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DESIGN AND STRUCTURAL ANALYSIS OF KNEE IMPLANTS USING DIFFERENT MATERIALS

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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 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. Prosthetics are specifically not orthotics, although given certain circumstances a prosthetic might end up performing some or all of the same functionary benefits as an orthotic. Prostheses (or prosthesis) are technically the complete finished item. For instance, a C-Leg knee alone is not prosthesis, but only a prosthetic part. The complete prosthesis would consist of the stump attachment system - usually a "socket", and all the attachment hardware parts all the way down to and including the foot. Based on data base of memory as often nomenclature is interchanged

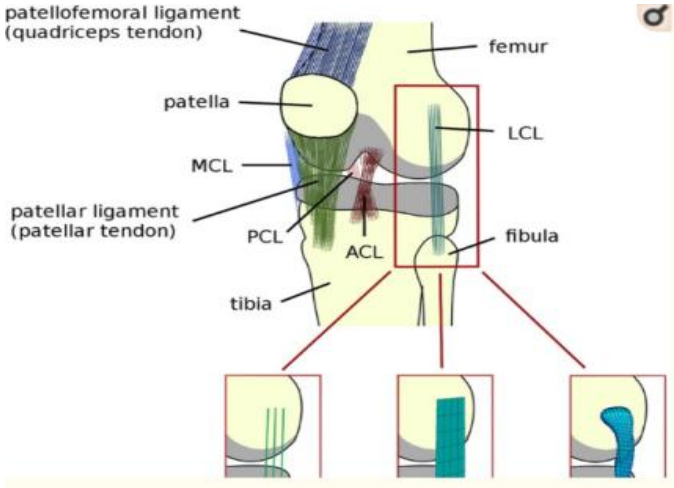

FIGURE 1 PARTS OF KNEE JOINT

1.11 KNEE JOINT:

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. 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.

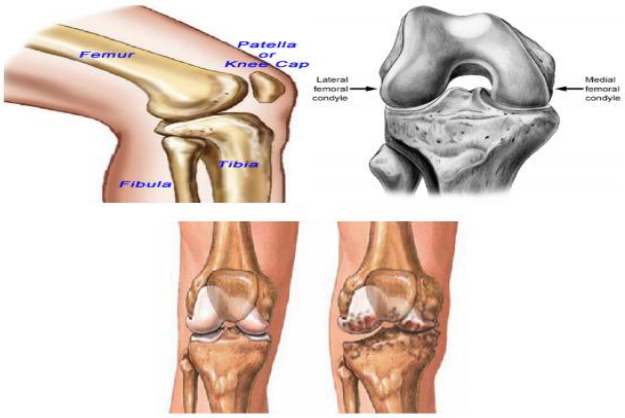

FIGURE 2 PARTS OF KNEE JOINT

II 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.

Knee joint in a human body is made up of mainly 3 components those are tibia, femur and patella with a presence of deformed body. People suffering from knee joint pain and any injury to knee risking every day and in sports activity leads to occurrence of wearing and tearing on the knee joint. Failure and improper functioning of knee joint due to defect occurrence in the knee may lead to operative solution i.e. removal of components of the knee with an artificial implant termed as knee prosthesis. Examination of defect in knee can be done by X-ray and CT scan as well as with MRI imaging. Mostly knee replacement is done through a small incision, small as 3-4’. According to the defect and failure condition total and partial knee replacement is carried out. In total knee replacement a large implant is inserted in place of the knee joint which favors long term durability and biocompatibility. In spite of excellent working and result it frequently fails in around 4-5 yrs due to chronic inflammation of generated wear particles which results in implant failure giving defective outcomes. Those wear particles interact with the immune system leading to toxicity affects in in- vivo.

Due to this hypersensitivity reaction occurred from immunotoxic. Ni, Co, Cr are common sensitizer but when comes in contact with Ti and its alloy they show hypersensitive reaction leading to corrosion and wear of metal implant.

