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OPTIMIZATION OF KNEE IMPLANT ADVANCE BIOMATERIAL USING FINITE ELEMENT ANALYSIS

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ABSTRACT

Joints in general represent junctions between two or more different bones, which can be attached by bone (synostosis), cartilage, fibrotic tissue or by a true joint cavity. The knee is the abundant synovial joint of the human body and it is one of the most complex. The use of artificial joints for the treatment of osteoarthritis is expected to expand considerably over the next decade, and the tribological testing of artificial knee joint in the laboratory has been ongoing for several decades. Orthopedic materials must fulfill the mechanical, biological and physical properties. The materials that are utilized as biomaterials incorporate polymers, metals, ceramics and composites. Out of those material titanium alloys, zirconium alloys, trabecular metal and UHMWPE most usually utilized biomaterials for knee implants. The aim of this study is to find out best implant material by considering different flexion angles (0˚-120˚) and loads (850N,1500N,4000N,5000N) acting on knee compartment like the femur, tibia, patella, so that to improve performance and implant survival. 3D modeling software is used to design a knee implant and finite element analysis is done by using software for numerical estimation of Von-misses stress, Total deformation and Wears factor. The implant material considering at different flexion angles and with vertical loading conditions by comparing the results of various biomaterial find out the best implant biomaterial for knee joint replacement.

Keywords: Artificial knee joint, Implant biomaterial, Von-misses stress

1. INTRODUCTION

Knee joint is the abundant and weighty joint of human body. It has three compartment medial, lateral and patellofemoral and four bones femur, tibia, fibula and patella. The joint is filled with synovial fluid inside the synovial membrane. Functions knee provides

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mobility and support during dynamic and static activities, it permits movements as extension (5˚-10˚) and flexion (120˚-150˚), as well as a slight medial and lateral rotation about the axis of lower leg in flexed position. Any kind of work during which knee undergo heavy stress may lead to knee pain, stiffness and degeneration as well, age also contributes to disorders of the knee particularly in older people, knee pain frequently arises due to osteoarthritis. In addition weakening of tissues around the knee may contribute to the problem, some more causes are accidents, injuries considerable strain on the knee, wear off etc. To overcome these problems some techniques are used such as arthroplasty, osteotomy prosthesis and implants this is nothing but artificial knee joint replacement they should be ergonomical, biocompatible and should satisfy the purpose. The materials that are used as biomaterials include polymers, metals, ceramics and composites. The metals used as biomaterials include titanium alloys, zirconium alloys, and stainless steels. In polymers UHMWPE (ultra high molecular weight polyethylene) is most commonly used biomaterial. On the basis of their properties like highly resistant to corrosive, low coefficient of friction, better abrasion and high strength which gives long survival to knee implants. The objectives of this paper are:

- To select the best material for knee implant as per the physical and mechanical properties.
- To study the nature of stresses and tribological parameters viz., wear factor, friction at different flexion angles.
- We studied the von misses stress on with the different biomaterials by applying load at various loading conditions with the use of Finite Element Analysis and find out best suited biomaterial.

After the replacement process stresses are developed at the interface of joint. This will lead in the performance of joint. To ensure the stress intensity, improved performance, it is important to optimize biomaterials, parameters at different conditions. Finite element analysis is the important tool to optimize the design of implant. FEM is the best understood from its practical application, known as finite element analysis.FEA as applied in engineering is a computational tool for performing engineering analysis. It

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includes the use of mesh generation techniques for dividing a complex problem into small elements as well as the use of software program coded with FEM algorithm. FEA is a good choice for analyzing problem over complicated domains, when domain changes (as solid state reaction with a moving boundary). **(Refer Fig.1.2)**

2. LITERATURE REVIEW

Knee replacement is a procedure of orthopedic surgery in which infected, damaged or dysfunctional joint is replaced with an implant. Whole leg is when replaced called prosthesis replacement also called artificial joint replacement. Knee replacement surgery can be performed as partial or total knee replacement. Major causes for knee replacement knee pain in older age, weakening of tissues, menisus tear, wear between femur and tibia while knee in motion. To overcome all these causes knee replacement is required to improve range of motion and longevity of knee joint.

In 1890 Gluck, he is from the charite hospital in berlin he proposed a fixed hinged knee replacement design. Due to short term failure gluck later improved this surgical procedure with UHMWPE in knee replacement.

Later in 1960s and 1970s Frank Gunston and Ewald, developed cemented implant design. Early use of individual condyles resurfacing of femur and tibia. Total knee arthroplasty is studied which replaces femure and tibia, as well as femure and patella. Gunston himself machined the first UHMEPE components for TKA. The main adoption of UHMWPE for TKR is in same year 1970 with incremental improvement in design of knee components to eliminate problems with loosening, wear and positioning.

