Design And Analysis of Prosthetic Knee Implant

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Abstract- *In the midst of ever-increasing population, there are many old and young people face a problem in their knee joint once in their lifetime. The cases would be degenerative arthritis and accidents, respectively. If the accidents are severe and cause unrecoverable damage, arthritis in depleting line cartilage of knee joint of people above the age of 50 often result in replacing the knee joint permanently. The purpose of this paper was to design a model of a prosthetic knee joint from the available literature and examine the distribution of contact stresses at the same by assigning it the material properties of Stainless Steel and Titanium Nitride as a coating for the Femur component in the knee implant. The Finite Element Analysis of the knee implant for the above material is calculated. Commercially available software (ANSYS 19.0) was used for the numerical estimation of contact stress. The effects of different weight on stresses in the joint were investigated.*

Keywords- Knee joint, contact stress, Finite element analysis

I. INTRODUCTION

Accidental injuries and illnesses result in impairment and degradation of body parts. These parts need to be replaced or repaired [2].Orthopaedic implants play a vital role in case of replacement of joints rebuilding of tissues, fixation of fractures etc. Implants are also employed in dentistry and ophthalmology. Ageing generation and people, whose activity level is affected because of damaged body parts due to accidents or diseases, wish to assert the same activity level and life quality as before. This has triggered the demand for development of implants. Another significant fact is people aspire for beauty and aesthetics in their personalities; this also has boosted the use of implants in cosmetics, plastic surge and dentistry. Degenerative arthritis of the knee joint is a disease that affects the lining cartilage of the tibia and the femur. It causes severe pain and may necessitate a replacement surgery of the affected knee with artificial components [3]. Artificial joints should satisfy certain design requirements, i.e., they should be ergonomic and biocompatible. During the use of the joint, stresses are developed at the interface of the joint, which dictates the operation of the joint. The volume of the stresses developed depends on several factors. To ascertain the stress intensity, it is important to optimize the design of a prosthetic knee joint. In this regard, FEM the most powerful numerical tool can be employed to optimize the design and improve the condition.

The primary objective of the paper is to develop a three-dimensional solid model of the knee joint and studied the effect of the distribution of contact stress and performance of the knee joint made out stainless steel with a titanium nitride as a coating while using Zirconia for the spacer.

II. IMPLANT DESIGN

There are two major components involved in the knee joint which are Femur and Tibia. The femur is the upper part and tibia in the lower portion of the knee. In TKR, the diseased cartilage surfaces of the femur, tibia and patella are replaced by prostheses made of metal alloys and high-grade polymeric materials [8]. The factors that are studied in the design are the easy movement of the tibia and the spacer component. The improper design may result in causing stiffness and other issues. For simplicity, the knee can be regarded as a hinge joint due to its flexion and extension ability. In reality, the joint represents a more complex structure because the knee flexion comprises of both rotational and translational motion.

The metallic femoral part bends around the finish of the condyle and has an inside depression so the kneecap can go all over easily against the bone as the knee flex and broaden. Some posteriorly stabilized designs have an internal post with a circular shaped cam that works with a corresponding tibial component to help prevent the thighbone from sliding forward too far on the shinbone when the knee is bent [9].The mechanical properties of the implant must be able to duplicate the natural structures to be replaced.

