OPEN ACCESS INTERNATIONAL JOURNAL OF SCIENCE & ENGINEERING

DESIGN AND STRUCTURAL ANALYSYS OF KNEE JOINT USING DIFFERENT MATERIALS WITH FINITE ELEMENT METHOD

1Mr.I.VIJAYAKANTH, 2T.LAKSHMAN KUMAR

M.Tech Student, Department of Mechanical Engineering,
HELAPURI INSTITUTE OF TECHNOLOGY AND SCIENCE, ELURU.[1]
Asst Professor, Department of Mechanical Engineering,
HELAPURI INSTITUTE OF TECHNOLOGY AND SCIENCE, ELURU. 2
[1]vijaykanthinje143@gmail.com,[2]tummalalakshman33@gmail.com

Abstract: Knee prosthesis has done a lot of advancement in the recent decade as this facilitates people to do various activities even after their old age or some injury. Knee-joint is a complex structure of the human body having a complex shape femoral condoyle which moves over the complex shaped meniscus of the tibia bone and acquires various critical loads at various walking, moving and sitting activities. Metal alloys have been the materials of choice since the start of orthopedic surgery. The materials that are utilized as biomaterials are cobalt-chromium alloy, titanium alloy, stainless steel, zr02 are most usually utilized biomaterials for knee implants. The objective of this Project is to prepare 3D CAD model of prosthetic knee joint implants study the distribution of von-misses stresses, total deformation, shear stress and in the same by assigning it the different combination of biomaterials for femoral and tibia components. 3D modeling software Catia is used for 3D modeling of knee implant and finite element analysis software ANSYS 14.5 and finally concluded the suitable material for knee prosthesis.

Keywords: *Bio materials, FEA (Finite Element Analysis), Prosthesis, von-misses stresses, total deformation, shear stress, femoral and tibia components.*

I INTRODUCTION

1.1 MILE STONES IN THE EVOLUTION OF PROSTHETIC KNEE:

In orthopedic medicine, prosthesis, prosthetic, or prosthetic limb is an artificial device extension that replaces a missing body part. It is part of the field of biomechatronics, the science of using mechanical devices with human muscle, skeleton, and nervous systems to assist or enhance motor control lost by trauma, disease, or defect. Prostheses are typically used to replace parts lost by injury (traumatic) or missing from birth (congenital) or to supplement defective body parts. Inside the body, artificial heart valves are in common use with artificial hearts and lungs being in less common use but under active technology development. Other medical devices and aids that can be considered prosthetics include artificial eyes.

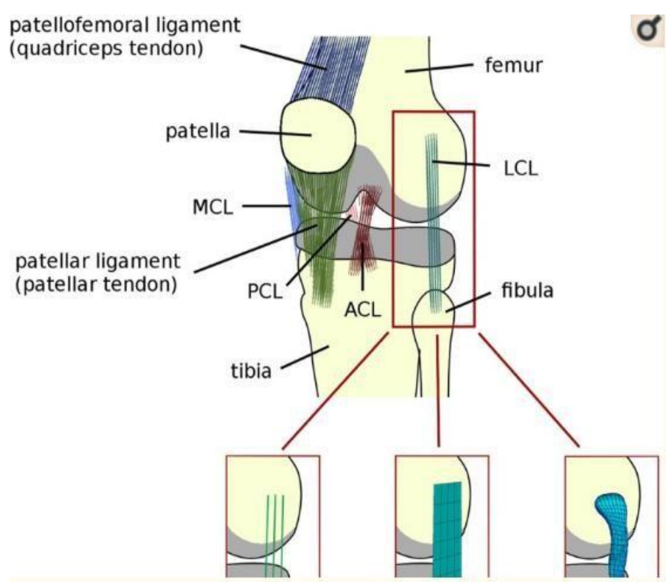

Figure 1 Parts of Knee joint

In the field of medicine prosthesis is defined as an artificial device which is replaced in the position of any defective body part or when any body part went missing because of trauma, disease or any congenital condition. Mainly two types of prosthesis are being used in i.e. craniofacial and somato (body). Craniofacial prosthesis is of two types i.e. extra oral prosthesis and intra prosthesis where as somato prosthesis are of many types like limb prosthesis, ear prosthesis any defective body parts when being replaced by an artificial organ.At the end of World War II, the NAS (National Academy of Sciences) began to advocate better research and development of prosthetics.

Through government funding, a research and development program was developed within the Army, Navy, Air Force, and the Veterans Administration. The development of prosthetic knee since ancient pyramids to world war-I

Figure 2 Prosthetic Knee From The Ancient Pyramids To World War I

1.2 HYSTORY

1.2.1 THE DARK AGES (476 TO 1000)

The Dark Ages saw little advancement in prosthetics other than the hand hook and peg leg. Most prostheses of the time were made to hide deformities or injuries sustained in battle. A knight would be fitted with a prosthesis that was designed only to hold a shield or for a leg to appear in the stirrups, with little attention to functionality. Outside of battle, only the wealthy were lucky enough to be fitted with a peg leg or hand hook for daily function. It was common for tradesmen, including armories, to design and create artificial limbs. People of all trades often contributed to making the devices; watchmakers were particularly instrumental in adding intricate internal functions with springs and gears.

1.2.2 THE RENAISSANCE (1400S TO 1800S):

The Renaissance ushered in new perspectives of art, philosophy, science and medicine. By returning to the medical discoveries of the Greeks and Romans concerning prosthetics, the Renaissance proved to be a rebirth in the history of prosthetics. Prostheses during this period were generally made of iron, copper and wood. The development of artificial hand in (1400s to 1800s) is shown in Fig

Figure 3 Artificial Hands in (1400s to 1800s)

II LITERATURE REVIEW

LITERATURE SURVEY OF KNEE JOINT PROTHESIS

Stress analysis is a discipline under engineering, an effective method to determine the strains and stress acting upon any material. Those materials are subjected to any particular load and forces in any direction. Stress analysis is used for keeping any specific structure in a functional state and maintaining its structure, with that investigating the causes which may lead to the failure and damage to that structure.

Stress analysis is done in any geometrically described structure with that checking the properties of the material used in that specific structure, where the loads being applied. Stress analysis can be done through computational analysis, mathematical techniques, and analytical, mathematical approach or combination of two three methods. Mechanical behavior of knee joints is a complex system. There are two states of mechanics in which the body behaves: one is the static state where body in a system is acting on a constant motion, it's either at a rest state or moving with a constant velocity.The other state of the body is dynamic, in which the body in the system is in motion where there is a presence of acceleration and the study of the body in that state is studied according to time, velocity, displacement, speed of the body in a particular linear direction or in any certain direction, with an involvement of forces acting on the body or any applied load. The knee joint is one of the most important joints in the human body. The knee joint is also called as the hinge joint which performs lots of activities like standing, walking, sitting, flexion, extension, with bending of knee etc. with different loads acting upon it with a certain pressure.

III PROJECT OVERVIEW

OBJECTIVE OF THE PROJECT:

Minimization of stress concentration developed on contact surface between the femur and tibia knee prosthesis. Finally Design and analysis selecting the proper prosthetic material.

3.1SPECIFIC OBJECTIVES:

• General evaluation of mechanical reliability for knee implants in terms of stress concentration.

• Determining the proper material using FEM.

• Analyzing the stress concentration on femur and tibia knee implants prosthesis geometry.

• Finally find out stress, total deformation, shear stress

• Recommending the geometry and the suitable material we should be using in future implant surgery.

3.2METHODOLOGY:

Step 1: Collecting information and data related to knee Prosthesis

Step 2: A fully parametric model of the Artificial knee created in catia software.

