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MODELING AND FINITE ELEMENT ANALYSIS OF KNEE JOINT PROSTHESIS

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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 tibial bone and acquires various critical loads at various walking, moving and sitting activities. From a biomechanical point of view, Metal alloys have been the materials of choice since the start of orthopedic surgery. Orthopedic materials must fulfill the mechanical, biological and physical necessities of their proposed utilization. Knee joint is the most complex joint in human body gets the discriminating loads conditions. Accordingly, the material utilized for knee implant assumes exceptionally essential part for long survival of knee prosthesis. 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 tibial components. 3D modeling software catia is used for 3D modeling of knee implant and finite element analysis software ANSYS 14.5, finally concluded the suitable material for knee prosthesis.

Keywords: *Biomaterials, FEA (Finite Element Analysis), prosthesis, TKR (Total knee replacement), von-misses stress, shear stress, total deformation*

I. INTRODUCTION

The knee joint is complex structure in the human body which undergoes critical loading simultaneously while performing different physical activities such as walking, running, in rotational motion, sitting, static positions etc. what we used to do in our day to day life. Major parts in a knee joint are femur, tibia, patella and meniscus. It has two articulation components one is in between the tibia and femur and another between the femur and patella. The knee joint is a pivot hinge joint. It permits extension and flexion of leg with that rotation in both internal as well as external part [1]. It's articular bodies are lateral and medial condyle were patella is present in the posterior region in between the lateral and medial condyle surfaces. Articular capsule of knee joints are the fibrous membrane and synovial membranes. Synovial membranes are those which are been attached near the cartilage of both tibia and femur. Cartilage is elastic thin tissue that acts as protection guard for bone and makes the joint surfaces. In knee joint there are two types of cartilages joint one is fibrous cartilage and other as hyaline cartilage. Fibrous cartilage has resistance to high pressure and has high tensile strength [2]. A meniscus is the articular disk present in the knee joint, having two components i.e. medial and lateral meniscus

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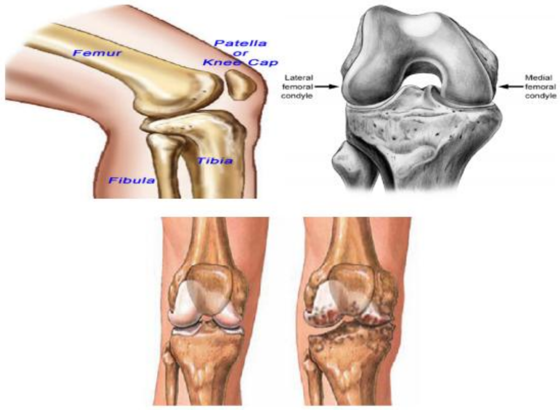

Figure: 1 Knee joint

II. BIOMATERIALS FOR KNEE IMPLANTS

The materials that are used as biomaterials include polymers, metals, ceramics and composites. The metals used as biomaterials include titanium alloys, cobalt-chromium alloys, and stainless steels. In polymers UHMWPE (ultra high molecular weight polyethylene) is most commonly used biomaterial. More recently ceramics demonstrated great promise for replacing metals in total knee replacement with the chief benefits of ceramics is their superior wear properties. In this study biomechanical analysis of titanium alloys, cobalt-chromium alloys, stainless steels and UHMWPE have been carried out using FEM and compare the results. Materials used for manufacturing the femoral component of implant are Ti6Al4V alloy, Co-Cr-Mo alloy, SS 316L alloy and oxidized zirconium and the commonly used material for manufacturing the linear insert now a days is UHMWPE (ultra high molecular weight polyethylene). The material properties that are being used for the analysis are mentioned in below tables.