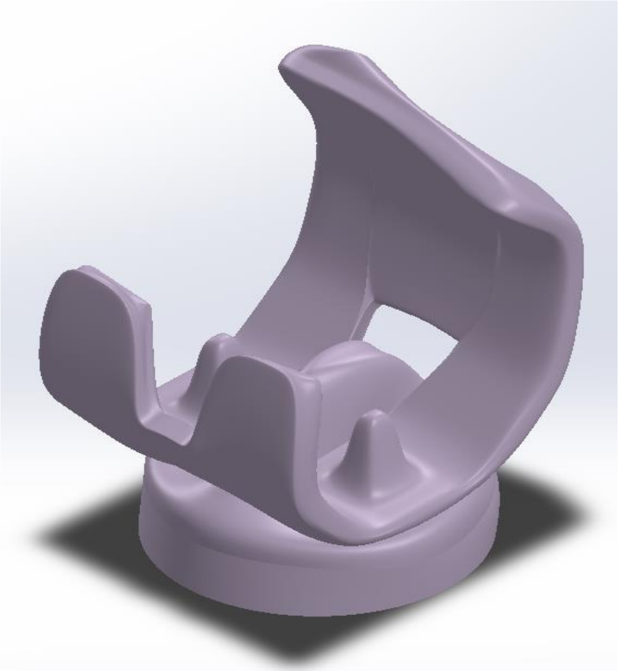

FIGURE.1. 3D MODEL OF KNEE JOINT

The design was done in Solidworks 2019. The dimensions were obtained from the literature [4]. The sagittal radii are the femoral component radii. Average human Knee femoral component was obtained and the sagittal radii were chosen as 55mm respectively. The component which holds the femoral component is known as a spacer or plastic component. It acts as a Joint for the femoral and the tibial component. The material should be substantial enough to bear the full body weight under repetitive loading in daily activities, flexible enough to bear stress without breaking and able to move smoothly against each other as required. Besides, the material should retain its strength and shape.

III. MATERIAL SELECTION

The main purpose of orthopaedic implants is to reinstate healthier and capability of defaced joints and bones.[1] To produce safe implants with a long lifetime and without causing rejection from the body, the biomaterials should own desirable characteristics, including mechanical properties, wear resistance, corrosion resistance, and biocompatibility.The mechanical requirements for orthopaedic implant materials are related to the intended working conditions and specific applications. The Young’s modulus, yield strength, ultimate tensile strength, fracture toughness, and elongation at break are five important mechanical properties. Other special mechanical properties such as resistance against fatigue can be correlated to and predicted from these five properties.If the implant materials have a larger Young’s modulus than the human bone, stress transfer to the adjacent bone will be prevented leading to bone resorption and implant loosening. Therefore, the orthopaedic implant materials should preferably have Young’s modulus similar to that of the human bones.In the human body, fatigue can happen along with stress and corrosion, which is known as fretting fatigue or fretting corrosion fatigue. Fatigue fracture becomes the major cause of premature failure of biomedical implants, and hence, materials with excellent fatigue strength are preferred for orthopaedic implants. Generally, materials with high ultimate tensile strength, Young’s modulus, and yield strength tend to have excellent fatigue resistance. Furthermore, the fracture toughness of implant materials, especially brittle ceramics, should be assured to resist crack propagation under a load, and a certain amount of elongation is also needed to improve the manufacturability.

A. Biomaterials

A biomaterial is used to make devices to replace a part or a function of the body in a safe, reliable, economic, and physiologically acceptable manner [5]. The success of biomaterials in the body depends on factors such as the material properties, design, and biocompatibility of the material used, as well as other factors not under the control of the engineer, including the technique used by the surgeon, the health and condition of the patient, and the activities of the patient. Biocompatibility involves the acceptance of an artificial implant by the surrounding tissues and by the body as a whole. Biocompatible materials do not irritate the surrounding structures, do not provoke an abnormal inflammatory response, do not incite allergic or immunologic reactions, and do not cause cancer.

B. Stainless steel –SS316L

Stainless steel has been utilized as an implant material since the early 1900s. In the initial period, bio-functionality was mainly considered for selection of biomaterials. It is invariably easy to satisfy the mechanical and physical functionality criterion. Thus, metals were the best choice traditionally. Metals have excellent fracture and fatigue resistance; hence it was a safe choice for traditional load-bearing applications. When metals were considered as a biomaterial, the susceptibility of metals to corrosion and its effect on body tissues were main factors considered to judge their biocompatibility. SS316L was popularized as a surgical implant material because of its corrosion resisting property. When it contacts with the body fluid. The Major advantage of SS316L is the lack of inclusion in this material. Material with inclusion will contain sulfur, which is a major factor that encourages corrosion. SS316L contains 17 to 19% of chromium and 14% nickel this enhances its corrosion resistance [6]. Mechanical properties and cost-effectiveness & machinability are also the major factors in preferring of SS316L as an implant material. Despite being a popular implant material, SS316L implant failed to examine itself as ideal biomaterial [6]. Following are certain concerns about the use of SS316L.