The usefulness of material tested according to hypersensitivity of the material as respect to the sensitizers CoCrMo towards the implant material and checking its reliability of the properties of the implant in the target site and its compatibility and durability checking its toxicity rate. Partial knee replacement is done by two methods i.e. unicompartmental partial knee replacement and tri/bicompartmental partial knee replacement. In unicompartmental partial knee prosthesis a Unicondylar fixed bearing knee implant, which is the most commonly used modeled prosthesis or a mobile bearing knee implant. Bi or Tricompartmental partial knee implant consists of one or more component of knee causing less damage to any healthy ligament during the implantation procedure.

2.2 KNEE PROSTHESIS:

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 .

2.2 KNEE REPLACEMENT:

Knee replacement is also termed as knee anthroplasty. A surgical method of replacing the load bearing surfaces present in the knee joint so as to cure the pain bearing regions and disability areas of the joint . Knee replacement is the surgical technique which has been carried out mostly during the cases like osteoarthritis. Other causes which may lead to pain in the knee joints are due to ligament tearing, cartilage defects, pain due to meniscus tearing etc. Knee replacement can be done using two methods i.e. by Total Knee Replacement and other is Partial Knee Replacement [6]. The principle of knee replacement technique is to remove those defective and damaged joint parts and surfaces of knee and replacing it with an implant made of metal and plastic.

2.3 TECHNIQUE OF KNEE REPLACEMENT:

Knee replacement is a surgical method where initially a post-operative method is being followed up so as to carry out the surgical method. In this first of all an X-Ray is done of the load bearing of knee joint for the knee replacement of both lateral and AP of knee with 30° flexion of knee were 30° flexion is done to see the narrowing occurred in between the joints of knee. With the X-Ray imaging, MRI is also done to see the cartilage effects and its defective regions to use to carry out the replacement and incorporating specific implant in that region. After that, the person going through the post-operative exercises being asked to perform certain physical activities like motion of the hip, knee, rotation of knee, hip, walking, sit ups etc. before entering to the surgery. Image collected from X-ray should be accurate for the measurement of the size of the different components of the implant replacing the organ .

III PROJECT OVERVIEW

3.1 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.

SPECIFIC OBJECTIVES:

1. General evaluation of mechanical reliability for knee implants in terms of stress concentration.
2. Determining the proper material using FEM.
3. Analyzing the stress concentration on femur and tibia knee implants prosthesis geometry.
4. Finally find out stress, total deformation, shear stress
5. Recommending the geometry and the suitable material we should be using in future implant surgery.

3.2 METHODOLOGY:

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 MATERIALS PROPERTIES:

MATERIAL PROPERTIES	(Co-Cr-Mo)	Titanium Alloy (Ti6Al4V)	Stainless steel 316L	Zr02
YOUNG?S MODULUS (GPA)	230	114	165	180
TENSILE STRENGTH (MPA)	530	850	580	564.8
ULTIMATE TENSILE STRENGTH (MPA)	890	960	515	570
DENSITY (KG/M^3)	8300	4420	8000	7800
POISSON RATIO	0.3	0.35	0.3	0.36

FIGURE 3(A) MATERIAL PROPERTIES

3.4 CONSIDER THE LOAD:

F=mg is the equation for the force of gravity. where, F is the force pulling objects toward the Earth. m is the mass of the object. g is the acceleration due to gravity; this number is a constant for all masses of matter. Studies have consistently estimated maximum compressive forces of the knee joint to be four to 4.5 times body weight during daily activities. During level walking, some studies have even estimated a higher number.