Table: 1 properties of Ti-6AL-4V

Ti-6AL-4V	
Young’s modulus	114
Tensile strength	850
Ultimate tensile strength	960
Density	4420
Poisson ratio	0.35

Table: 2 properties of Co-Cr-Mo

Co-Cr-Mo	
Young’s modulus	230
Tensile strength	530
Ultimate tensile strength	890
Density	8300
Poisson ratio	0.3

Table: 3 properties of SS 316L

SS 316L	
Young’s modulus	165
Tensile strength	580
Ultimate tensile strength	515
Density	8000
Poisson ratio	0.3

Table: 4 properties of ZrO_2

ZrO_2	
Young's modulus	180
Tensile strength	564.8
Ultimate tensile strength	570
Density	8700
Poisson ratio	0.36

III. MODELING OF FEMUR AND TIBIAL JOINT

The geometry of prosthesis has a significant influence in its performance therefore need of adopting the standard procedure to model the prosthesis is required. Catia V5 is a computer graphics system for modeling various mechanical designs and for performing related designs and manufacturing operations. Catia V5 is a feature based parametric solid modeling system with many extended design and manufacturing applications. As a comprehensive CAD/CAM/CAE system, covering many aspects of mechanical design, analysis and manufacturing, Catia V5 represents the leading edge of CAD/CAM/CAE technology. The geometrical models were developed by using Catia V5

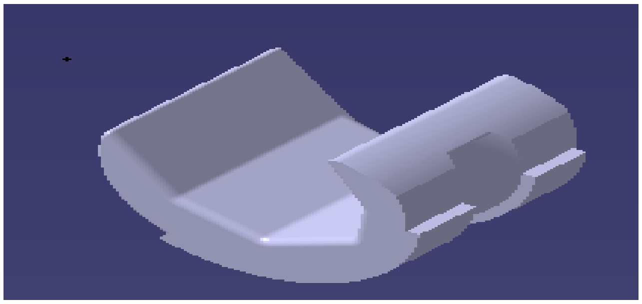

Figure: 2 Design of Femur in knee implant

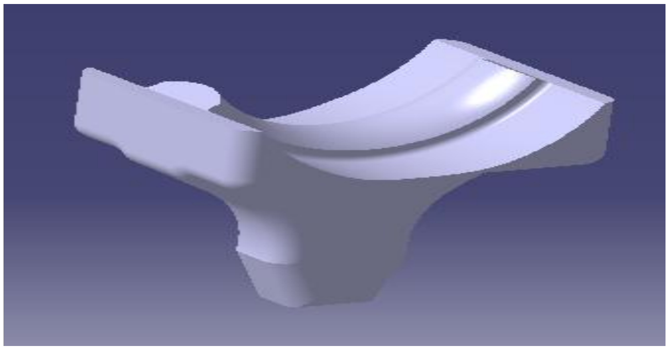

Figure: 3 Design of Tibial in knee implant

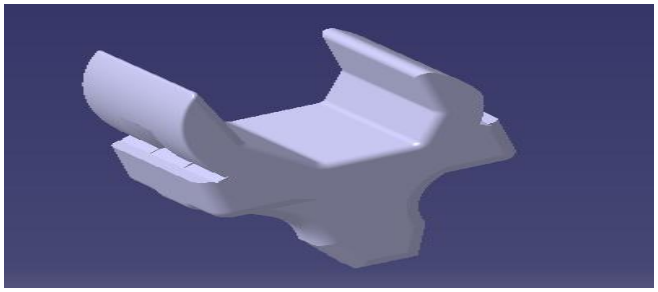

Figure: 4 Design of Femur And Tibial Assembly Component

1. FEM analysis of knee prosthesis using different biomaterials

FEM analysis of prosthetic knee joint, when knee is in straight position was carried out in ANSYS 14.5. Analysis performed for different combination of biomaterials. After Cad Modeling the file is converted into IGES format and imported to the ANSYS 14.5 Environment, and then the solid model is assigned with the material properties and next secernated into smaller units so called Meshing, Dividing the component assembly into finite no of elements.

