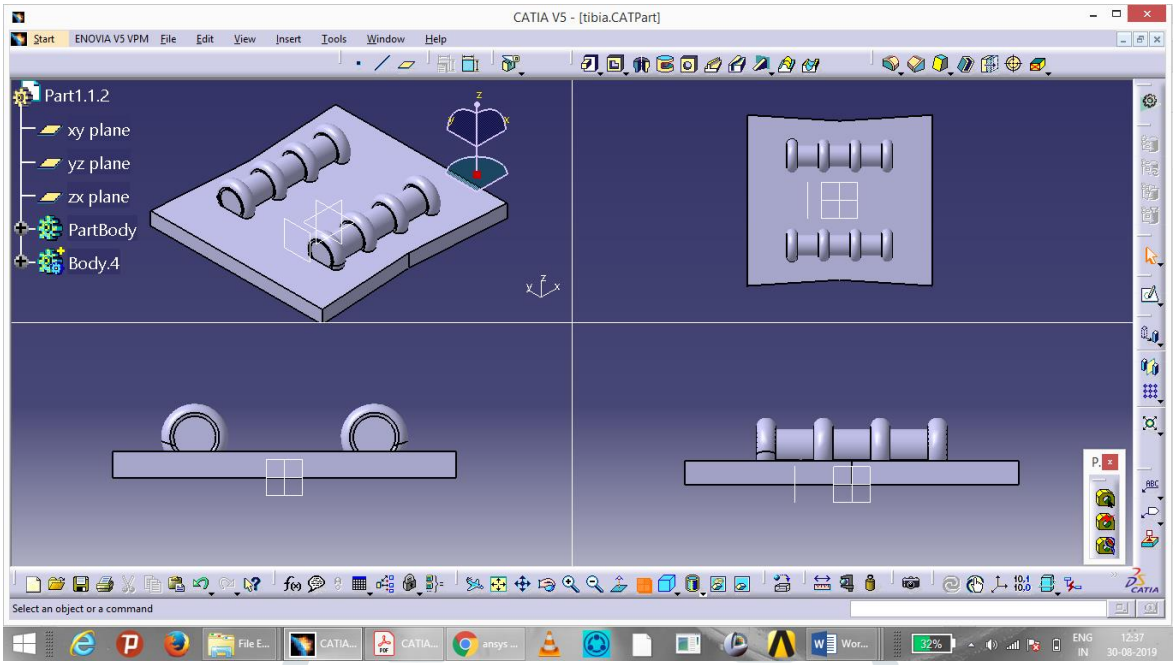


Fig: 8 tibial component

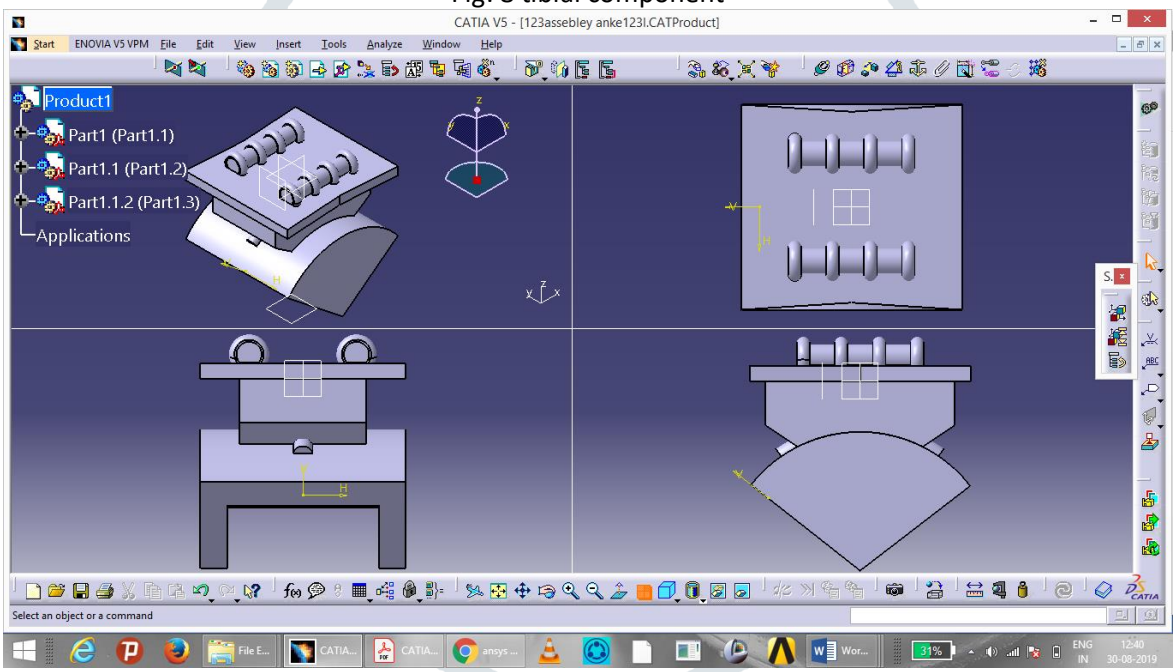


Fig: 9 Assembled ankle joint

B.3D PRINTING:

3D printing is a method of Additive manufacturing. In which 3D model is produced by adding layer by layer of material. It plays a very important role in orthodontics, bone replacements and other surgeries in the medical industry. It reduces the cost and time of the operation. In a short time, complex geometric models were also manufactured.

- In the fracktory software, load the. STL file.
- Provide the desired model printing requirements.
- Save the external device data and load it into a 3D printing machine.
- Print the model with properties of PLA filaments.

1) PLA filament printing requirements in FDM machines: printing conditions for the imported. STL documents on a 3D printing machine.

The printing requirements for PLA material is as follows for the imported. STL files on 3D printing machine.