Step 3: Model obtained in igs. Analyzed using ANSYS 14.5(workbench), to obtain stresses, deformation, Shear stress etc.

Step 4: Taking boundary conditions.

Step 5: Finally, we compare the results obtained from ANSYS and compared geometry with different materials.

3.3 PROSTHESIS DESIGN:

Various mobile devices can be used for amputees who lose a limb due to congenital defects or bone deformities. Prosthetics is the rapidly changing field involving orthopedic supports and artificial limbs. The prosthetic limb resembles a human leg in function and appearance. In recent years computers have been used to help fit amputees with prosthetic limbs. Prosthetic facilities use Computer Aided Design of modeling the patient's arm or leg. For the design to be optimal, it should have less weight at optimal strength. Hence the materials with high strength that can be used for manufacture of various parts of a prosthetic limb are also studied in this work. Various parts of the prosthetic limb are designed and assembled. The design and development of a side clamp has been studied and its deflections when forces applied are considered. Materials for different parts of the prosthetic limb are studied. The analysis of a side clamp used in the design of a prosthetic limb is undertaken and an optimal design for the side clamp is proposed.

Aluminum alloy and steel and titanium and considered for analysis. The design and analysis was done using proe and hyper mesh. Designing of prosthesis inculcates in itself knowledge and understanding of a number of fields and collaborating with specialists in medicine and manufacturing to come up with an efficient prosthesis. shows the generic protocol for prosthesis development. This includes requirements and data collection from patients for generalizing the prosthesis components, bio mimetic shapes based on measured data, biomechanics studies for functional and motions, mechanical design based on basic shapes and motion requirements revealed during biomechanics study (since natural)

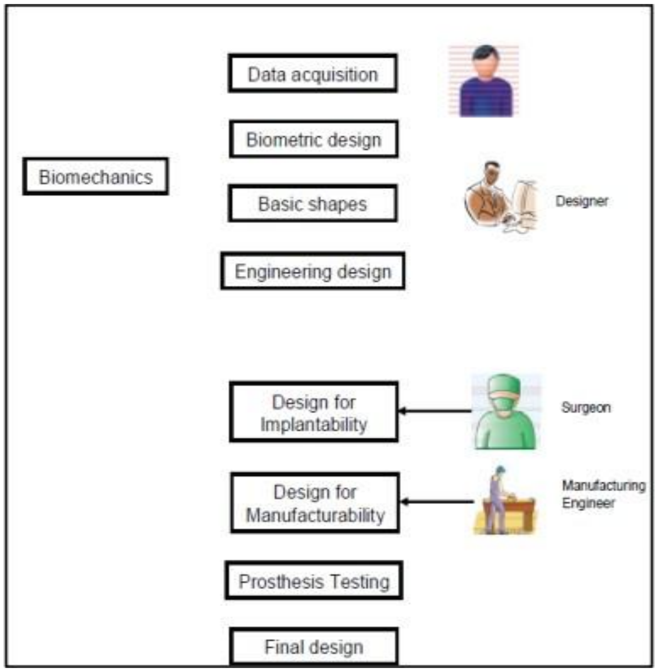

FIGURE 4 STEPS INVOLVED IN COMPONENT

IV INTRODUCTION TO CATIA V5R20

4.1INTRODUCTION TO CATIA V5R20:

Welcome to CATIA (Computer Aided Three Dimensional Interactive Application). As anew user of this software package, you will join hands with thousands of users of this high-end CAD/CAM/CAE tool worldwide. If you are already familiar with the previous releases, you can upgrade your designing skills with the tremendous improvement in this latest release.

CATIA V5, developed by Dassault Systems, France, is a completely re-engineered, Next- generation family of CAD/CAM/CAE software solutions for Product Lifecycle Management.

Through its exceptionally easy-to-use and state-of-the-art user interface, CATIA V5 delivers innovative technologies for maximum productivity and creativity, from the inception concept to the final product. CATIA V5 reduces the learning curve, as it allows the flexibility of using feature-based and parametric designs.

CATIA V5 provides three basic platforms: P1, P2, and P3. P1 is for small and medium-sized process-oriented companies that wish to grow toward the large scale digitized product definition.

V INTRODUCTIONS TO ANSYS

5.1INTRODUCTION TO ANSYS:

ANSYS is a large-scale multipurpose finite element program developed and maintained by ANSYS Inc. to analyze a wide spectrum of problems encountered in engineering mechanics.

5.2PROGRAM ORGANIZATION:

The ANSYS program is organized into two basic levels:

• Begin level

• Processor (or Routine) level

The Begin level acts as a gateway into and out of the ANSYS program. It is also used for certain global program controls such as changing the job name, clearing (zeroing out) the database, and copying binary files. When you first enter the program, you are at the Begin level. At the Processor level, several processors are available.

Each processor is a set of functions that perform a specific analysis task. For example, the general pre-processor (PREP7) is where you build the model, the solution processor (SOLUTION) is where you apply loads and obtain the solution, and the general postprocessor (POST1) is where you evaluate the results of a solution.

5.3MATERIAL MODELS:

ANSYS allows several different material models like:

• Linear elastic material models (isotropic, orthotropic, and anisotropic).

• Non-linear material models (hyper elastic, multi linear elastic, inelastic and Viscous elastic

• Heat transfer material models (isotropic and orthotropic)

• Temperature dependent material properties and Creep material models.

VI FINITE ELEMENT METHOD

6.1INTRODUCTION OF FEM:

The Basic concept in FEA is that the body or structure may be divided into smaller elements of finite dimensions called “Finite Elements”. The original body or the structure is then considered as an assemblage of these elements connected at a finite number of joints called “Nodes” or “Nodal Points”.

Simple functions are chosen to approximate the displacements over each finite element. Such assumed functions are called “shape functions”. This will represent the displacement with in the element in terms of the displacement at the nodes of the element.

The Finite Element Method is a mathematical tool for solving ordinary and partial differential equations. Because it is a numerical tool, it has the ability to solve the complex problems that can be represented in differential equations form. The applications of FEM are limitless as regards the solution of practical design problems.

6.2PROCEDURE OF STATIC ANALYSIS:

Create the geometry in Catia workbench and save the file innings format and open Ansys workbench apply engineering data(material properties), create or import the geometry, apply model(meshing), apply boundary conditions(setup) shown the results(stress, deformation, strain, shear stress).

6.3MESHING AND BOUNDARY CONDITIONS:

Meshing of artificial knee prosthesis for analysis knee implant imported to Ansys workbench for meshing in the static analysis and the knee is meshed with the tetrahedron meshing is done on the whole 3D model to define and refinement is done on the knee and the meshing style is free. The statics denied after meshing the model is divided into 8172 element s and the number of nodes formed is 14547 and fixed top side and apply forces1500, 3000, 4500 N as shown below figures.