- Wear resistance of SS316L is comparatively low. As a result after a certain time,the joint gets loosen due to wearing of metal. 90% of Corrosion resistance of SS316L relies on its passivation by this surface layer of oxide as stainless steels are least corrosion-resistant.[6]
- Implants fail before the prescribed period.[7]
- Wearing of SS316L releases microscopic properties, which are trapped in the tissue which leads to body reaction [7].
- The metal or ions released may lead to tissue damage and inflammatory reaction [10].
- SS316L implants prematurely fail due to crevice corrosion [6].

These factors indicate that the surface failures are the root cause of this implant material. Hence a proper coating improves the surface flaws as well as improve the performance of the implant material.

C. Titanium Nitride

Titanium nitride is a material of interest because of its excellent wear resistance, corrosion and erosion resistance and diffusion barrier properties [11].The titanium nitride coating has been used for implants for a particular period. The main idea to choose this coating film is to improve the corrosion resistance of stainless steel. It has been noted that crevice corrosion occurs in the stainless steels. The process of applying a thin film of coating ensure the corrosion as well as improving the wear resistance of the implant

IV. FINITE ELEMENT MODEL OF PROSTHETIC KNEE JOINT

Finite element analysis (FEA) is a widely used technique to analyze stress-strain states in various biomedical devices and prosthetic bone joints, in particular. The software used was ANSYS WORKBENCH 2019 R3.Geometric models of the tibial and spacer component were selected to be imported.Three-dimensional models of the knee joint of 55mm with different weights were imported andanalyzed. SS316L- Stainless Steel with Titanium Nitrate as a coating for the femur part was applied in the FEA software. The finite element model was generated by meshing the solid model with meshing space of 4mm. The boundary conditions were set as fixed support for the face of the spacer component.

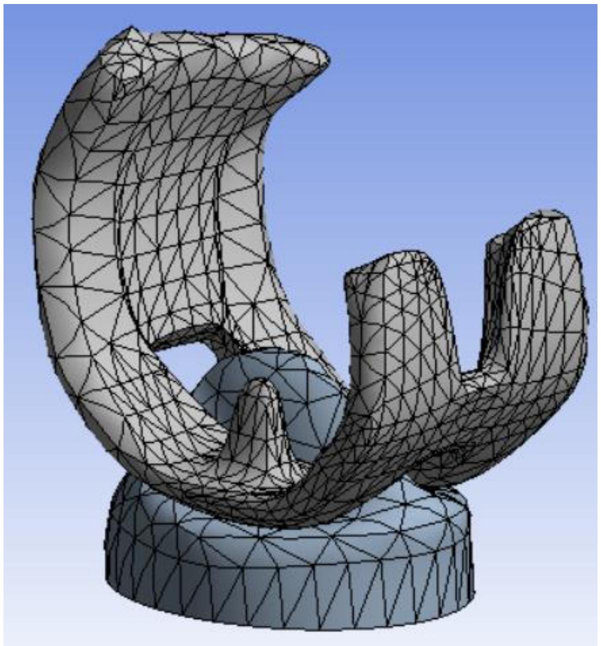

FIGURE.2. FINITE ELEMENT MODEL OF PROSTHETIC KNEE JOINT WITH BOUNDARY CONDITIONS

A compressive load was applied to the femoral component at the bearing points. Stresses were analyzed for a particular femoral-tibial alignment position.