PROPERTIES	PRINTING CONDITIONS
Height of the layer	0.1mm
Top/bottom thickness	1.2mm
Shell thickness	1.2mm
Nozzle temperature	215^0c
Bed temperature	60^0c
Fill density	80%
Filament flow	100%

Table 1: Printing conditions for PLA material

- The saved .STL files are loaded into fracktory workbench as shown in below figure

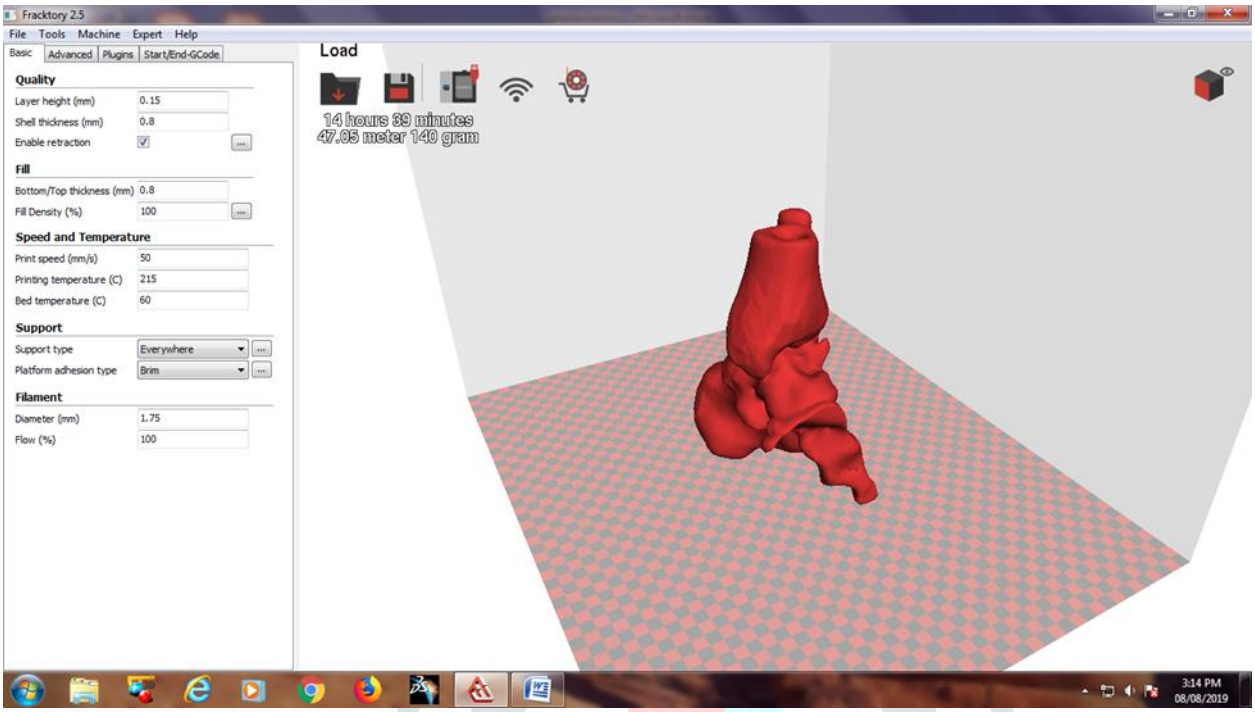


Fig: 10 natural ankle joint in fracktory workbench