3. METHODOLOGY

In this study biomaterial analysis of titanium alloy, zirconium alloy, tantalum and UHMWPE have been carried out using FEA. Finite element analysis (FEA) is a very powerful tool for the evaluation of biomechanics in orthopedics. Finite element (FE) simulations can effectively and efficiently evaluate thousands of variables (such as implant variation, surgical techniques, and various

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pathologies) to optimize design, screening, prediction, and treatment in orthopedics.

Finally, FE simulations are used to evaluate implants, procedures, and techniques in a time- and cost-effective manner. In this work, an overview of the development of FE models is provided and an example application is presented to simulate knee biomechanics for a specimen with medial meniscus insufficiency. FE models require the development of the geometry of interest, determination of the material properties of the tissues simulated, and an accurate application of a numerical solver to produce an accurate solution and representation of the field variables.

Finite Element Analysis of Knee Implants-

Finite Element Analysis (FEA), is a numerical method for solving problems of engineering and mathematical physics. The method yields approximate values of the unknowns at discrete number of points over the domain. To solve the problem, it subdivides a large problem into smaller, simpler parts that are called finite elements. These finite elements are then assembled into a larger system of equations that models the entire problem.

The subdivision of a whole domain into simpler parts has several advantages

- Accurate representation of complex geometry
- Inclusion of dissimilar material properties
- Easy representation of the total solution
- Capture of local effects.

FEA is a good choice for analyzing problems over complicated domains (like cars and oil pipelines), when the domain changes (as during a solid state reaction with a moving boundary), when the desired precision varies over the entire domain, or when the solution lacks smoothness.FEM is best understood from its practical application, known as **finite element analysis (FEA)**. FEA as applied in engineering is a computational tool for performing engineering analysis. It includes the use of mesh generation techniques for dividing a complex problem into small elements, as well as the use of software program coded with FEM algorithm

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Set of procedures that cover :

(a) The creation of finite element meshes,

(b) The definition of basis function on reference elements (also called shape functions) and

(c) The mapping of reference elements onto the elements of the mesh.

FEM allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements. FEM software provides a wide range of simulation options for controlling the complexity of both modeling and analysis of a system. Similarly, the desired level of accuracy required and associated computational time requirements can be managed simultaneously to address most engineering applications. FEM allows entire designs to be constructed, refined, and optimized before the design is manufactured. Benefits of FEM include increased accuracy, enhanced design and better insight into critical design parameters, virtual prototyping, fewer hardware prototypes, a faster and less expensive design cycle, increased productivity, and increased revenue.

For the FEA, the IGES or STP file with femur and tibia is imported in software. The model is mesh with element type tetrahedral element with 534968 nodes and 356403 are elements. Total number of elements. The Finite element analysis of knee joint has carried out for different loading condition, range of motion (Flexion angle of knee) and observed Von misses stress, total deformation as per material properties. **(Refer Table.3.1)**

Methods design mainly involves the following Steps:

Stress analysis of implants materials (Ti6Al4V, ZrO2, Tantalum)

Force (N) : 850,1500,4000,5000

Flexion Angle: 0^0 - 120^0

CONCLUSION

- Finite element analysis of the knee joint has great significance, as analytical results gives knowledge about the mechanical behaviour of knee implant under loading conditions.

- From the FEA analysis when knee is in straight position (at 0 deg with

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vertical load) the knee is safe and gives good results for all selected biomaterials- Ti-6Al-4V, ZrO_2,Tanatalum and UHMWPE.

- Loading at different flexion angles knee implants are well with von-misses stress as shown in results.
- Knee implant made from ZrO_2 shows little bit high stress compare to others so its performance is not as good as others.
- Polymer insert of UHMWPE made from Ti-6Al-4V and Tantalum is best material of choice for knee implant because it shows the minimum stress at extreme flexion and loading condition.