2. Meshing 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.

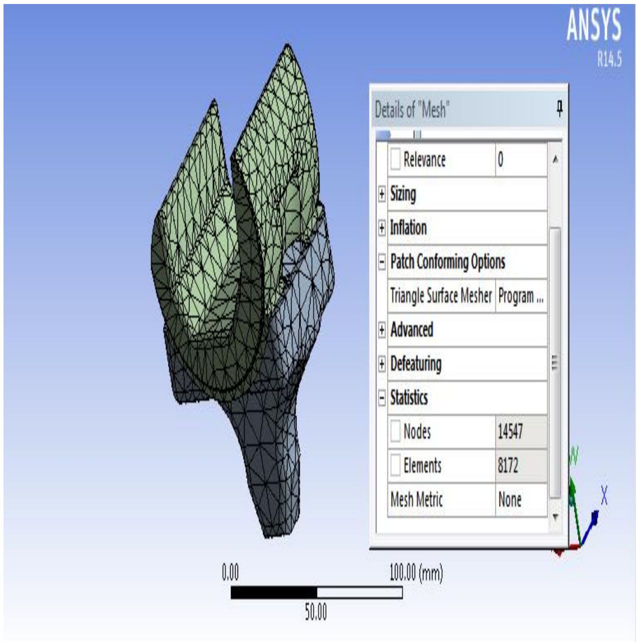

Figure: 5 meshing of femur and tibial component

IV. RESULTS AND DISCUSSION

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

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(i) Ti6Al4V *Material* Prosthetic Knee Implants at the Load of 3000N

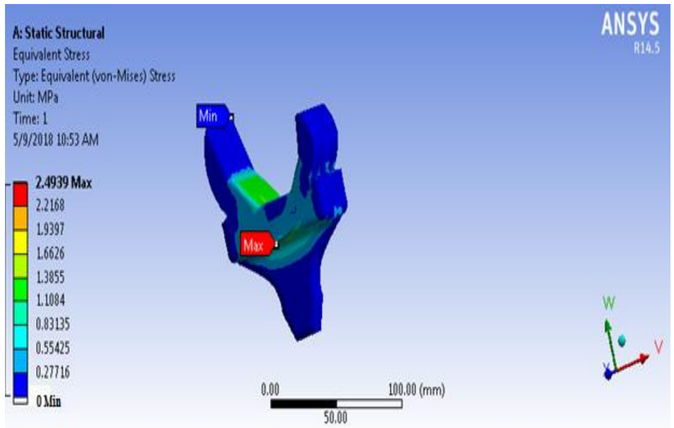

Figure: 6 Von-Mises* Stress *of* Ti6Al4v *Material at 3000 N

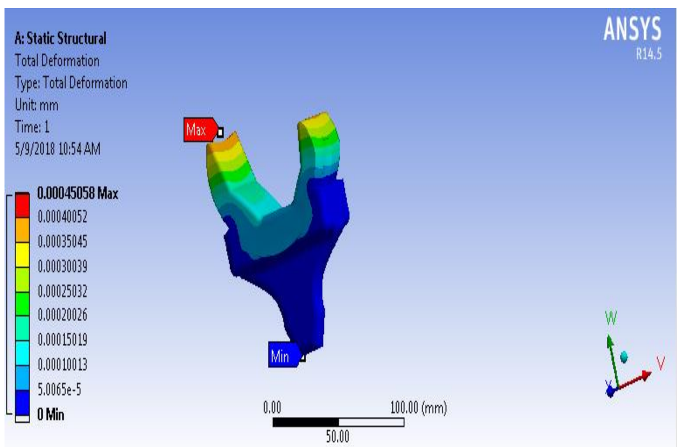

Figure: 7 Total Deformation*of *Ti6Al4v Material at 3000 N

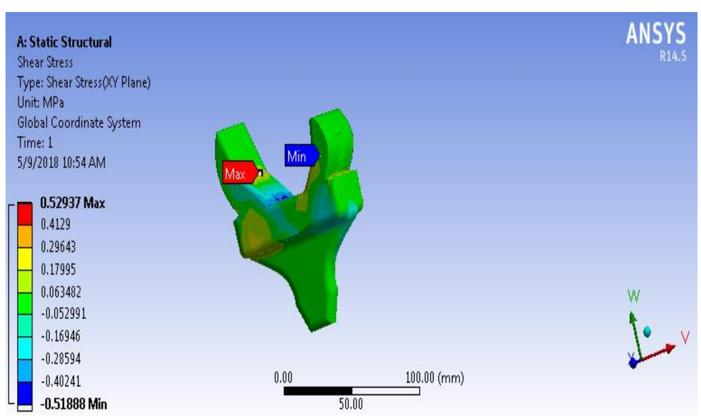

Figure: 8 Shear Stress of SS316l Material at 3000 N

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(ii) Co-Cr-Mo Prosthetic Knee Implants at the Load Of 3000N