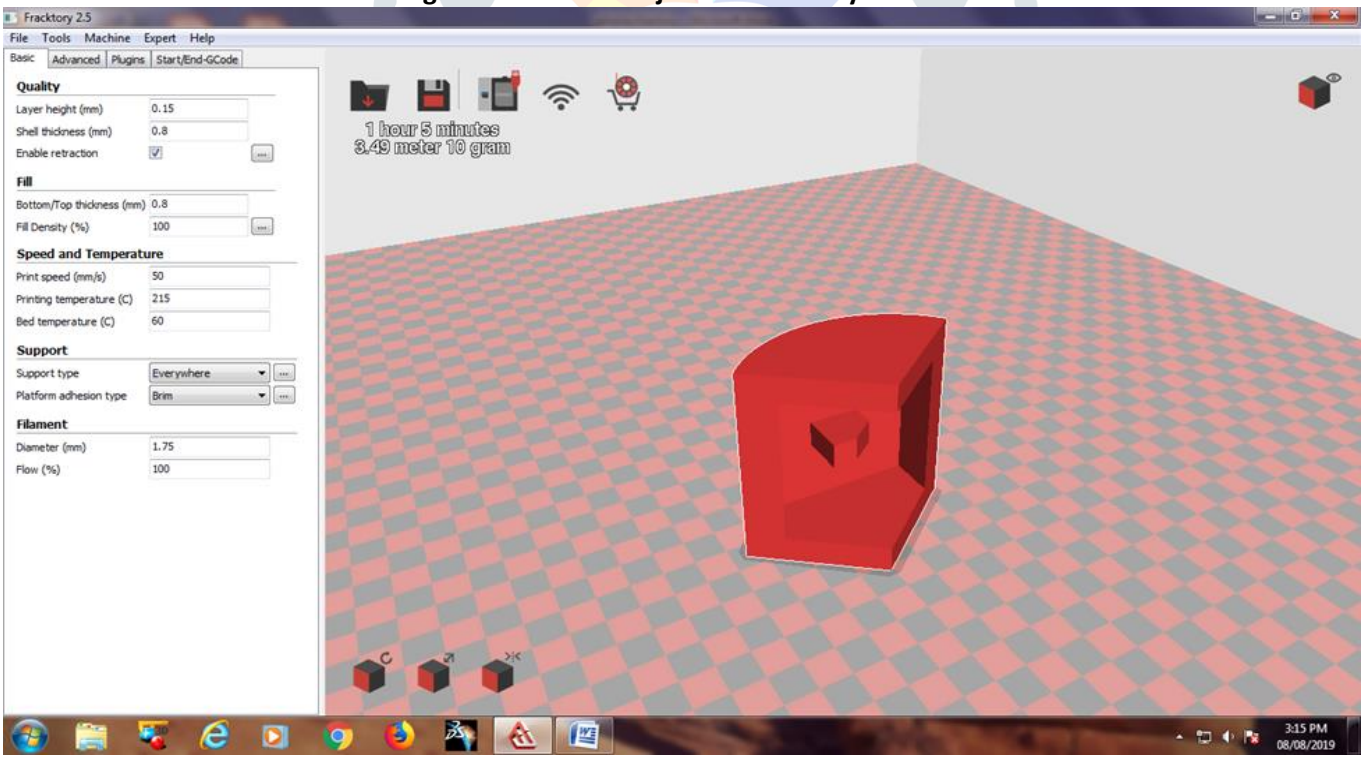


Fig: 11 Talar component in fracktory work bench

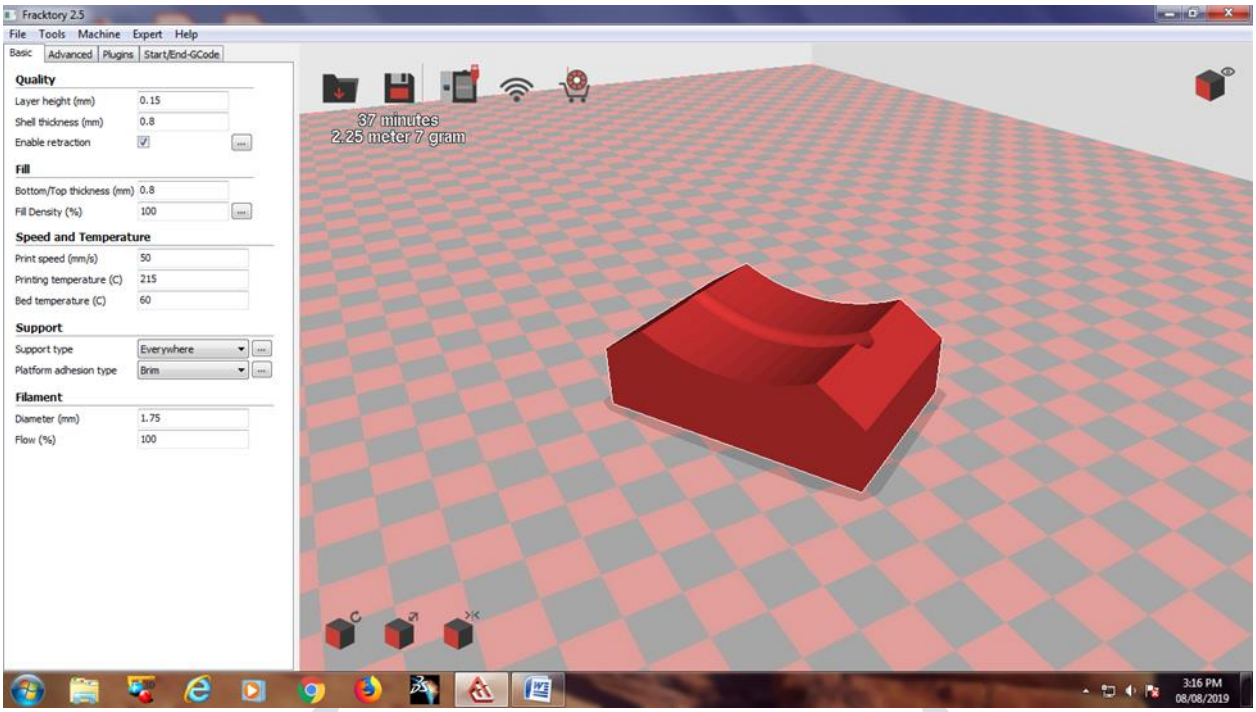


Fig: 12 mobile bearing component in fracktory software work bench

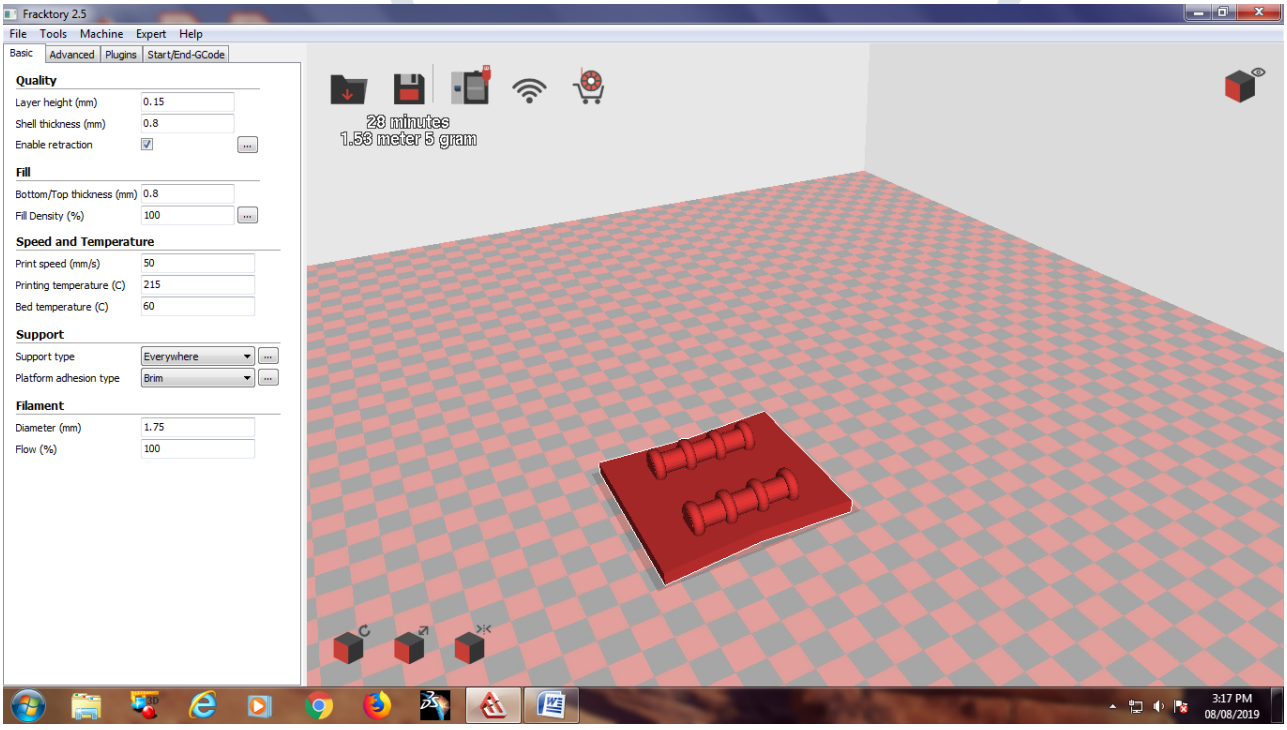


Fig: 13 tibial component in fracktory software work bench

•Then adjust the printing conditions for PLA material mentioned in the table.

•Artificial ankle joint implants are printed with PLA material.