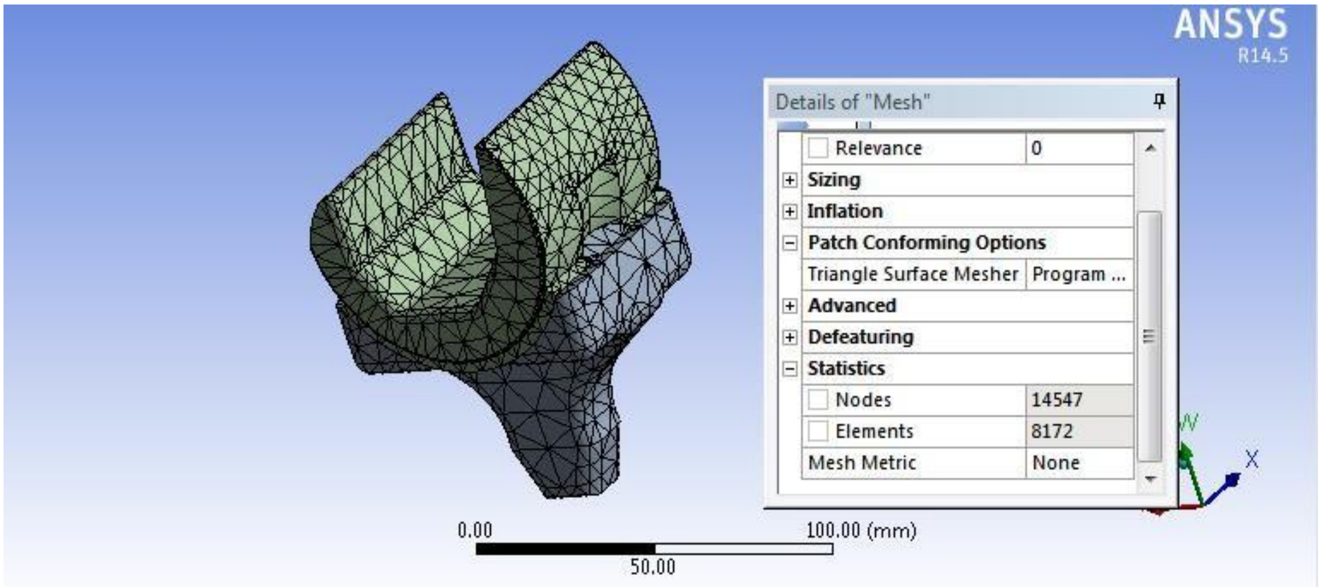

Figure 5 Meshing of knee implants

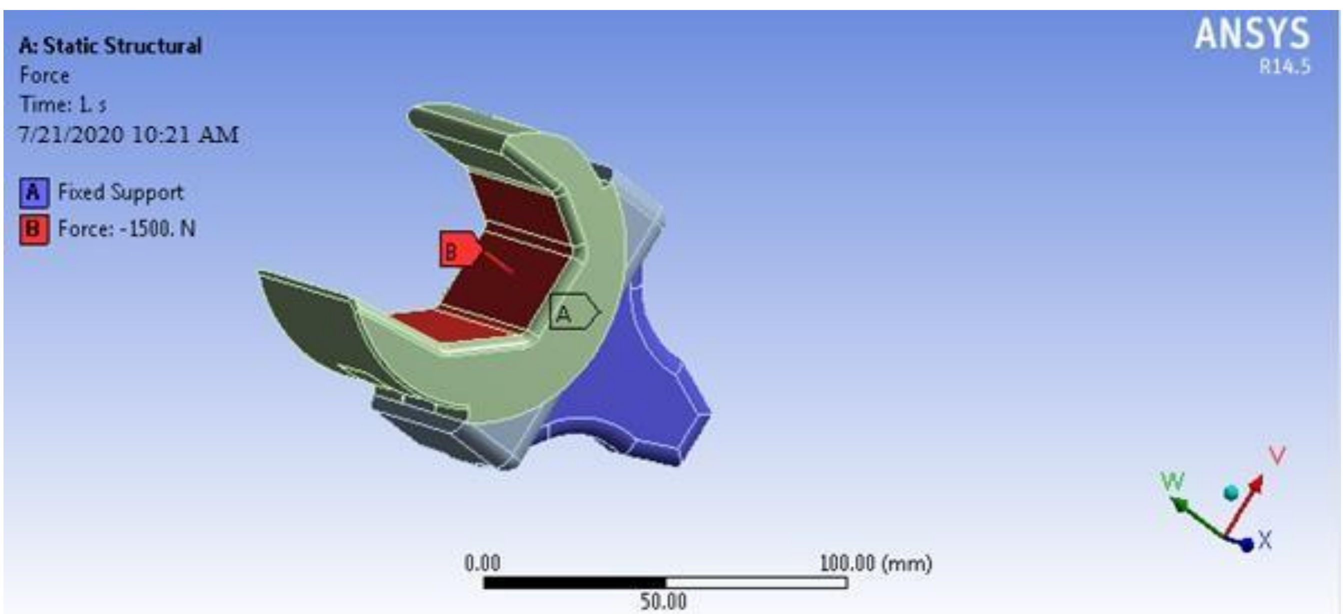

Figure 6 LOAD IS 1500 N

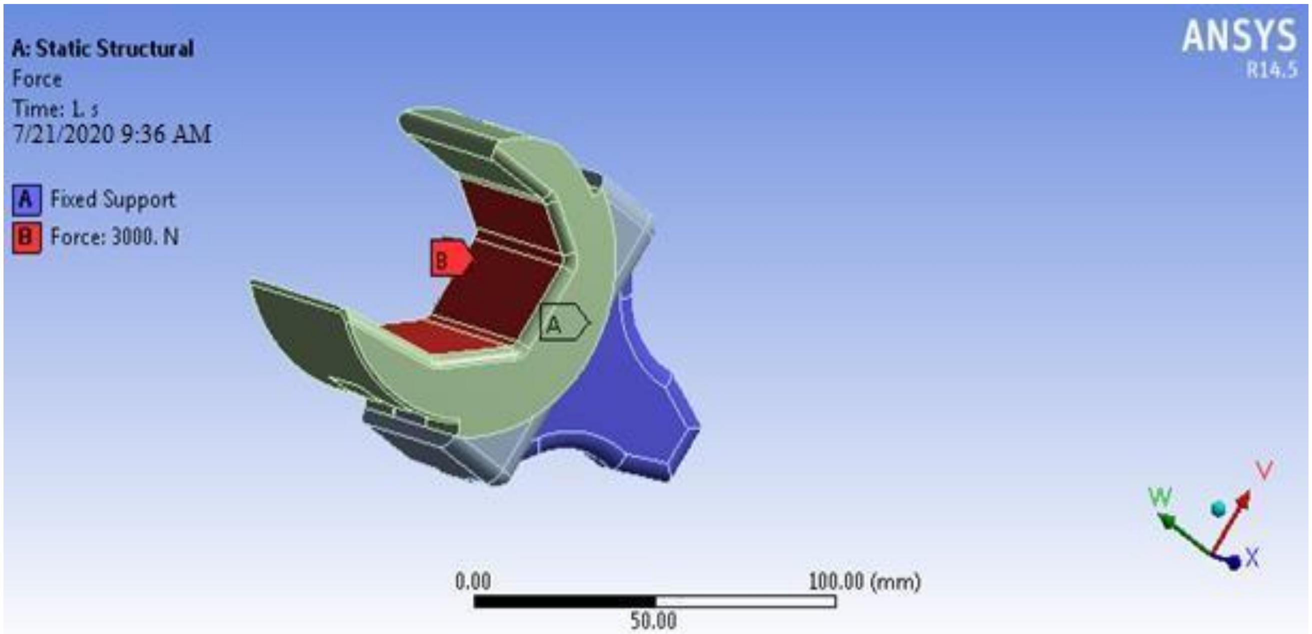

Figure 7 LOAD IS 3000N

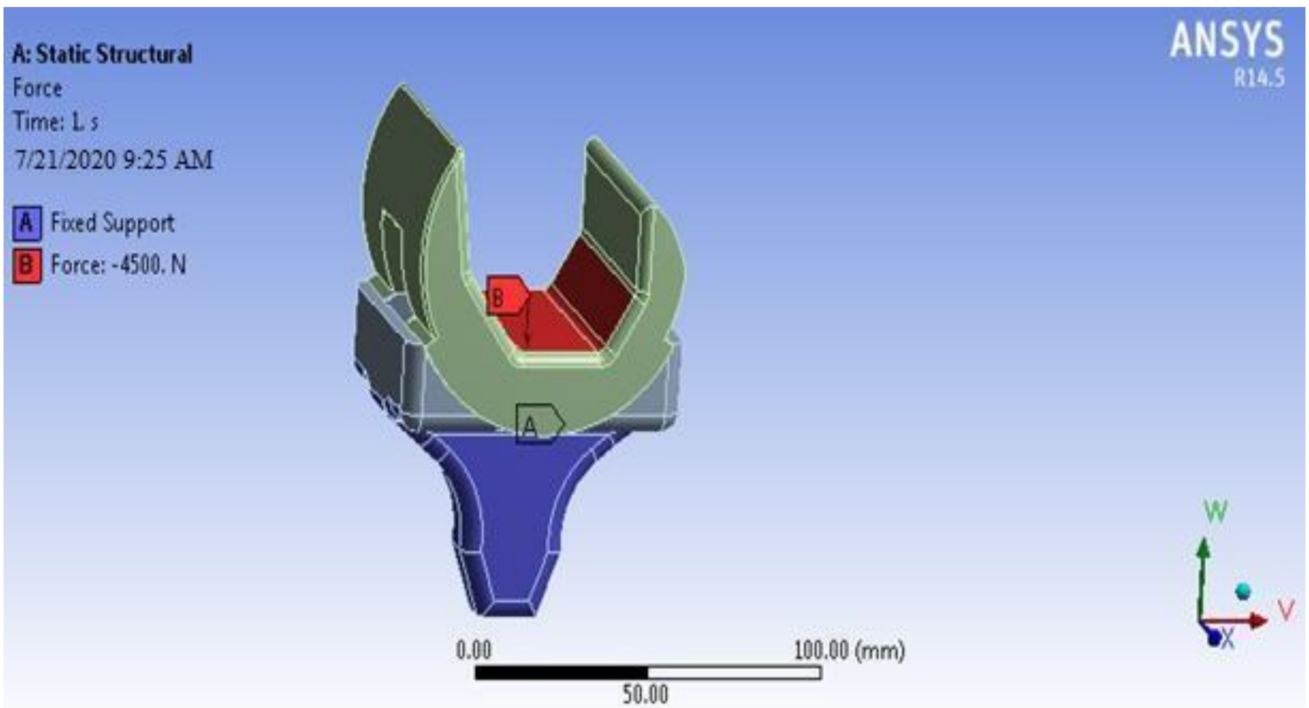

Figure 8 LOAD IS 4500N

7 RESULTS AND DISCUSSION

The constructed Knee implants in Catia is analyzed using ANSYS 14.5 and the results are as shown in below.

CO-CR-MO ALLOY :

Here the stresses, shear stress, deformations, are obtained by analyzing the knee implant assembly by using **CO-CR-MO ALLOY** material, with different load conditions as shown in below figures.