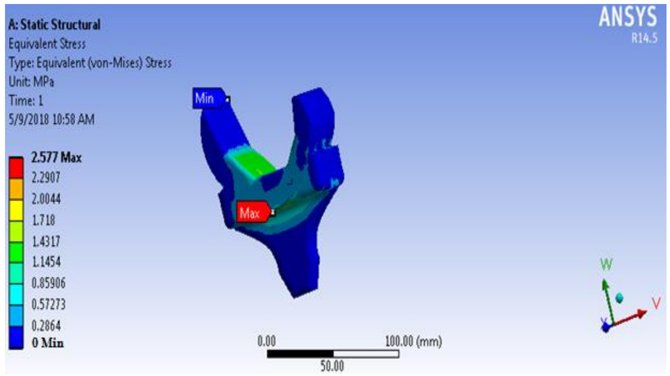

Figure: 9 Von-Mises Stress Of Co-Cr-Mo Alloy at 3000N

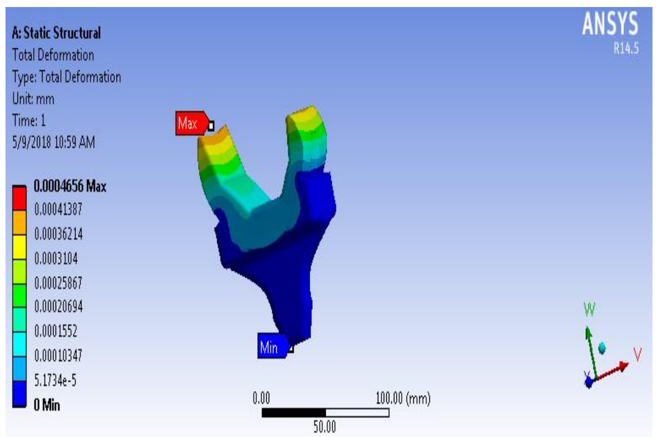

Figure: 10 Total Deformation Of Co-Cr-Mo Alloy at 3000N

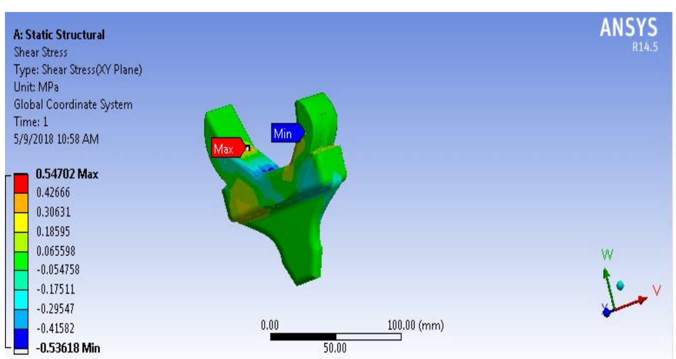

Figure: 11 Shear Stress **of Co-Cr-Mo Alloy at 3000N**

***(iii) Stainless Steel* prosthetic Knee Implants at the Load Of 3000N**

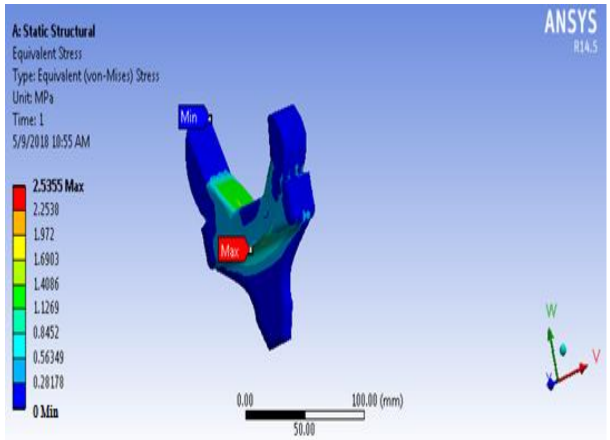

Figure: 12 Von-Mises Stress Of SS316l Material at 3000 N

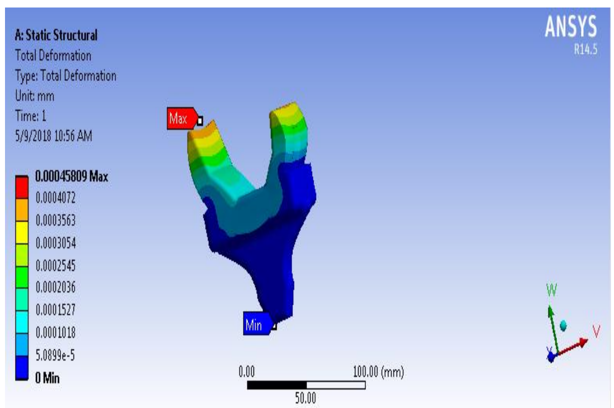

Figure: 13 Total Deformation of SS316l Material at 3000 N

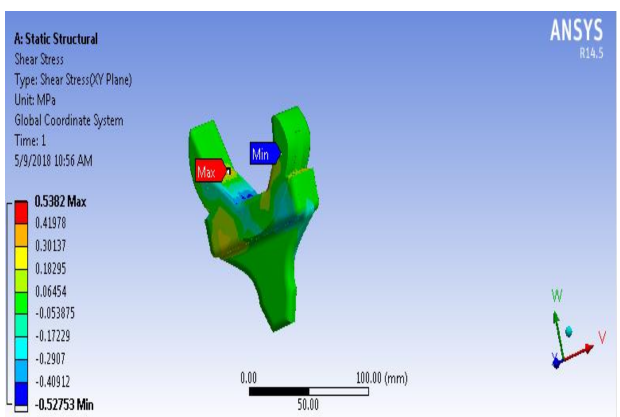

Figure: 14 Shear Stress of SS316l Materials at 3000 N