HUMAN LOAD	NEWTONS
152.96	1500
356.9	3000
407.89	4000

FIGURE 3 (B) LOADING CONDITIONS

3.5 DIMENSIONS OF KNEE PROSTHESIS

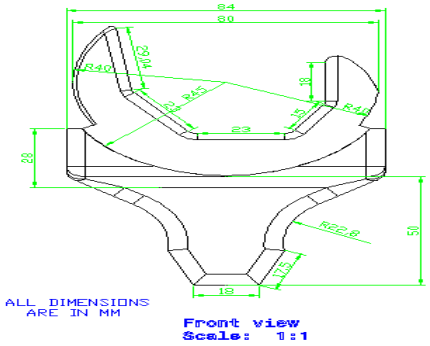

FIGURE 2 ASSEMBLY OF MODEL OF FEMUR AND TIBIAL

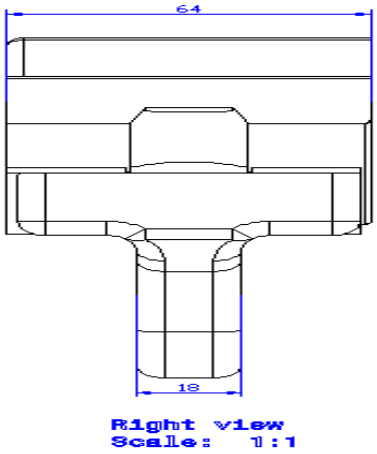

FIGURE 3 PROSTHETIC KNEE ASSEMBLY

IV DESIGN PROCEDURE IN CATIA

4.1 FEMUR DESIGN PROCEDURE:

Create the circles in sketcher workbench 45 and 40 Radius, after create the distance is 29.4,23,23,15,18 as shown above figure after go to the part design apply pad 64mm their again select the centre plane project the outer circle after create the plane on the arc create the circle radius is 7.5 after apply the slot as shown above figure.

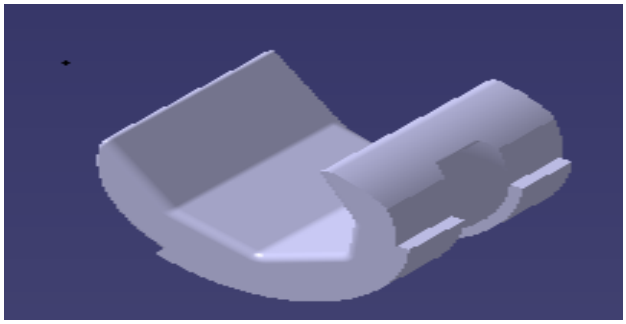

FIGURE 6 FEMUR OF KNEE IMPLANT

4.2 TIBIAl DESIGN PROCEDURE:

Create a circle radius is 45 mm after create the box dimensions is 84x28 after create v shape design as per above dimensions after go to Part design work bench apply pad is 18mm, again project the centre plane project the centre circle go to the plane create the circle radius is 7.5 apply rib option after go to fillet option apply radius is 7.5mm all boundaries.

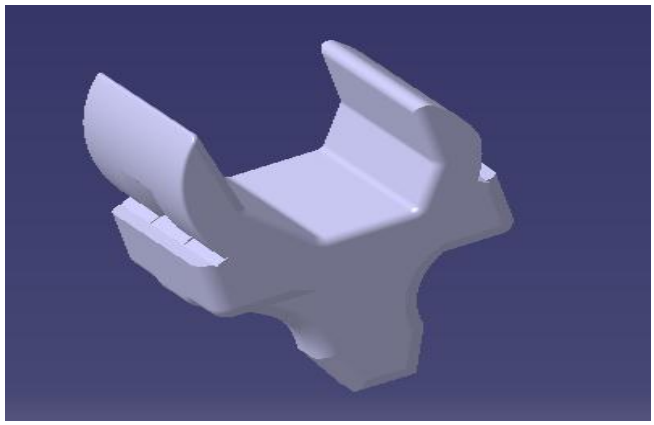

FIGURE 4 FEMUR AND TIBIAL ASSEMBLY COMPONENTS

V STEPS INVOLVED IN ANSYS

5.1 ANALYSIS PROCEDURE IN ANSYS:

Designed component in CATIA V5 workbench after imported into ANSYS workbench now select the Static ANALYSIS.

1.ENGINEEERING MATERIALS (MATERIAL PROPERTIES).
2. CREATE OR IMPORT GEOMENTRY.
3. MODEL (APPLY MESHING).
4. SET UP (BOUNDARY CONDITIONS).
5. SOLUTION.
6. RESULT.

5.2 PROCEDURE OF STATIC ANALYSIS ANALYSIS:

Create the geometry in Catia workbench and save the file in igs 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).

5.3 MESHING AND BOUNDARY CONDITIONS:

Meshing of artificial knee rosthesis for analysis knee implant imported to Ansys orkbench 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 are 14547 and fixed top side and apply forces1500,3000,4500 N as shown below figures.