7.1 CO-CR-MO PROSTHETIC KNEE IMPLANTS AT THE LOAD OF 1500N

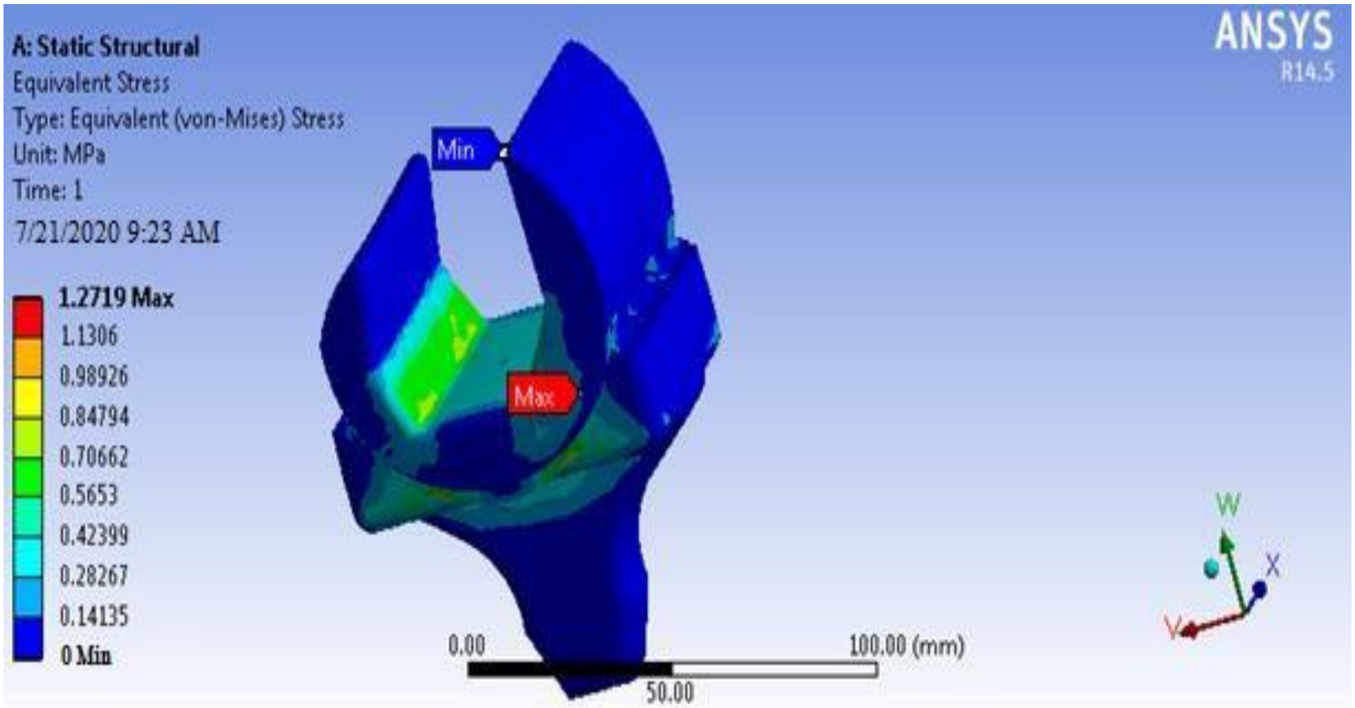

Figure 9 VON-MISES STRESS OF CO-CR-MO ALLOY AT 1500N

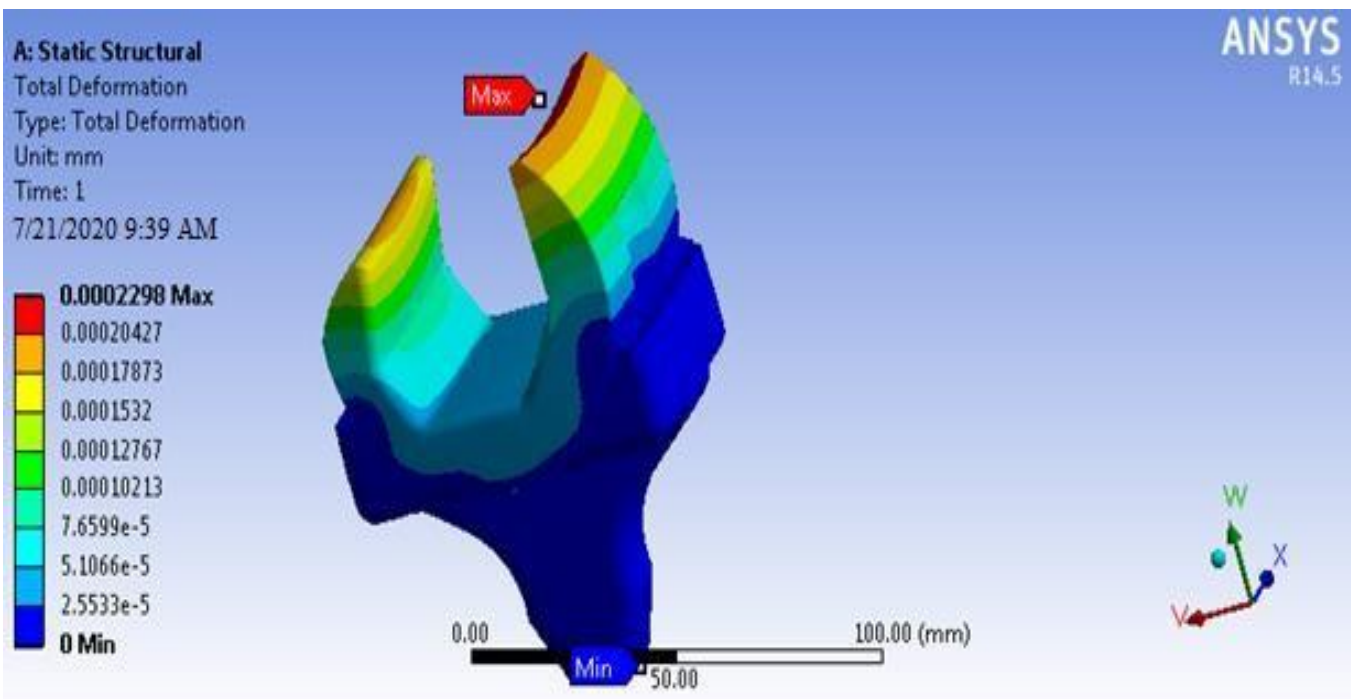

Figure 10 TOTAL DEFORMATION OF CO-CR-MO ALLOY AT 1500N

7.2STAINLESS STEEL PROSTHETIC KNEE IMPLANTS AT THE LOAD OF 3000N