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(iv) ZrO_2 Material prosthetic knee implants at the load of 3000N

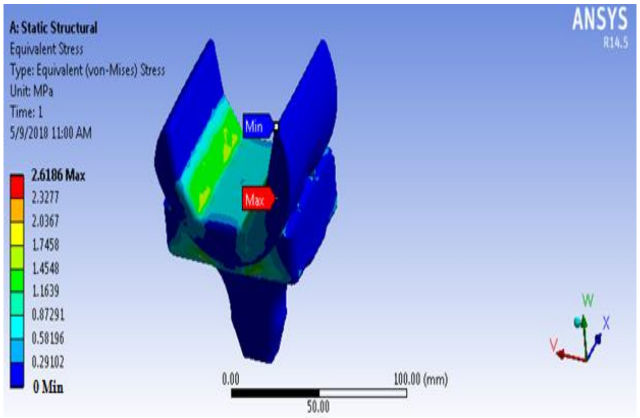

Figure: 15 Von-Mises Stress **of** *$Zr0_2$ material at 3000 N*

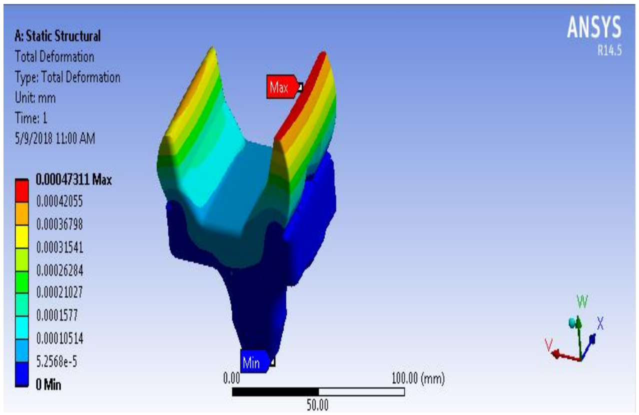

Figure: 16 Total Deformation of $Zr0_2$ material at 3000 N

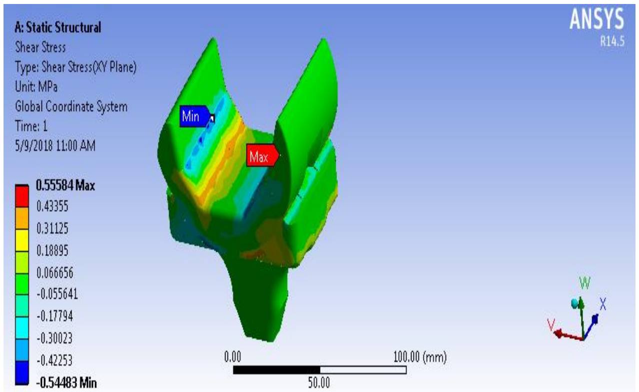

Figure: 17 Shear Stress Of $Zr0_2$ material at 3000 N

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(v) Results Summary

Table: 5 Results summary of Ti-6Al-4V under different loads

Ti-6AL-4V	maximum load(N)	von-mises stress (mpa)	total deformation(mm)	shear stress(mpa)
	1500	1.247	0.00022	0.25
	3000	2.49	0.00045	0.52
	4500	3.7	0.00067	0.778