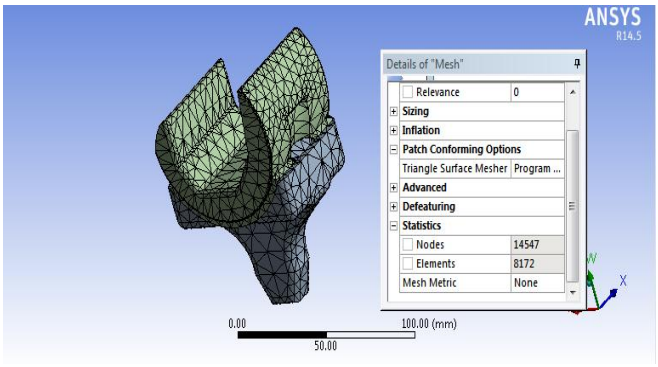

Figure 5 Meshing of knee implants

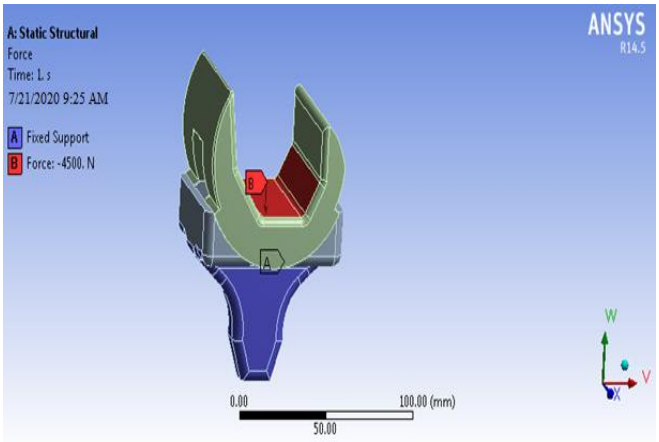

Figure 6 LOAD IS 4500N

VI RESULTS AND DISCUSSION

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

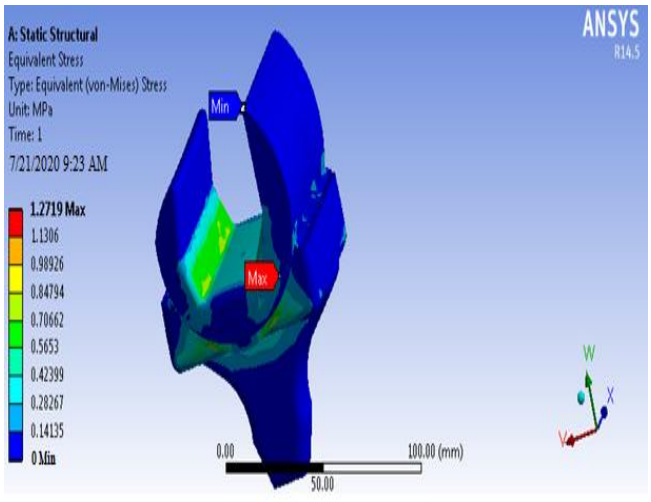

Figure 7 VON-MISES STRESS OF CO-CR-MO ALLOY AT 1500N

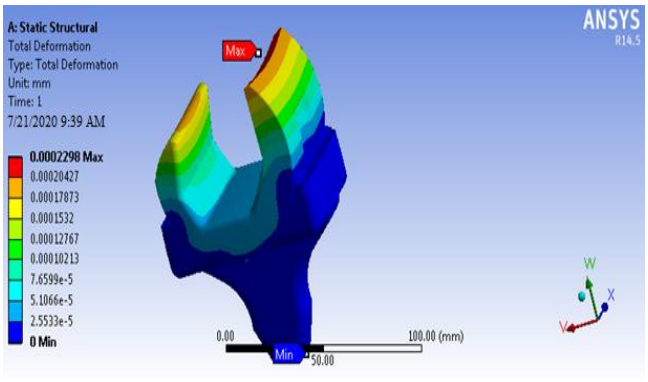

Figure 8 TOTAL DEFORMATION OF CO-CR-MO ALLOY AT 1500N

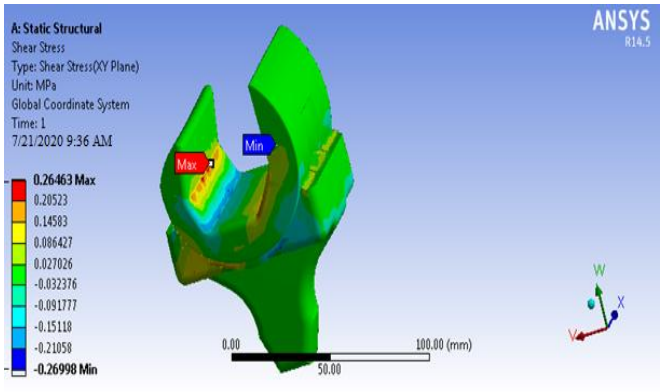

Figure 9SHEAR STRESS OF CO-CR-MO ALLOY AT 1500N

VII GRAPHS:

7.1 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.