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Fig 1.1 Steps used for Knee modeling FEA analysis

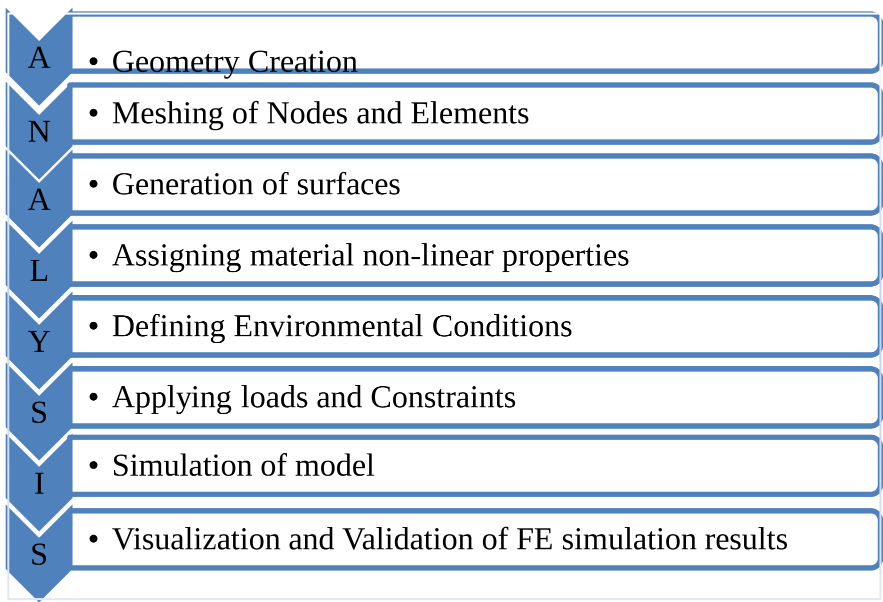

Fig 1.2 Anatomy of Knee Human Joint

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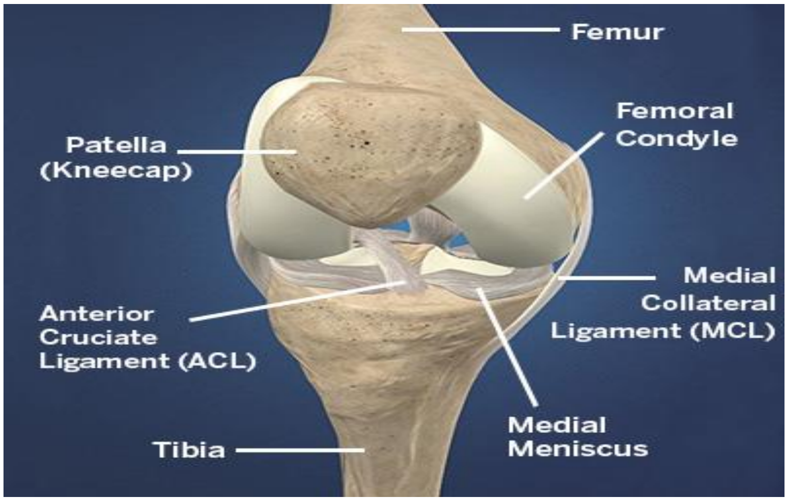

Fig 1.3 Von-misses stress at maximum flexion angle 120˚ with load 5000N for Ti6Al4V

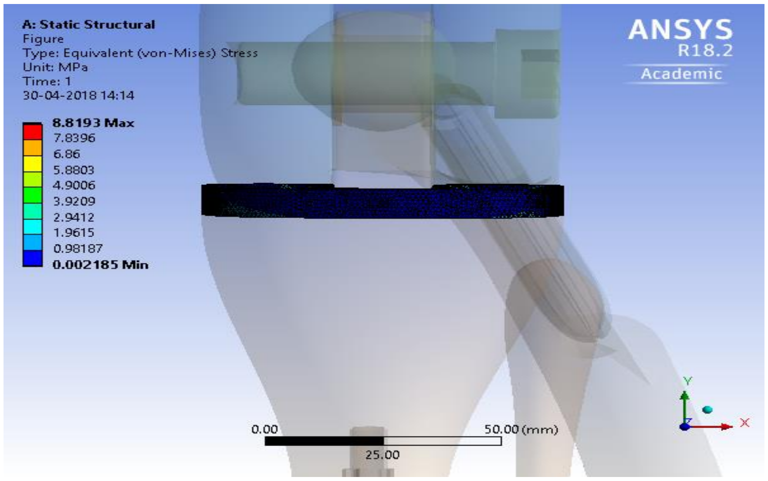

Fig 1.4 Von-misses stress at maximum flexion angle 120˚ with load 5000N for Tantalum