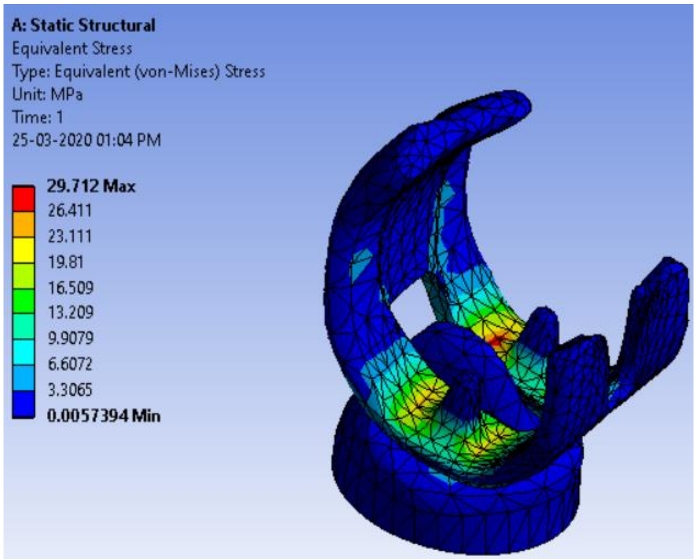

FIGURE.2.VON MISES STRESS DISTRIBUTION FOR 1000 N LOAD

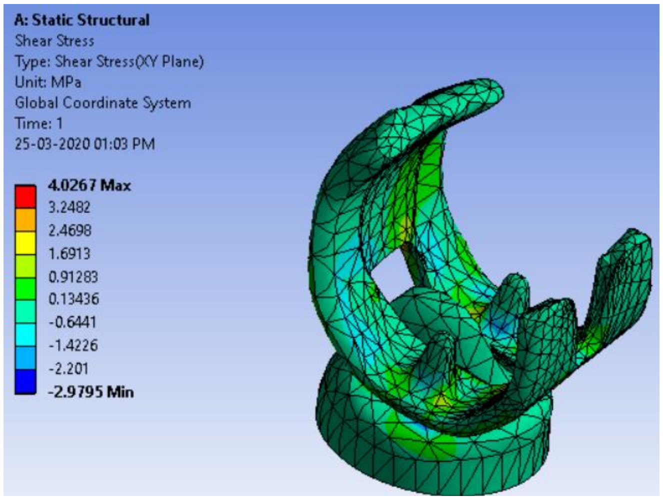

FIGURE.3. SHEAR STRESS DISTRIBUTION FOR 1000 N LOAD

A. Stress distribution on different weights

The tibial and the femur component are applied with a different load to understand the stress distribution of the material. The von Misses stress and the shear stress values are obtained from the software. The boundary conditions are applied the same and the mesh is generated. The load value is applied in a range, based on the average weight of the human body.

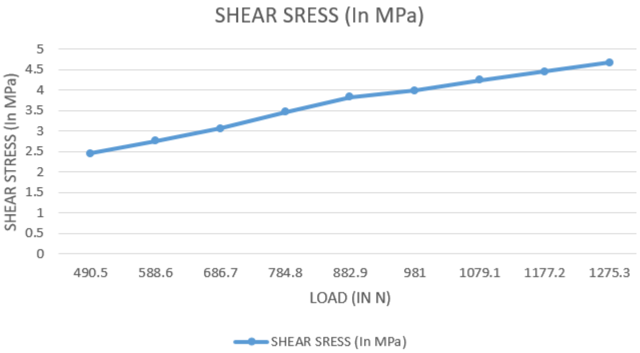

FIGURE.4. SHEAR STRESS FOR DIFFERENT LOADS

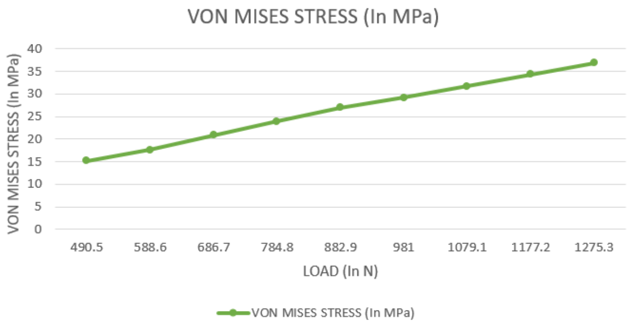

FIGURE.5. VON MISES STRESS FOR DIFFERENT LOADS

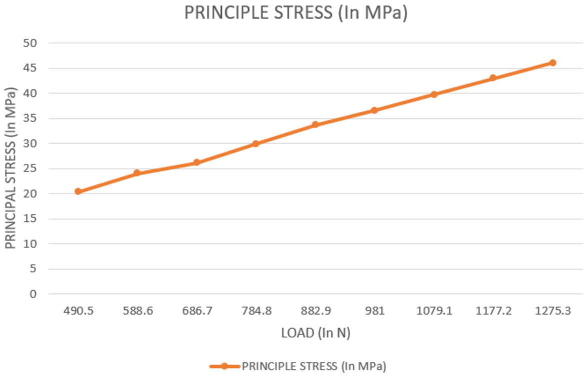

FIGURE.5. PRINCIPAL STRESS FOR DIFFERENT LOADS

It has been observed that the stresses increase as the load increases. The shear stress lies in between the range of (2-4.6 MPa). Then comes the Von Misses Stress which ranges between (15-39 MPa). The Principle of stress increases steadily over the range of (20-46 MPa). As the weight increases the contact stress acting over the femur component increases.