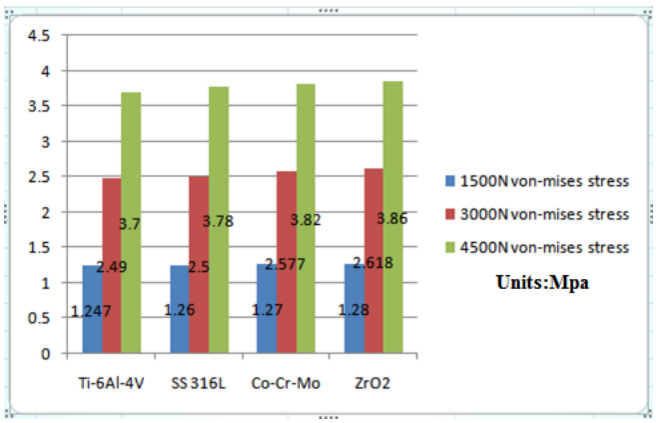

Figure 10VON-MISES STRESS (Mpa)

7.2 TOTAL DEFORMATION:

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.

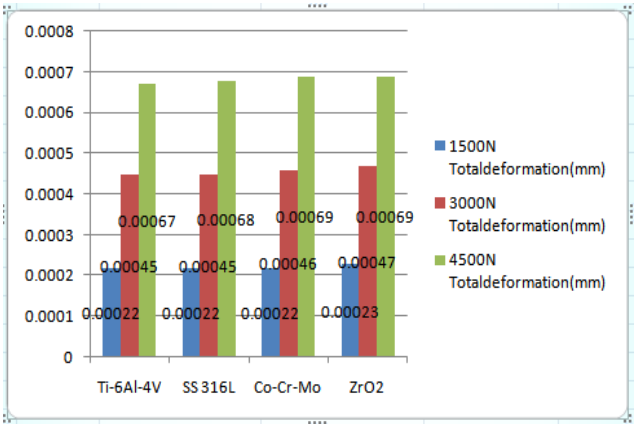

Figure 11TOTAL DEFORMATION (mm)

7.3 SHEAR 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.

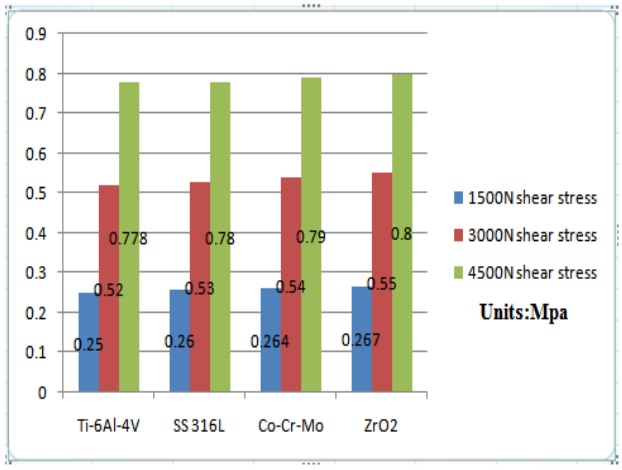

Figure 12 SHEAR STRESS

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 a 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 is the increase the life span.

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