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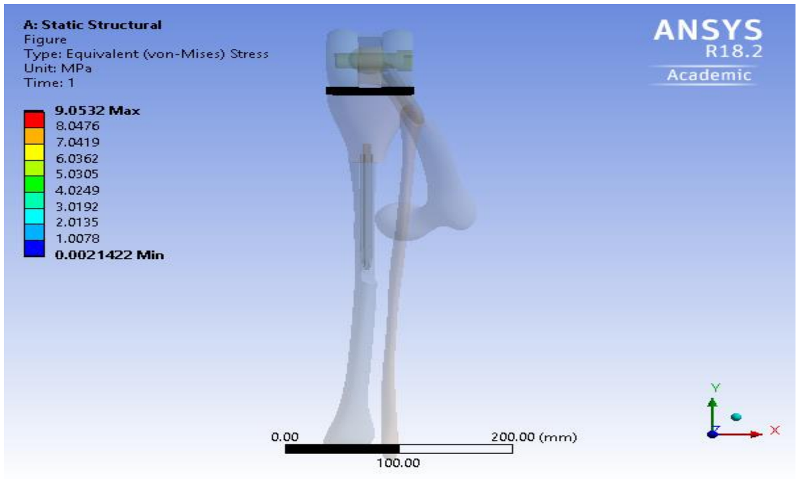