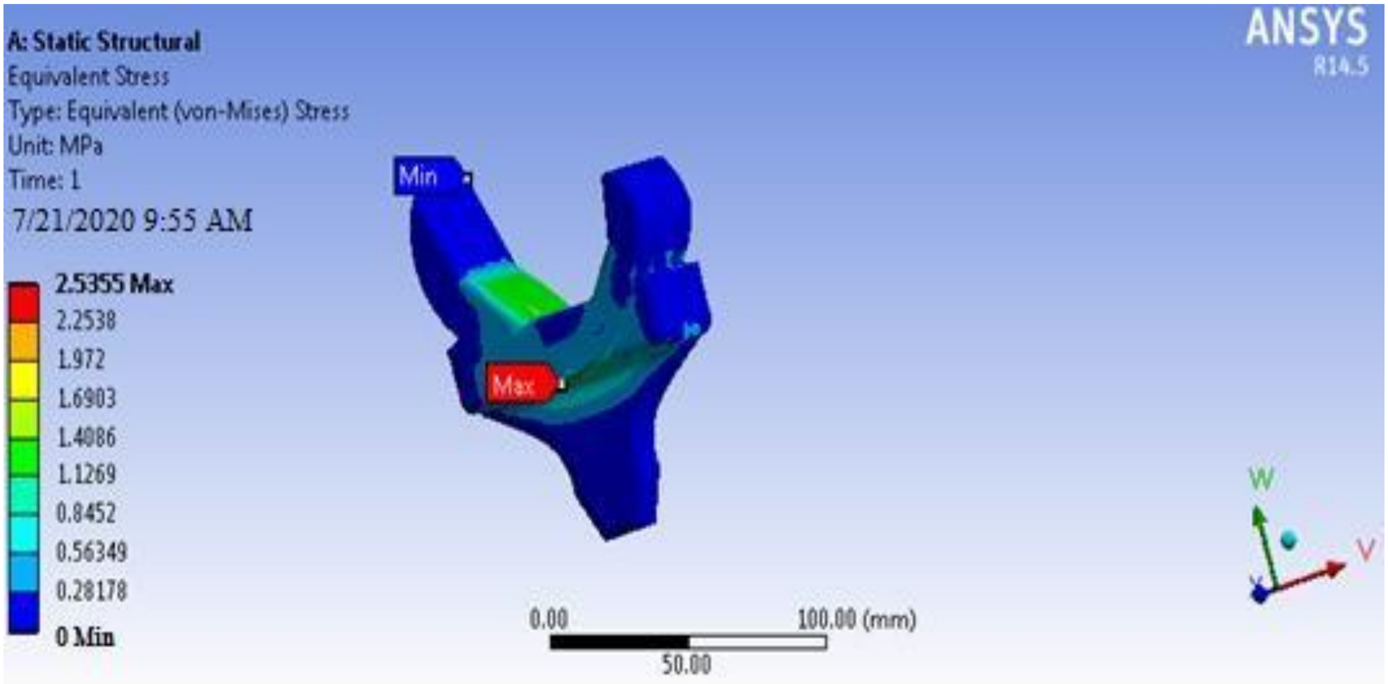

Figure 11 STRESS OF SS316L MATERIAL:3000 N

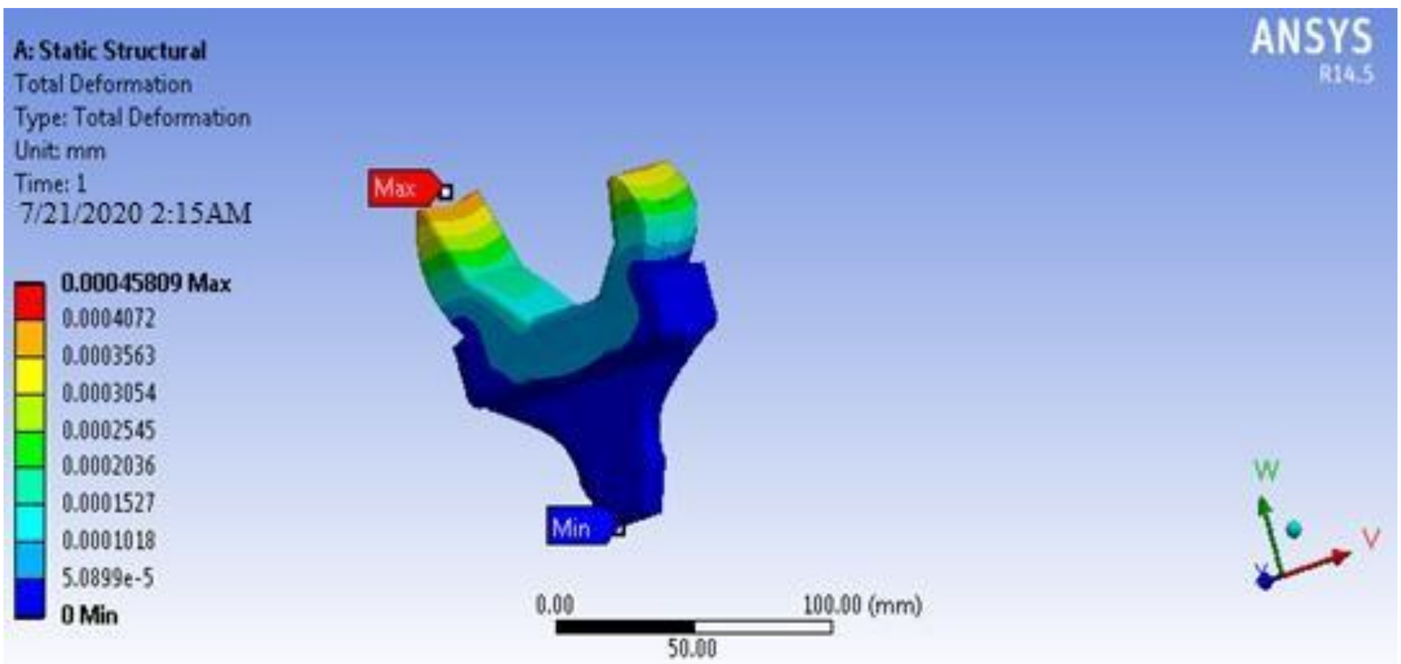

Figure 12 TOTAL DEFORMATION OF SS316L MATERIAL:3000 N

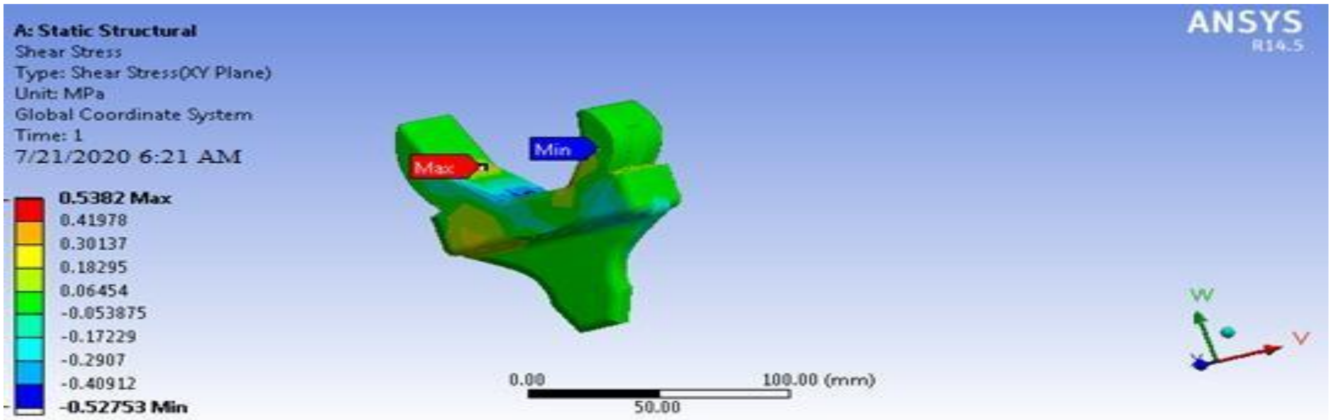

Figure 13 SHEAR STRESS OF SS316L MATERIAL:3000 N

7.3STAINLESS STEEL PROSTHETIC KNEE IMPLANTS AT THE LOAD OF 4500N:

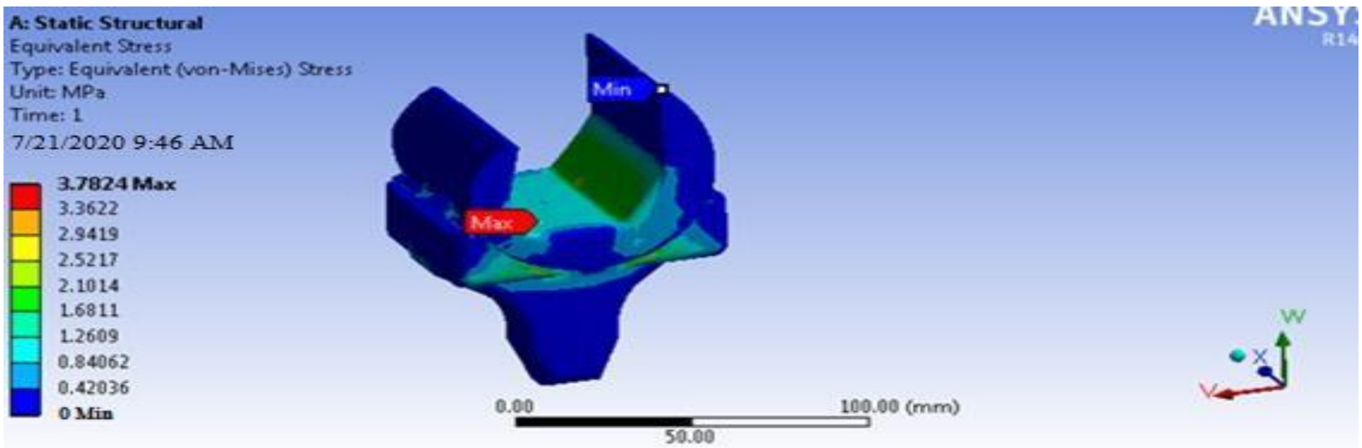

Figure 14 STRESS OF SS316L MATERIAL:4500N

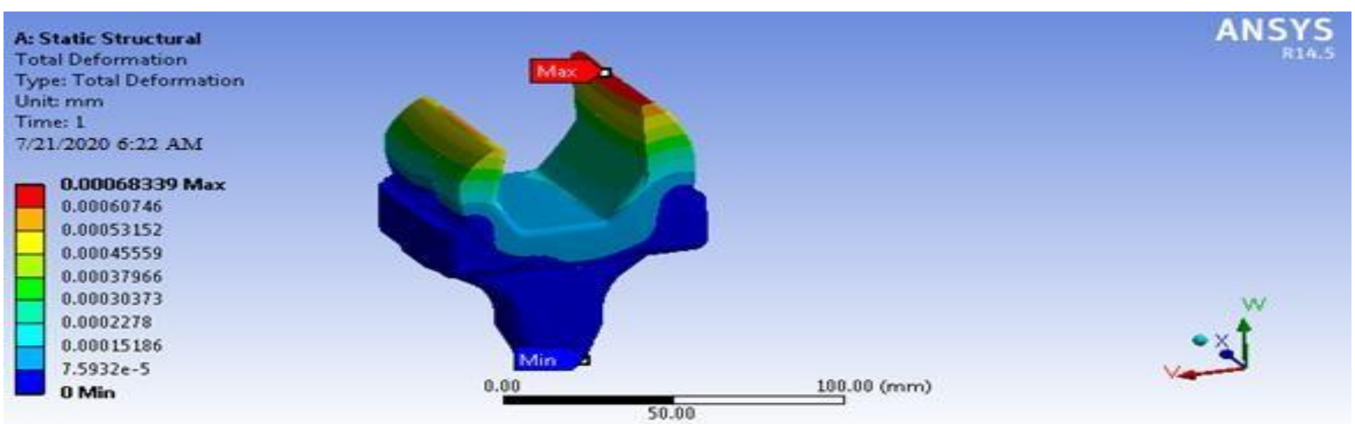

Figure 15 TOTAL DEFORMATION OF SS316L MATERIAL:4500N

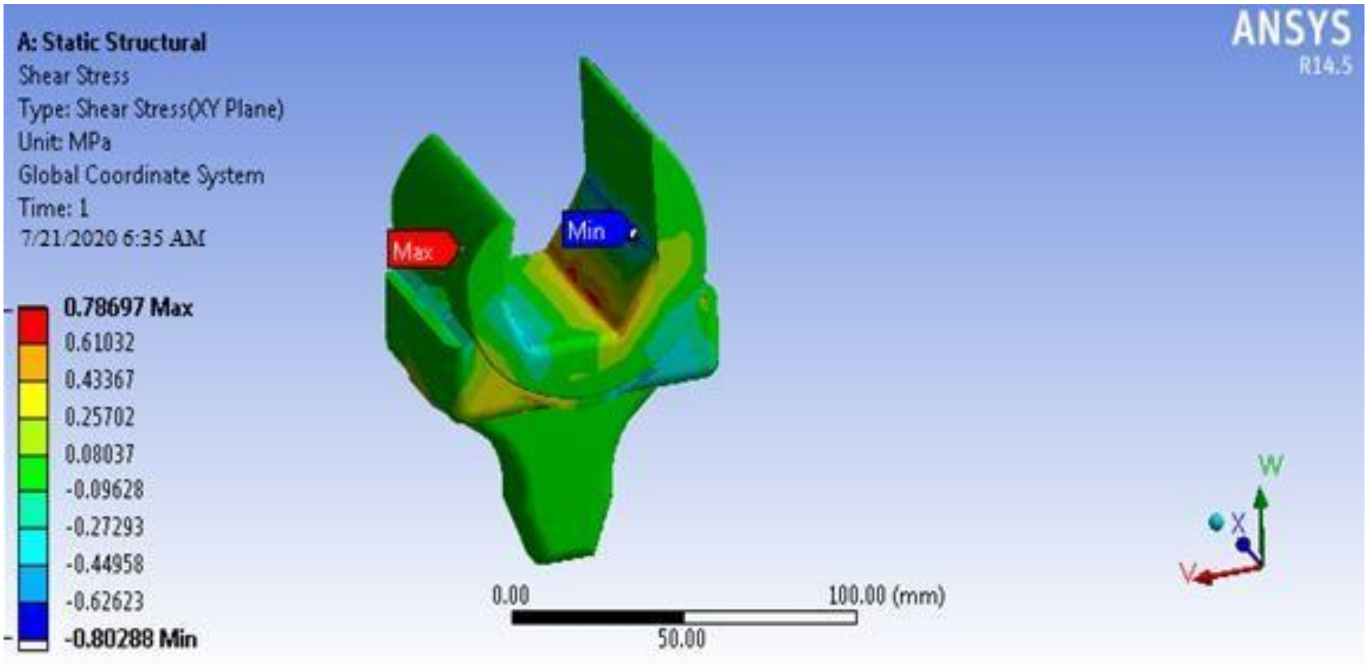

Figure 16 SHEAR STRESS OF SS316L MATERIAL:4500N

7.4GRAPHS:

7.4.1 VON-MISES STRESS (MPA):

we can observe that in case of equivalent (von-mises) stress, knee implant made of titanium alloy is found to have least stress of 1.247(1500N),2.49(3000N), 3.7(4500N) in comparison with remaining materials including the present material.

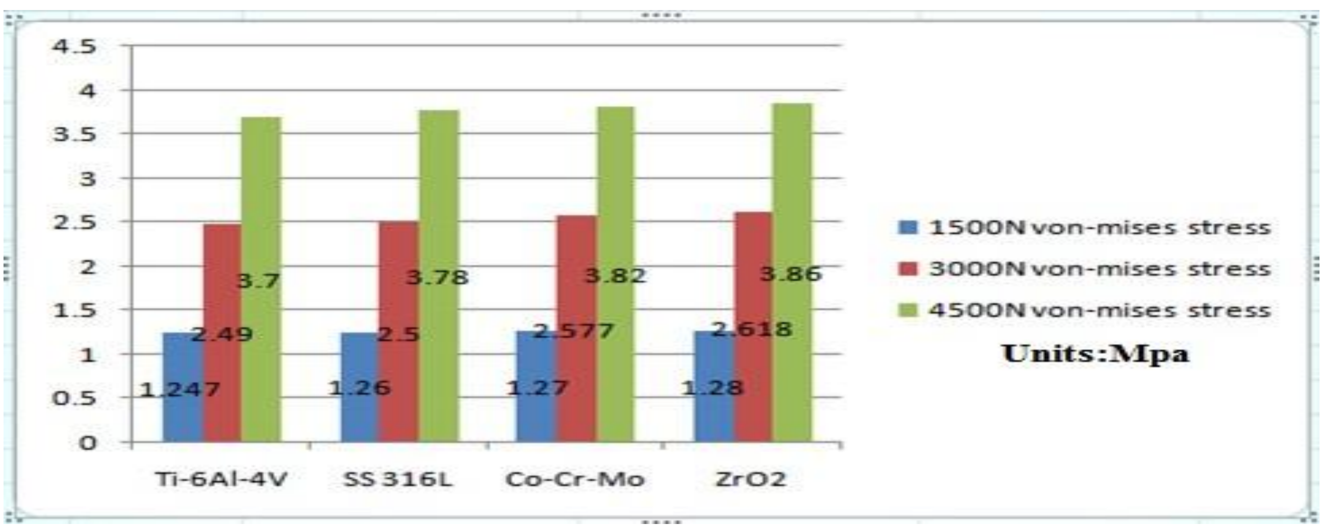

Figure 17 VON-MISES STRESS (Mpa)