B. Fatigue Analysis

Fatigue analysis itself usually refers to one of two methodologies: either the Stress-Life (S-N) or S-N method, commonly referred to as Total Life since it makes no distinction between initiating or growing a crack, or the Local Strain or Strain-Life (e-N) method, commonly referred to as the Crack Initiation method which concerns itself only with the initiation of a crack.

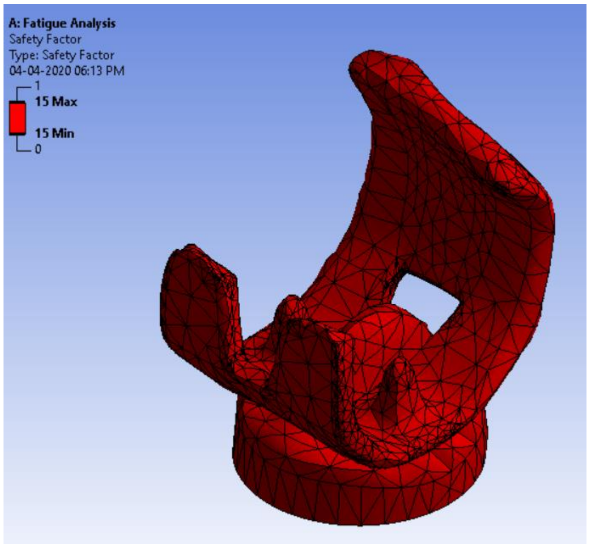

FIGURE.6. SAFETY FACTOR OF THE IMPLANT WITH TiN COATED 316L SS AS FEMUR AND ZIRCONIUM AS INSERT

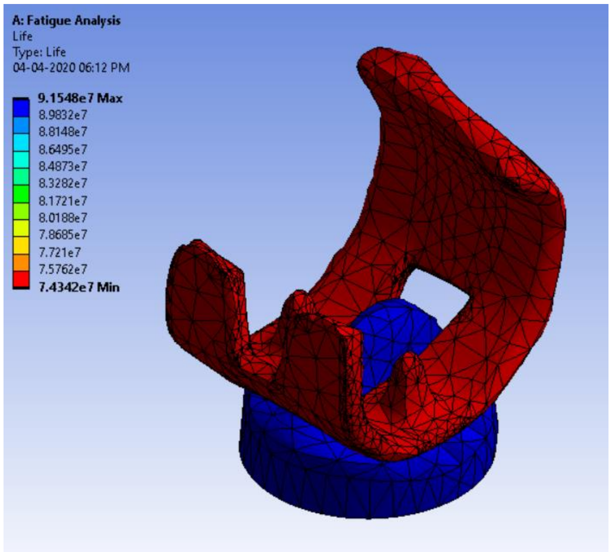

FIGURE.7. LIFE OF THE IMPLANT WITH TiNCOATED 316L SS AS FEMUR AND ZIRCONIUM AS INSERT

The finite element meshes of implants were generated using a solid tetrahedron element. Each complete model consisted of around 71,53 elements and 85,60 nodes. To capture the accurate value of stresses, fine meshing is required. So the element size of the model was reduced from 8 mm to 2 mm in steps of 1 mm. It is an essential step to identify that results obtained are relevant (correct) or not because if any variation more than 5% are identified for the same load than results calculated are of no use. So, the mesh size of 6 mm was taken from the convergence test on prosthesis [12].