Fig 1.5 Von-misses stress at maximum flexion angle 120˚ with load 5000N for ZrO2

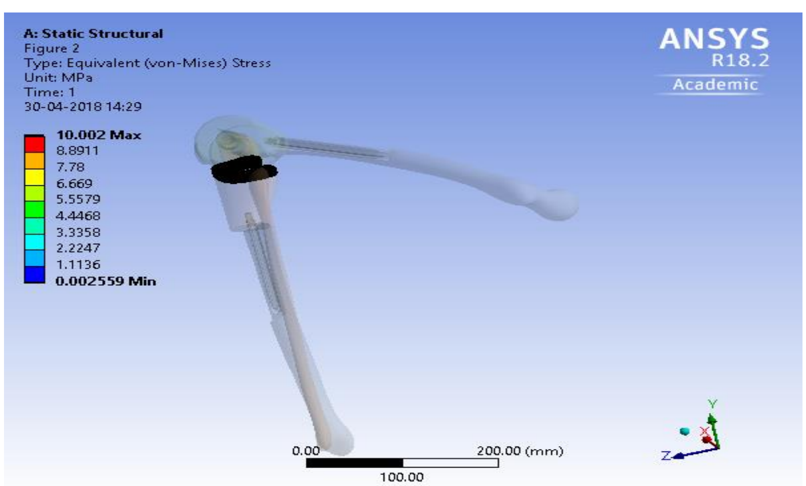

Fig 2.1 Stress Vs Load for material Ti6Al4V

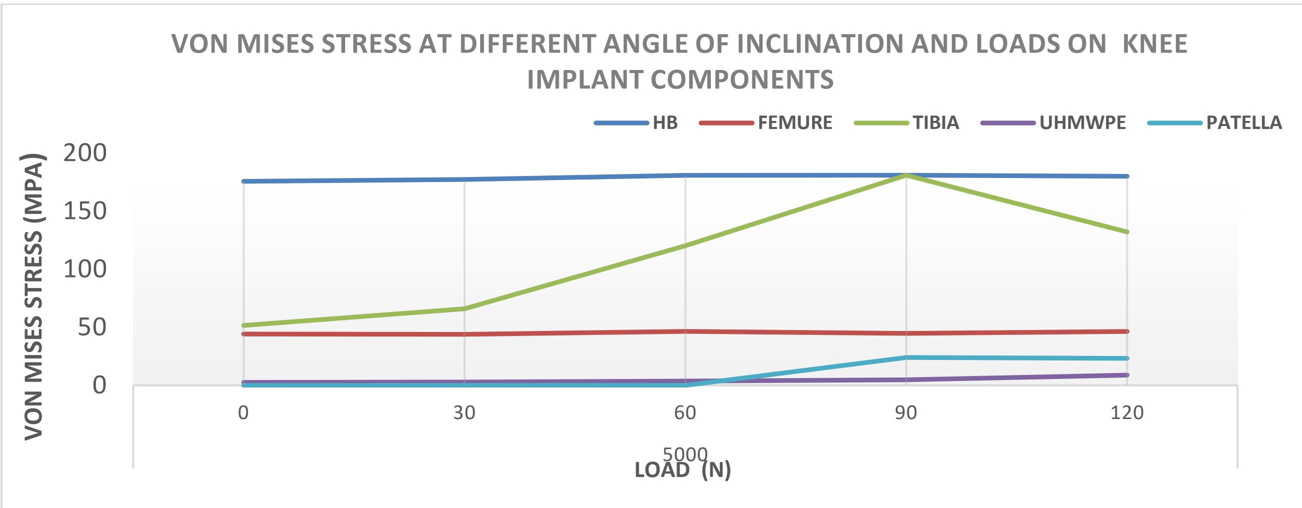

Fig 2.2 Stress Vs Load for material Tantalum

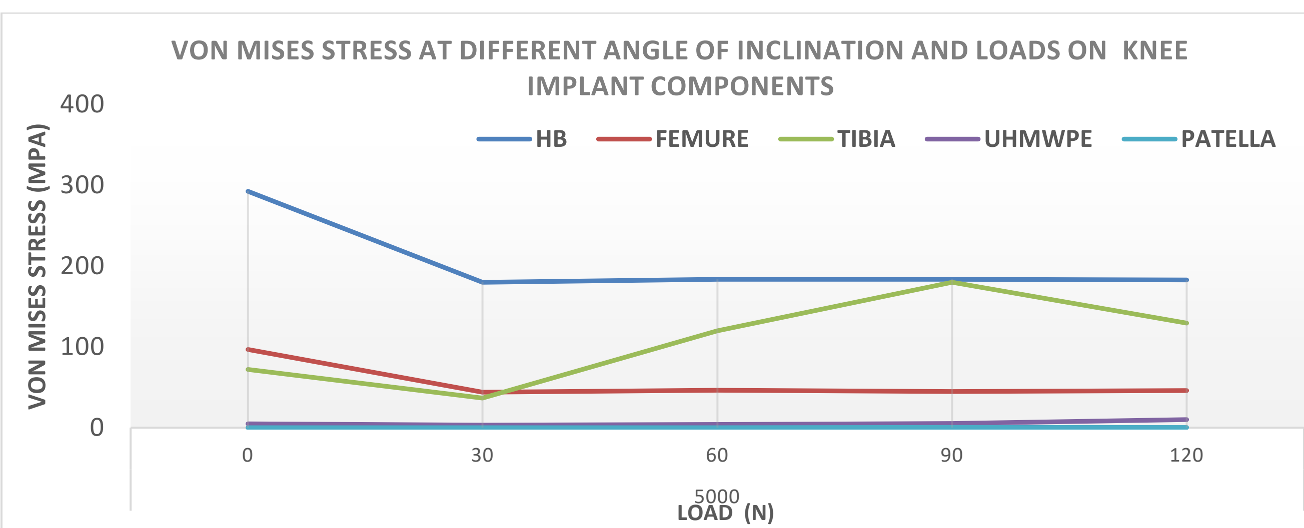

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Fig 2.3 Stress Vs Load for material Oxidized Zirconium

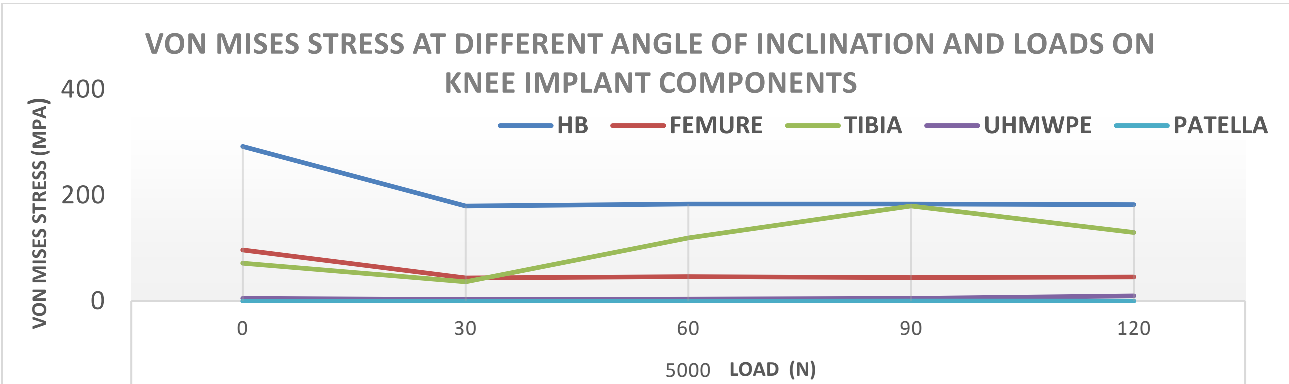

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Table 3.1 Properties of knee implant biomaterial

Material	Density (g/cm^3)	Young's modulus (Gpa)	Yield Strength (Mpa)	Ultimate Tensile Strength (Mpa)
Ti6Al4V	4.42.4.5	113	880	950
ZrO2	6.52	100	900	330
Tantalum	16.60	3	48	67
UHMWPE	0.94	0.69	21-28	39-48

Table 3.2 Comparison of Von-misses stress for different implant biomaterials at extreme

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Material	Stress On Polymer Insert (Mpa)	Stress on Human Bone (Mpa)
Ti6Al4V	8.8193	180.09
ZrO2	10.002	182.59
Tantalum	9.055	180.57