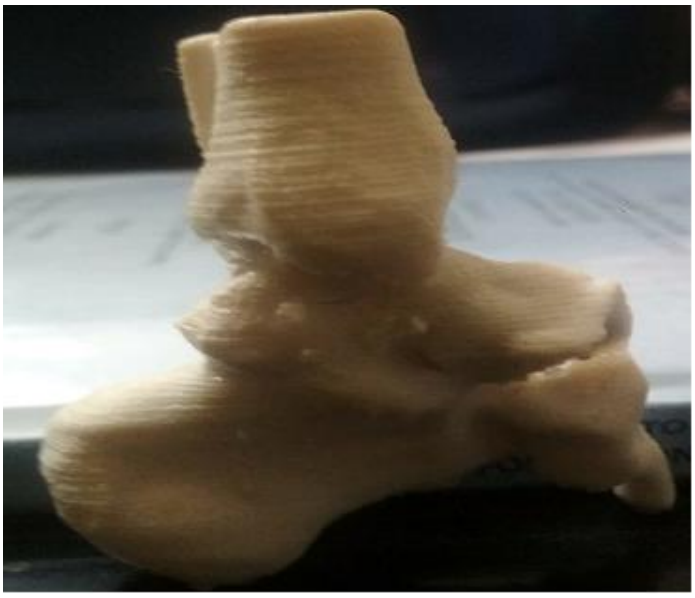


Fig:14 natural ankle joint

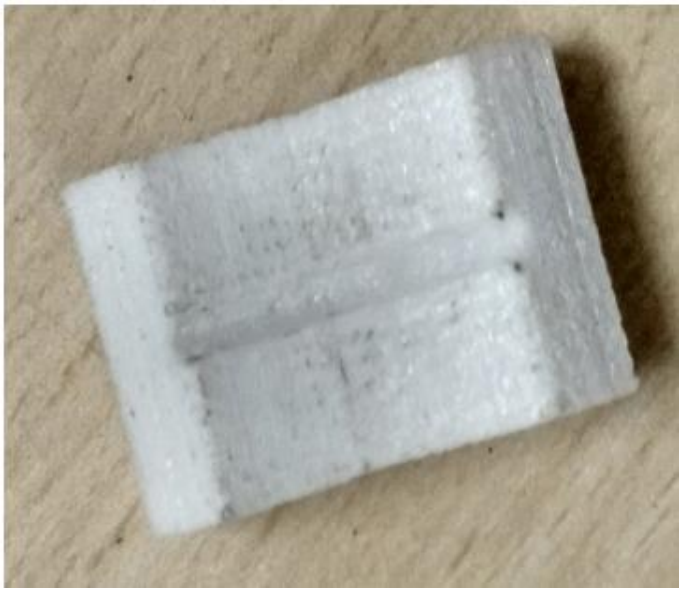


fig:15 mobile bearing component

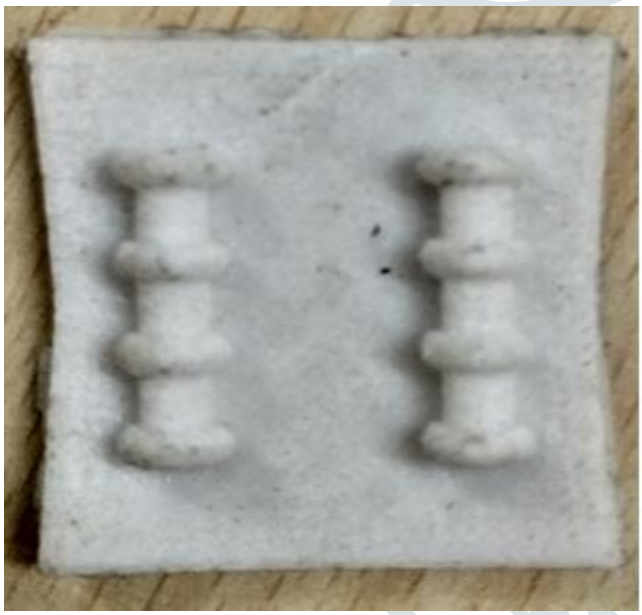


Fig:16 tibial component

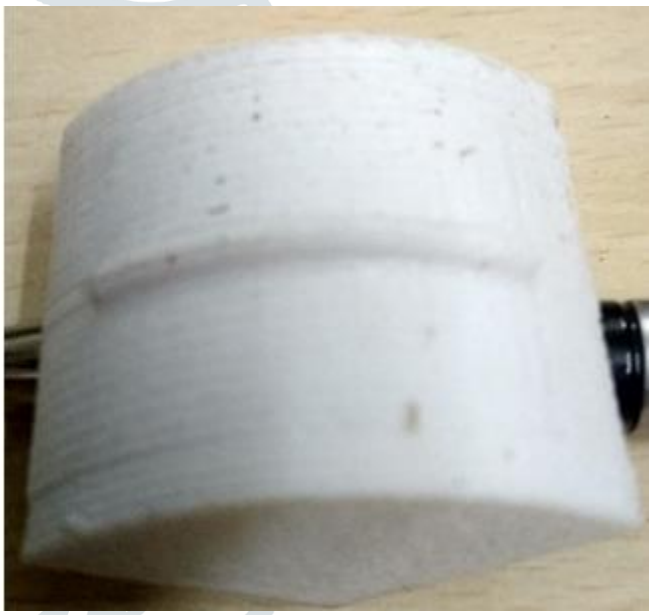


Fig: 17 talar component

Fig: 18 assembled ankle joint

VI.LINEAR AND NON-LINEAR ANALYSIS

ANSYS

ANSYS Mechanical is an instrument for analysis of finite elements for structural evaluation, including linear, nonlinear and dynamic analyses. This product for computer simulation offers finite elements for modeling behaviour and supports material models and equation solvers for a wide variety of product design tasks.

How does ANSYS work?

•Pre Processor

•FEA Solver

•Post Processor

Pre Processor	**FEA Solver**	**Post Processor**
Create solid model Create FEA model Define Material Properties Element Types Meshing (Free or Mapped) Loads & Boundary Conditions	Function of the solver is to solve the system of linear simultaneous equations Form stiffness matrix for each element Assemble the global stiffness matrix Solve matrix equation Find displacement Calculate strain & stress	To review results of the analysis Two postprocessors: 1) General Postprocessor 2) Time-History Postprocessor Represented in the form of a table, graph, contour plot, deformed shape or mode shapes of component & animation

Table 2 FEA PROCEDURE

LINEAR ANALYSIS

A linear static analysis is an evaluation where the applied forces and displacements have a linear relationship. The stiffness matrix of the model is steady in a linear static analysis, and the method of solving is comparatively brief compared to a nonlinear analysis on the same model.

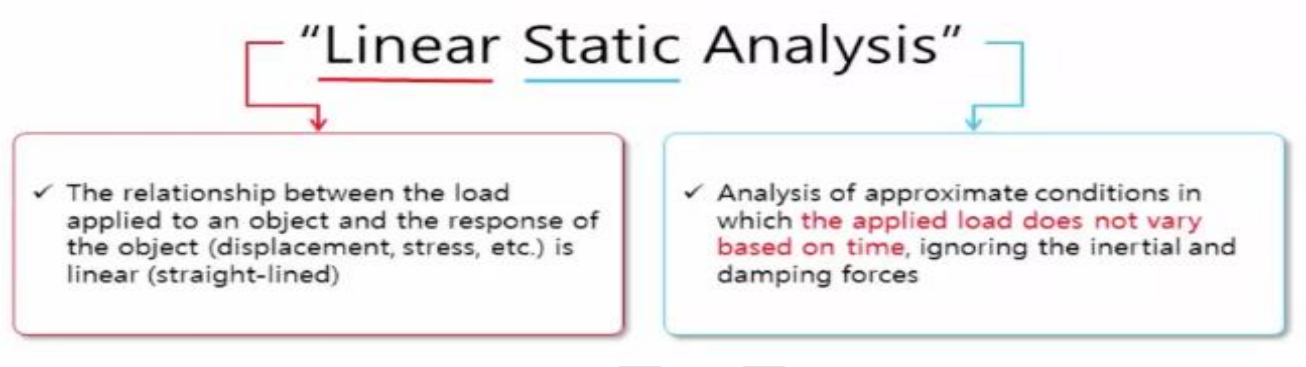


Fig: 19 linear static analysis

Material properties:

PROPERTEY	**ABS**	**PLA**	**CO-CR-MO**	**Ti-6Al-4v**
Young's modulus(MPa)	2600	3500	21000	113
Density(g/cm3)	1.4	1.3	8.3	4.512
Poisson's ratio	0.35	0.35	0.29	0.37
Ultimate tensile strength(MPa)	89	37	655	950

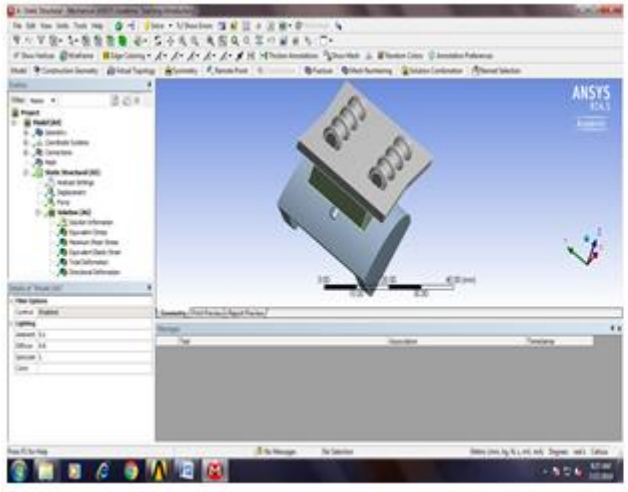


Fig : 20 ankle joint imported ansys work bench

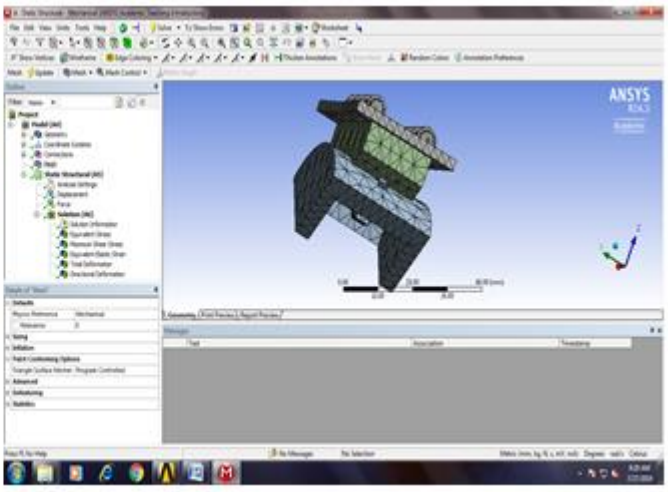


Fig: 21 ankle joint mesh generation in ansys work bench

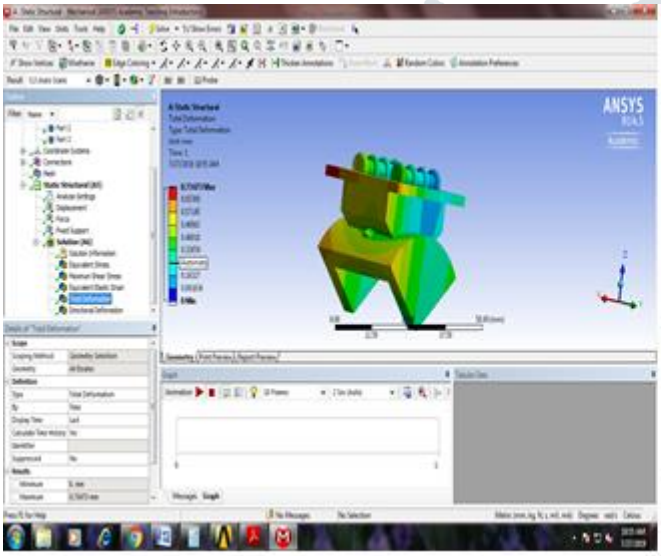


Fig: 22 Von-mises stress

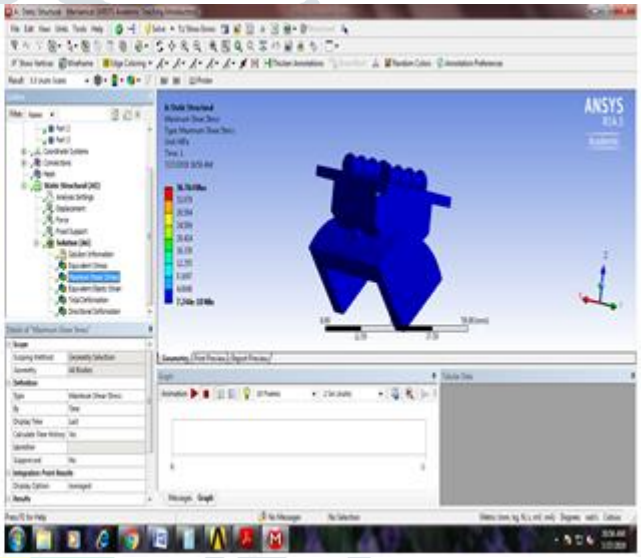


Fig:23 Shear stress

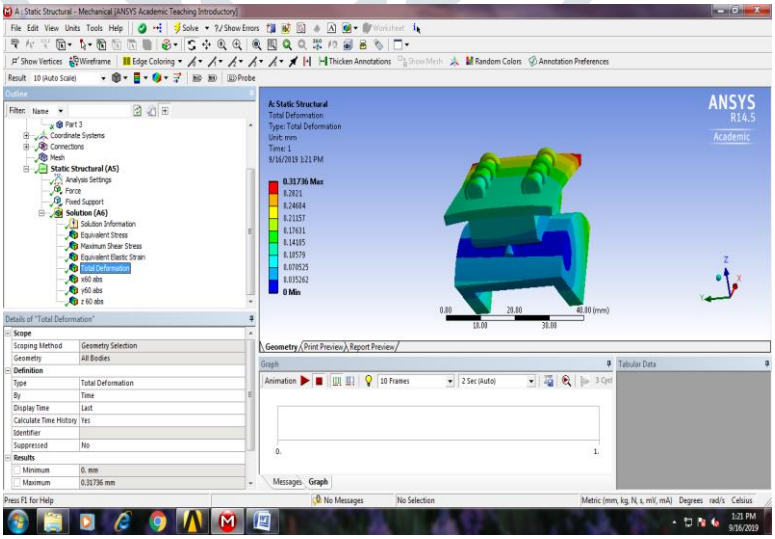
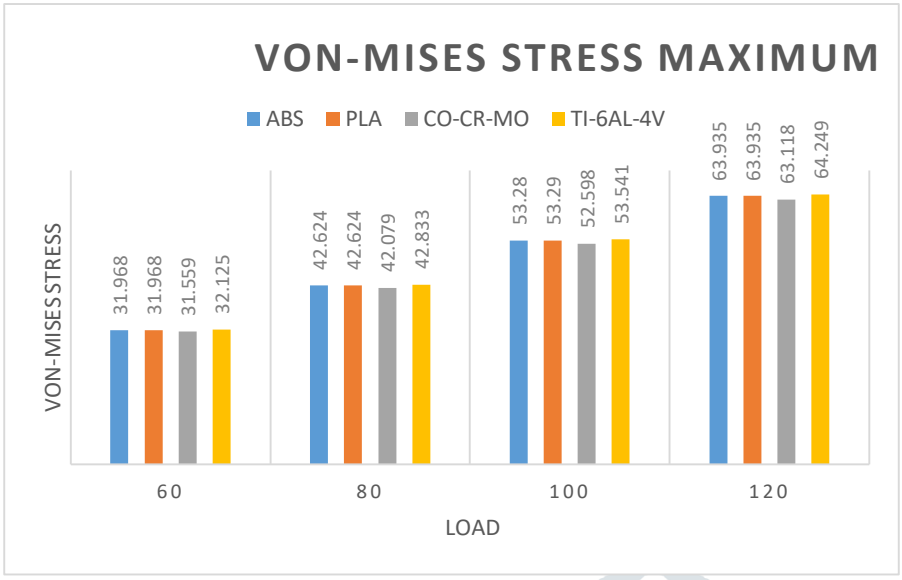


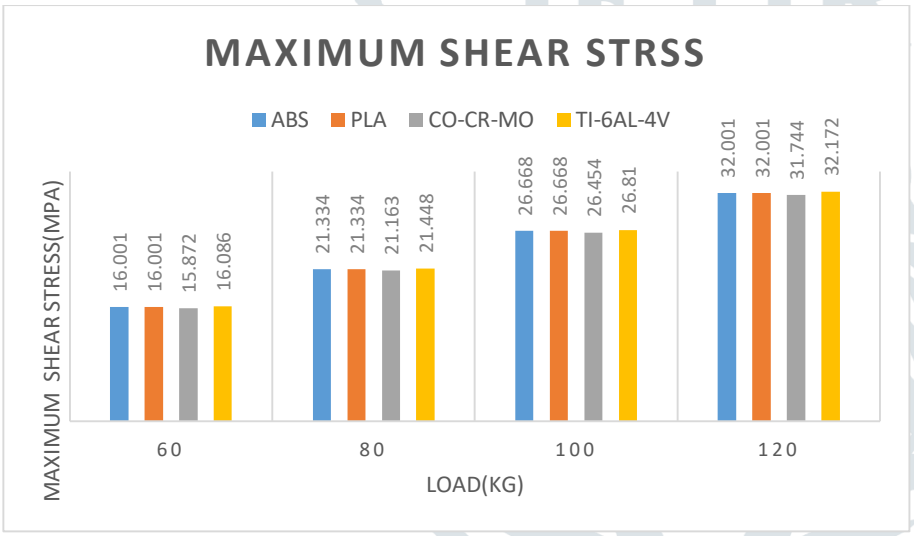
Fig:24 total deformation

Von-mises stress maximum



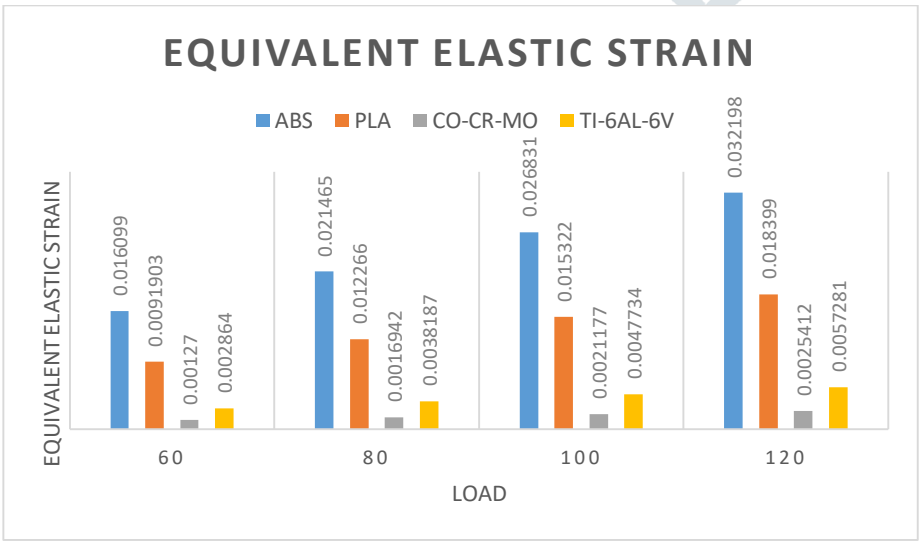
Graph: 1

Maximum shear stress



Graph: 2

Equivalent elastic strain



Graph: 3

NON-LINEAR ANALYSIS

The Stiffness matrix keeps on changing, it gives rise to a Non Linear Simulation. In addition to the stiffness matrix being non - constant, it has to be calculated multiple times in the course of the non-linear analysis. Non Linear analysis is solved by Newton Raphson technique and it requires multiple iterations in each incrementation to arrive at a converged result.

Non linearity kinds in FEA are

1. Non-linearity of geometry
2. Non-linearity of materials
3. Boundary Conditions Non-Linearity

PROCEDURE FOR NON-LINEAR ANALYSIS:

- First import the teeth solid model in the working platform of ANSYS.
- Give the required material properties of PLA.
- Generate the 3D mesh by using meshing.
- After meshing the load is applied boundary conditions on the solid part.
- After loading we have to go to solutions.
- Finally go to results.