Table: 6 Results summary of SS316L under different loads

SS316L	maximum load (N)	von-mises stress (mpa)	total deformation (mm)	shear stress (mpa)
	1500	1.26	0.00022	0.26
	3000	2.5	0.00045	0.53
	4500	3.78	0.00068	0.78

Table: 7 Results summary of CO-CR-M0 under different loads

CO-CR-M0	maximum load (N)	von-mises stress (mpa)	total deformation (mm)	shear stress (mpa)
	1500	1.27	0.00022	0.264
	3000	2.577	0.00046	0.54
	4500	3.82	0.00069	0.79

Table: 8 Results summary of $Zr0_2$ under different loads

$Zr0_2$	maximum load(N)	von-mises stress (mpa)	total deformation(mm)	shear stress(mpa)
	1500	1.28	0.00023	0.267
	3000	2.618	0.00047	0.55
	4500	3.86	0.00069	0.8

Analysis of knee joint replacement implant materials under different loading conditions are shown in bar chart in terms of von-misses stresses, displacement, shear stresses

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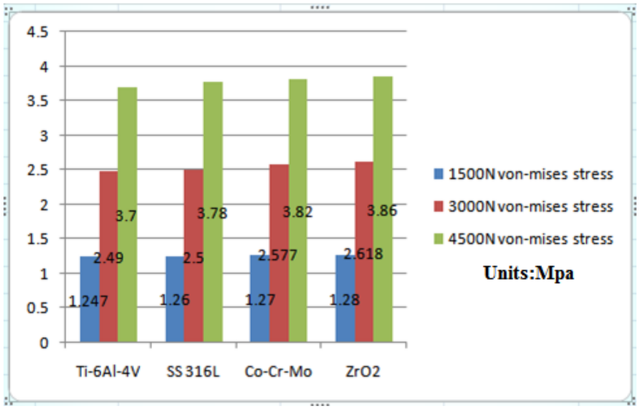
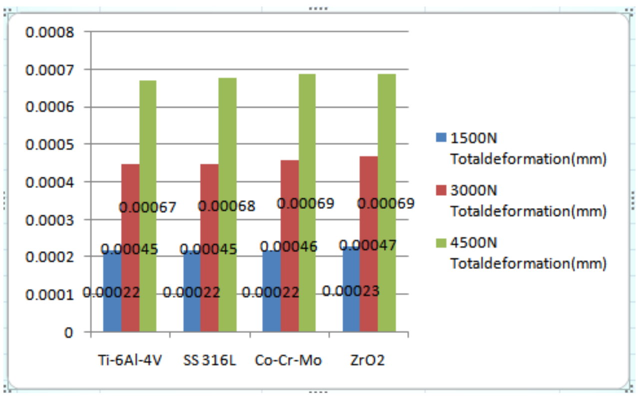
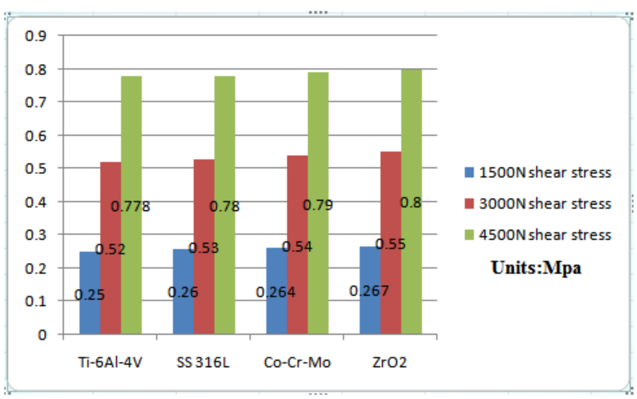
1. von-misses stress bar chart for implant materials under different loading conditions



2. Deformation bar chart for implant materials under different loading conditions



3. Shear stress bar chart for implant materials under different loading conditions



V. CONCLUSION

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

[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.*