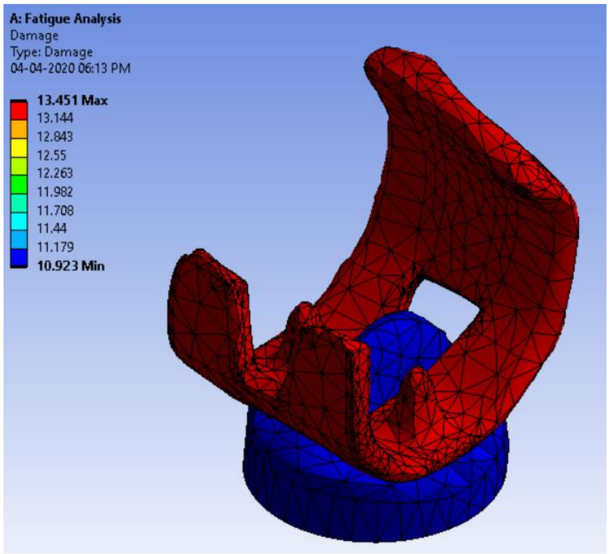

FIGURE.8. DAMAGE OF THE IMPLANT WITH TiN COATED 316L SS AS FEMUR AND ZIRCONIUM AS INSERT

The S-N curve for the 316L Stainless Steel material was obtained from the research paper [12]. The S-N curve for zirconium for the insert was also obtained from a research paper. After providing the software with material fatigue properties, then the meshing was successful and with the help of fatigue life tools, the fatigue analysis of the material was done. The data was which obtained were found to be satisfactory.

V. CONCLUSION

After performing the whole analysis and simulation the following conclusions have been drawn. The life cycle of the prosthesis in this project is defined as the proper functioning of its intended function within prescribed load limits and environmental condition without causing any kind of pain for a particular interval of time.Several other factors are involved in deciding the life of prosthesis like alignment, loosening of the implant, biocompatibility etc. which hinder its performance.Titanium Nitride alloy as a coating to SS316L steel has better characteristics and has improved the material quality thereby also being a biomaterial.

REFERENCES

[1] Kienzle T.C, Stulberg S.D, Peshkin M, Quaid A , "Total Knee Replacement",Journals & magazines, IEEE Engineering in Medicine, Volume:14 Issue 3

[2] Sudesh, S, Mathew. Lazar, Steven R. Schmid, “Design of an artificial high flexion knee”, Life science Systems and applications Workshop,2007. IEE/NIH 8 -9 Nov. 2007 Page (s):112-115

[3] Aaron Essner, Robert Klein, Michael Bushelow, Aiguo Wang, Michael Kvitnitsky, Ormond Mahoney. ―The effect of sagittal conformity on Knee wears‖, Wear, 255, 1085- 1092, 2003.

[4] G Mallesh, Sanjay S.J, "Finite Element Modeling and Analysis of Prosthetic Knee Joint", International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, Volume 2, Issue 8, August 2012

[5] Gheysen G, Ducheyne P, Hench LL, and de Meester P. 1983. Bioglass composites: a potential material for dental application. Biomaterials. 4:81–84.

[6] Pratapsinh Kakasaheb Desai, "Development and characterizations of bioceramic re-enforced Polymer matrix composites for orthopaedic implants as an alternative for SS316L",

[7] N.H. Othman, B.H.A. Bakar, M.M. Don, M.A.M. Johari, Cockleshell ash replacement for cement and filler in concrete, Malaysian Journal

[8] “A patient’s guide to artificial joint replacement of the knee”,Orthopod, URL

http://www.eorthopod.com/content/artificial-jointreplacement-knee, October 2008.

[9] J. D. Bronzino, “Biomedical engineering fundamentals”, 3rd ed., New York: CRC Press, 2006

[10] Mohammed Razzaq Mohammed. Ahmed Namah Hasi– Effect of Egg-shell powder on some Mechanical and Physical properties of natural Rubber NR. The Iraqi Journal for mechanical and material engineering 12(3) 2012, 446-458

[11] H. Z. Wu, T. C. Chou, A. Mishra, D. R. Anderson AND J. K. Lampert, "CHARACTERIZATION OF TITANIUM NITRIDE THIN FILMS", Metallurgical and Protective Layers, Thin Solid Films, 191 (1990) 55 67.

[12] B.R.Rawal, Amit Yadav, Vinod Pare, "Life estimation of knee joint prosthesis by the combined effect offatigue and wear",3rd International Conference on Innovations in Automation and Mechatronics Engineering, ICIAME 2016