7.4.2 TOTAL DEFORMATION (mm):

We can observe that in case of Total deformation, knee implant made of titanium alloy is found to have least deformation of 0.00022(1500N),0.00045(3000N), 0.00067(4500N) in comparison with remaining materials including the present material.

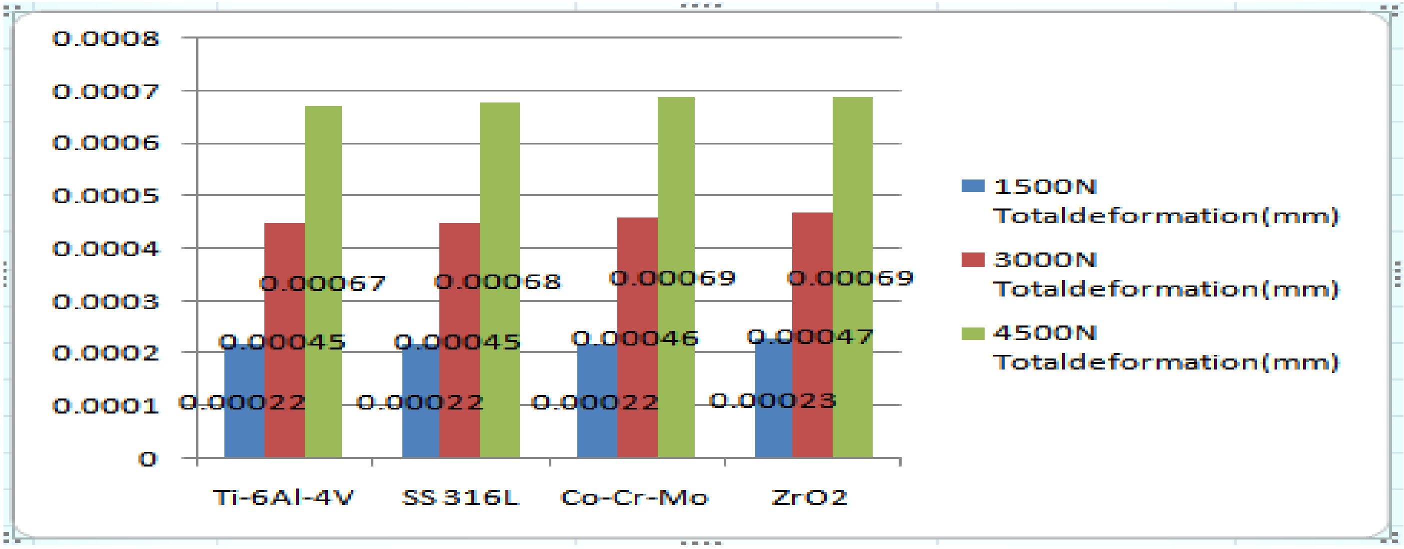

Figure 18 TOTAL DEFORMATION (mm)

7.4.3SHEAR STRESS (MPA):

we can observe that in case of Shear stress, knee implant made of titanium alloy is found to have least shear stress of 0.25(1500N),0.52(3000N), 0.7(4500N) in comparison with remaining materials including the present material.