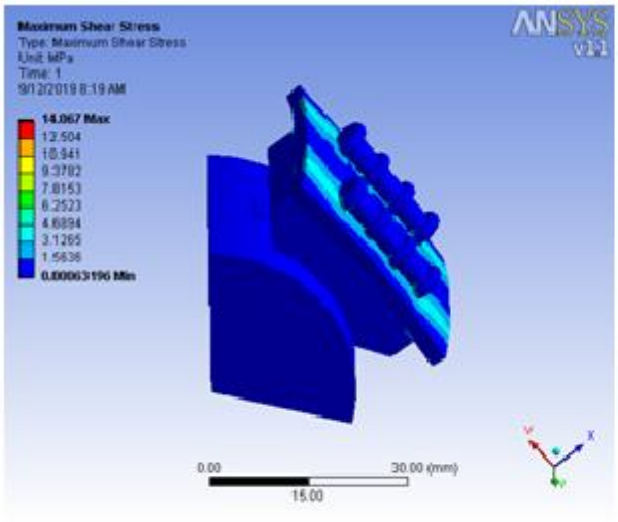


Fig: 25 Maximum shear stress

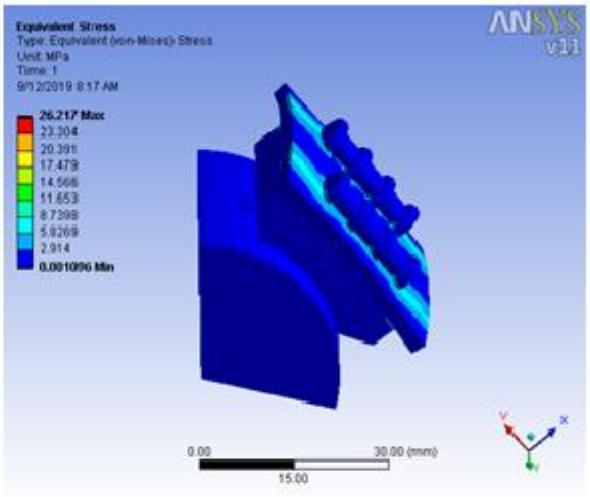


Fig: 26 von-Mises stress

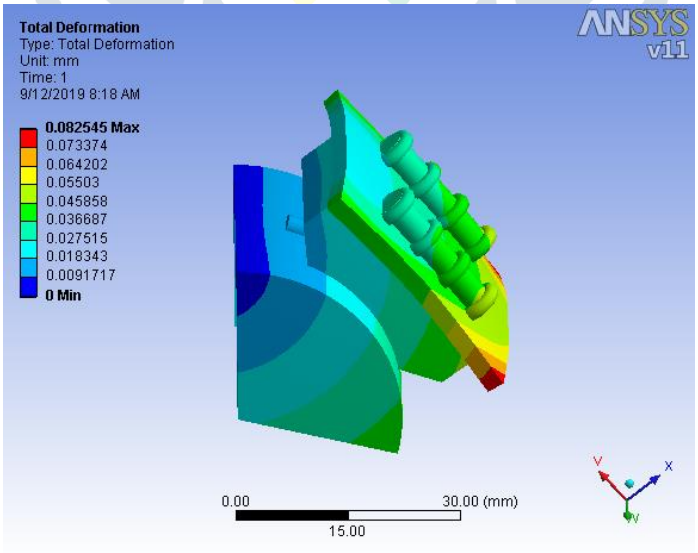
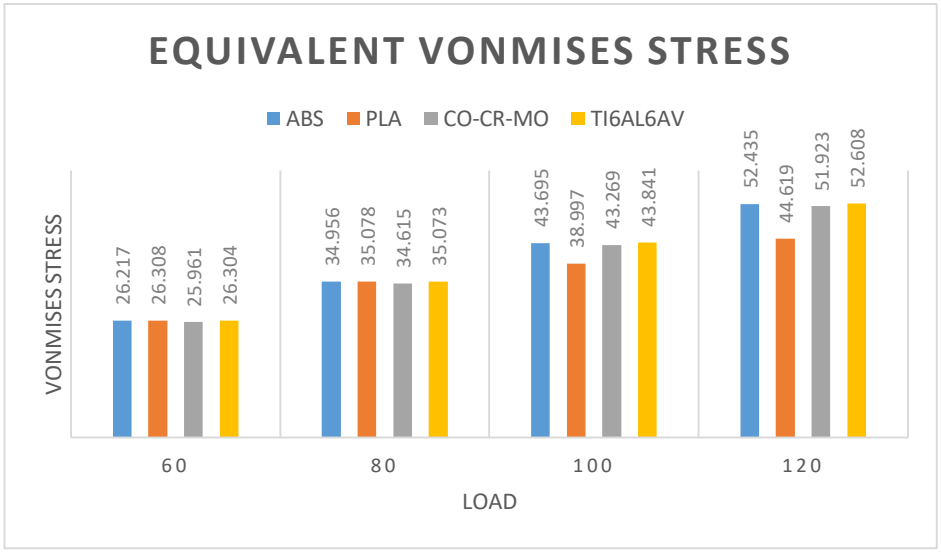


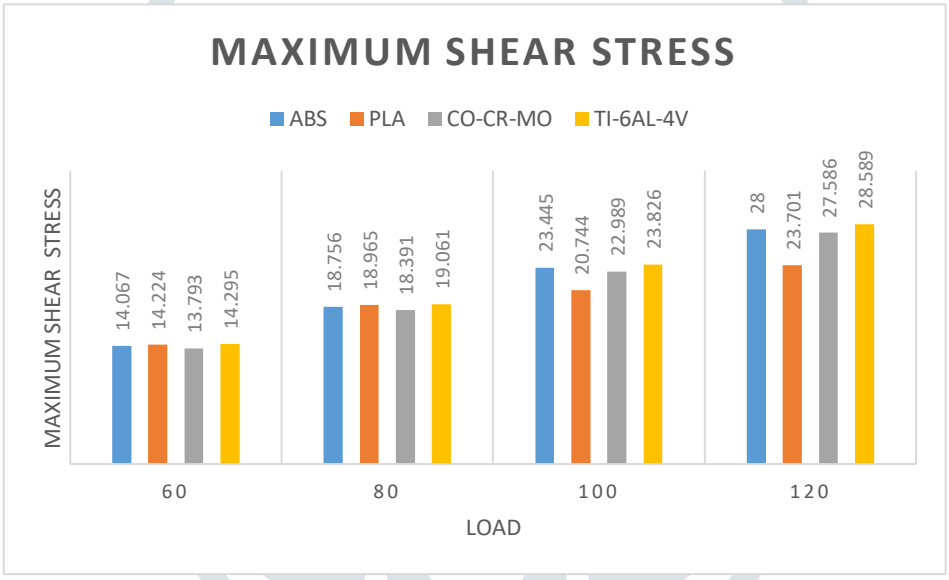
Fig: 27 Total Deformation

EQUIVALENT VONMISES STRESS



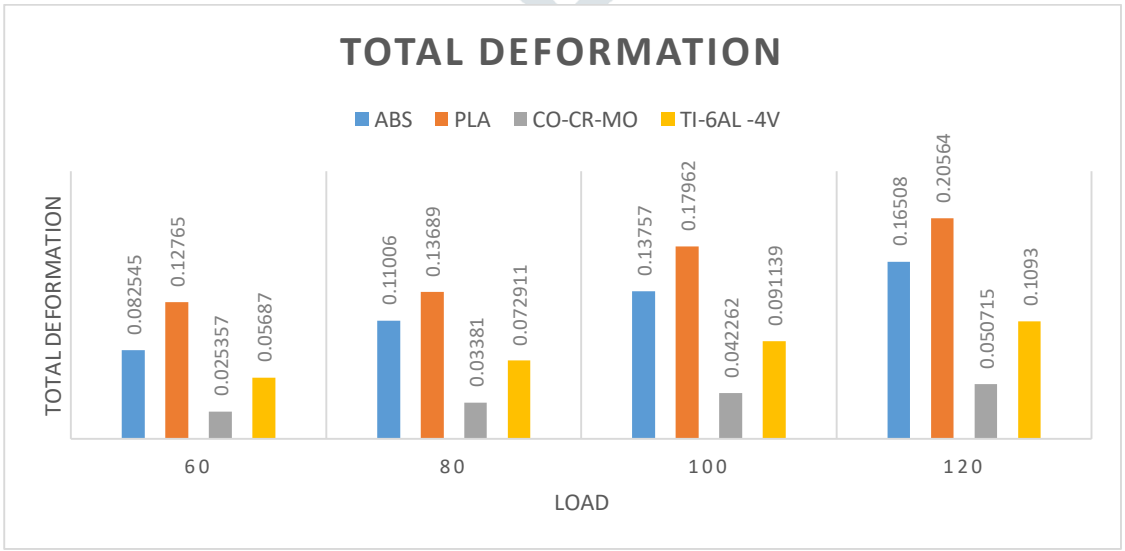
Graph: 4

MAXIMUM SHEAR STRESS



Graph: 5

TOTAL DEFORMATION



Graph: 6

VII.RESULT AND DISCUSSIONS

In this work an attempt has been made to manufacture artificial Human Ankle joint by 3D printing technique. CT/MRI scan digital images of human leg are taken and these images are converted to 3D printing language using 3D Slicer. Design the Tibial component, mobile bearing and Talar component by using CATIA V5 software. The artificial ankle joint implant is printed by 3D printing machine through PLA filament. The 3D printed Ankle joint implant is used mainly for medical demonstration. Artificial teeth implant with Titanium alloy and co-cr-mo alloy materials can be manufactured traditional method as per the dimensions requires more cost and time required. By doing these the ordering cost as well as processing time can be reduced. And compare maximum stress, total deformation, and maximum shear stress of a PLA and ABS with alloy material Ti-6Al-4v and Co-Cr-Mo.

Both static linear and non-linear analysis executed

Linear analysis

Among the static structural liner analysis, considered on material ABS material exhibited the maximum stress 63.935MPa, shear stress 32.001MPa and total deformation 0.63472mm at 120 kg load.

Among the static structural liner analysis, considered on material PLA material exhibited the maximum stress 63.935MPa, shear stress 32.001MPa and total deformation 0.3627mm at 120 kg load.

Among the static structural liner analysis, considered on material Co-Cr-Mo alloy material exhibited the maximum stress 63.118MPa, shear stress 31.744MPa and total deformation 0.5259mm at 120 kg load.

Among the static structural liner analysis, considered on material Ti-6Al-4V alloy material exhibited the maximum stress 64.249MPa, shear stress 32.172MPa and total deformation 0.1108mm at 120 kg load

Non-linear analysis

Among the static structural liner analysis, considered on material ABS material exhibited the maximum stress 52.435MPa, shear stress 28MPa and total deformation 0.16508mm at 120 kg load

Among the static structural liner analysis, considered on material PLA material exhibited the maximum stress 44.619MPa, shear stress 23.701MPa and total deformation 0.3564mm at 120 kg load

Among the static structural liner analysis, considered on material Co-Cr-Mo alloy material exhibited the maximum stress 51.923MPa, shear stress 27.586MPa and total deformation 0.050712mm at 120 kg load

Among the static structural liner analysis, considered on material Ti-6Al-4V alloy material exhibited the maximum stress 52.608MPa, shear stress 28.589MPa and total deformation 0.1093mm at 120 kg load

We conclude that PLA is light weight and better material suitable for artificial ankle joint implant

VIII.CONCLUSIONS

In this job an effort was produced by 3D printing method to manufacture artificial Human Ankle Joint Implant. 3D printing provides initial prospects for the manufacture of structured tissue buildings. Digital human Leg CT scanning pictures are taken and these pictures are transformed to 3D printing language using 3D Slicer and dimensions are measure by using 3d tool. After design by using CATIA V5. The Human Ankle joint is printed through PLA filament by a 3D printing device. This prototype model is used to offer medical students demonstration and enhance patient consciousness. It can reduce the total cost and time required to manufacture the artificial Ankle joint.

Conclude by conducting Linear and nonlinear analysis that the Total strain is much less than the permissible percentage limit of the standard pla and compared to standard material Ti-6Al-4V And Co-Cr-Mo alloy PLA material elongation

REFERENCES

1. Stefan –catalin popescu1 and Gheorghe I2 “Research on implementation orthopaedic prostheses Ankle by the process Rapid Prototyping”. International Journal of Mechatronics and applied mechanics, 2017, issue1.

2. Kranthi Nagaraju. K1, A.S.Ganapathi2”Modeling and Structural Analysis of artificial ankle joint under various loading conditions”. International journal of scientific development and research (IJSDR).

3. Claudio Belvedere PhD1, Sorin Siegler PhD2, Andrea Ensini MD3, Alessandro Fortunato PhD4, and Stefano Durante BS5”A New Comprehensive procedure for custom-made total ankle replacements: medical imaging, joint modeling, prosthesis design, and 3D printing. “Journal of Orthopaedic Research.

4. Nikolaos E. Gougouliias1Anil khanna2and Nicola Maffulli3”History and evolution in total ankle arthroplasty “British Medical Bulletin 2009.

5. Ariel Palanca, MD1, Roger A. Mann, MD2, Jeffrey A. Mann, MD3,and Andrew Haskell, MD4” Scandinavian Total Ankle Replacement: 15-Year Follow-up

6. Claire L Brockett PhD1 Graham J Chapman PhD2”Orthopaedics and trauma”. Biomechanics of the ankle-Science Direct

7. H.J.L.Vander heide I.Novakova and M.C.Dewall malefijt. ”The feasibility of total ankle prosthesis for severe arthopathy in haemophilia and prothrombin deficiency “Journal compilation 2006 black well publishing Ltd.