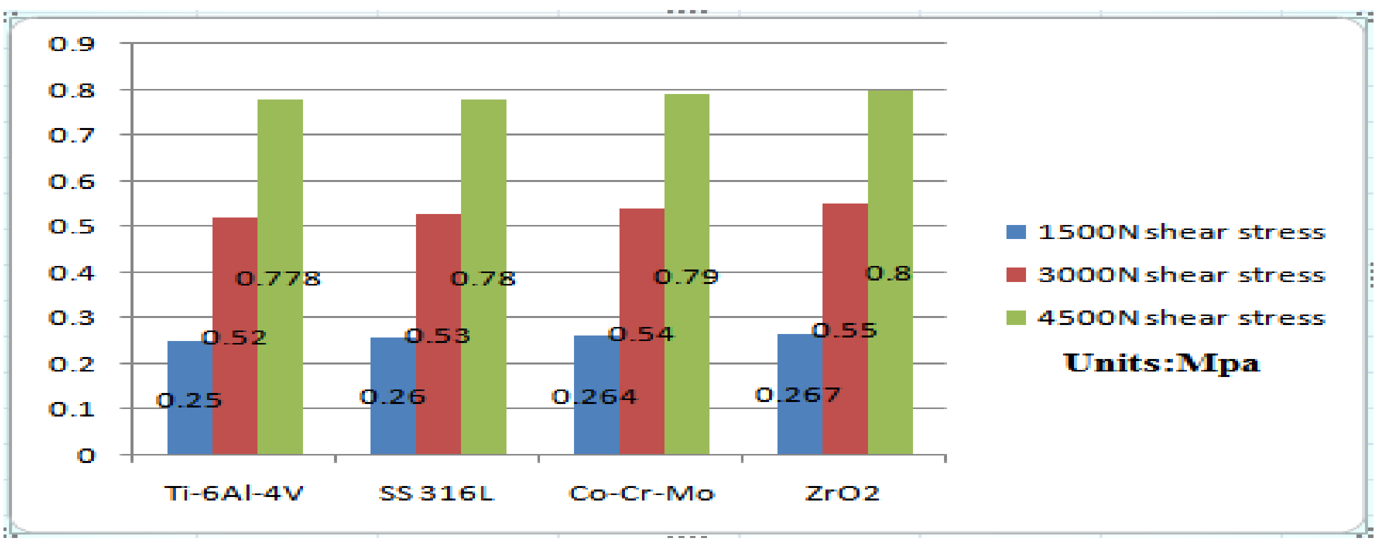

Figure 19 SHEAR STRESS

VIII CONCLUSIONS

Diligent study of normal Knee joint biomechanics and review of previous implant failures has led to the development of a new generation of implants. This improvement coupled with improved cement less fixation, has led to prosthetic designs with decreased failure rates. However, appropriate selection of patients remains a cornerstone for a successful Knee replacement.

• In this study, the design approach for a tibial and femur -component implants using CATIA software has been developed.

• By introducing the contact pair in between the components, non-linear static analysis of an knee joint has been done using ANSYS software.

• Normally the load acting on the knee joint .

• The analysis is carried out by walking condition varying the load on the knee implant from 1500,3000,4500 Newton's.

• We are analyzed four different materials cobalt-chromium alloy, titanium alloy, stainless steel, zr02.

• Static analysis done finally concluded it is that TITANIUM ALLOY material is suitable for Knee joint replacement.

• Finally concluded titanium alloy implants are the increase the life span.

REFERENCES

1. Zaffagnini, S., et al., A Standardized Technique in Performing Pivot-Shift Test on the Knee Joint Provided More Consistent Acceleration Curve Shape, Allowing to Highlight Side-to-Side Differences. Arthroscopy: The Journal of Arthroscopic and Related Surgery, 2013. 29(10): p. e175-e175.

2. Haque, M.A., T. Kurokawa, and J.P. Gong, Super tough double network hydrogels and their application as biomaterials. Polymer, 2012. 53(9): p. 1805-1822.

3. Metzger, R., et al., Patient specific knee alignment guide and associated method. 2012, Google Patents.

4. Padhi, A.K., Development of a Limb prosthesis by reverse mechanotransduction. 2013.

5. Baran, G.R., M.F. Kiani, and S.P. Samuel, Biomaterials Applications in Medicine and Case Studies, in Healthcare and Biomedical Technology in the 21st Century. 2014, Springer. p. 249- 285.

6. Carr, A.J., et al., Knee replacement. The Lancet, 2012. 379(9823): p. 1331-1340.

7. Nogler, M., et al., Alignment for total knee replacement: a comparison of kinematic axis versus mechanical axis techniques. A cadaver study. International orthopaedics, 2012. 36(11): p. 2249- 2253.

8. Pallante, A.L., et al., Treatment of articular cartilage defects in the goat with frozen versus fresh osteochondral allografts: effects on cartilage stiffness, zonal composition, and structure at six months. The Journal of Bone & Joint Surgery, 2012. 94(21): p. 1984-1995.

9. Robinson, J.C., et al., Variability in costs associated with total hip and knee replacement implants. The Journal of Bone & Joint Surgery, 2012. 94(18): p. 1693-1698.

10. Pal, S., The Hip Joint and Its Artificial Replacement, in Design of Artificial Human Joints & Organs. 2014, Springer. p. 177-194.

11. Hetaimish, B.M., et al., Meta-analysis of navigation vs conventional total knee arthroplasty. The Journal of arthroplasty, 2012. 27(6): p. 1177-1182.

12. Smith, H., et al., Meta-analysis and systematic review of clinical outcomes comparing mobile bearing and fixed bearing total knee arthroplasty. The Journal of arthroplasty, 2011. 26(8): p. 1205-1213.

13. Enab, T.A. and N.E. Bondok, Material selection in the design of the tibia tray component of cemented artificial knee using finite element method. Materials & Design, 2013. 44: p. 454-460.

14. Morrison, D.R., Body, Self, Device: Nonhuman Objects and Human Identity. 2012, Vanderbilt University.

15. Maas, S.A., et al., FEBio: finite elements for biomechanics. Journal of biomechanical engineering, 2012. 134(1): p. 011005.

16. Crisfield, M.A., J.J. Remmers, and C.V. Verhoosel, Nonlinear finite element analysis of solids and structures. 2012: John Wiley & Sons.

17. Machado, M., et al., Development of a planar multibody model of the human knee joint. Nonlinear dynamics, 2010. 60(3): p. 459-478.

18. Hernandez-Vaquero, D., A. Noriega-Fernandez, and A. Suarez-Vazquez, Total knee arthroplasties performed with a mini-incision or a standard incision. Similar results at six months follow-up. BMC musculoskeletal disorders, 2010. 11(1): p. 27.

19. Shih, C.-J. and K.-C. Shih, Minimally invasive total knee arthroplasty using a cruciate- retaining knee system: A 3–5 year study with comparison to a standard approach. Formosan Journal of Musculoskeletal Disorders, 2012. 3(1): p. 19-23. 20. Worsley, P., Assessment of short-term knee arthroplasty function using clinical measures, motion analysis, and musculoskeletal modelling. 2011, Univiersity of Southampton.