Homogeneous Modelling and Analysis of Hip Prosthesis Using FEA

Ravikant Sharma¹, Vinod Kumar Mittal² and Vikas Gupta³

¹Department of Mechanical Engineering, Amity University Haryana, India
²Department of Mechanical Engineering, NIT Kurukshetra, Haryana, India.
³Department of Mechanical Engineering, CDLSIET, Panniwala Mota, Haryana, India

rsharma1@ggn.amity.edu

Abstract. With keen interest in hip prosthesis, optimization of orthopaedic implant is carried out in this work to limit probability of implant failure and increase success rate of surgery. The focal point of work is to calculate stress at the interface between implant and bone. Reduction of stress level in the femur implant because of major load carried by prosthesis because of its higher stiffness cause aseptic loosening of the implant which is a consequence of bone resorption phenomenon. The problem of bone resorption can be resolved by using porous titanium-based alloy with low young’s modulus but these materials cannot sustain desirable mechanical properties because of high porosity. In proposed work finite element analysis of hip prosthesis by using three different titanium-based alloys with varying young’s modulus (Homogeneous Material) has been carried out to identify material with optimum balance of porosity and stress shielding. On doing comparisons of results among three different models, model with intermediate value of young’s modulus was realised to deliver the best result.

1. Introduction

An implant is an artificial medical device fabricated to replace a missing/deteriorated biological entity. It supports a damaged biological entity or enhance an existing biological entity or if need replace the natural ones. It is notable fact that knee replacement surgery, total hip joint replacement and spinal fusions surgery rate has tremendously increase in last few decades reason being more active life style, accidents or ageing [1]. Keeping the fact in mind the restrained life of artificial joint is a major concern for the medical Science.

Natural material such as bones and soft tissues (cartilage) are heterogeneous in nature due to variable distribution of hydroxyapatite and collagen components [2]. Bones exhibit variation of porosity, strength, stiffness and density. Cortical bones are stiffer to have more stress tolerating properties as compared to trabecular bones [3]. Cortical and trabecular bones differ in mechanical response to stress loading [4]. The smaller system is consisting of the canaliculi and lacunae. Fluid in solid matrix of bone sustain a pressure gradient when bone is loaded. Pressure gradient drives a flow of cellular fluid around bone cells to sustain its nutritional and mechanosensory responses [5].

The reason for the failure of the implant are corrosion, fibrous encapsulation, inflammation and stress shielding. Along with infection stress shielding is also a major post-surgery concern which leads to aseptic loosening between implant and bones [6]. Mismatch of modulus of elasticity between implant and bone shield the stress needed by cells surrounding the implant and thus cells does not live, which further increase micro motion resulting in to severe discomfort to patients and leads to implant replacements [7].
The revision surgery is expensive as well as its favourable outcome is also low in comparison to the preceding implantation. The choice of biomaterials depends on its medical utilization and viability. A design with preferable stiffness can be obtained by using material of compatible modulus of elasticity and varying it to overcome stress shielding along with various coordinates [8]. Porosity is also a major concern to provide desirable environment for bone in growth which facilitate high linking between the implant and encircling bone. Pores are essential for bone tissue generation as a primary healing process as they allow movement and procreation of osteoblast [9].

Selection of biomaterial plays an important role in designing an implant. Development of new biomaterial needs a collaboration of material science, design engineers, biomedical engineers, pathologist and clinicians. Biomaterial should have optimum mechanical properties i.e. hardness, tensile strength, modulus and elongation. Along with this these materials should be biocompatible, nontoxic and should not be allergic in nature. While selecting a biomaterial the low wear rate and high corrosion resistance also taken due care [10]. Biomaterial with higher modulus of elasticity exhibits problem of stress shielding while with low modulus of elasticity biomaterials desirable mechanical properties cannot be obtained [11]. Thus, for gilt-edge performance biomaterial with enticing biological and mechanical properties, porosity has been developed. Cobalt chromium (Co-Cr), 316 L stainless steel, alloys, titanium alloys are used for surgical implants these days. Materials having same composition throughout are called homogeneous materials. These materials have uniform properties throughout. In proposed work a prototype has been developed by giving due attention to mechanical properties and porosity of prosthesis. An appropriate computational analysis has been carried out by simultaneously varying material and graded porosity using different titanium alloys and alloy with optimum properties has been identified and suggested to be used in femur prosthesis.

2. Material Selection and Methodology
The work proposed here consist of two parts first designing a femur prosthesis model in solid works and second finite element analysis of the model by using Ansys 16.0 workbench.

Improper design of implant leads to hip prosthesis failure. Stress shielding causes aseptic loosening of implant and bone which is main focal post-surgery concern [6]. Difference of elastic modulus of bone and implant material leads to stress shielding. This elasticity mismatch leads to induced bones resorption which may cause future fracture [12]. After implantation bone and implant behave like a single entity and bear the load of body. Because of more stiffness of implant, load carried by implant is higher which result in to reduction of load carried by bones and leads to bone resorption. Fig.1.represent the framed model of the prosthesis used for the research.

2.1. Material Used
Commercially pure titanium and its alloys are considered successful biomaterials to be used for prosthesis, because of its viable biomechanical and bio functional balance. But titanium-based alloys have higher elastic modulus as compare to bone. Development of an implant with low elastic modulus providing optimum mechanical and functional balance is focus of the software analysis. Table 1 provide list of materials used for homogenous distribution to carry out FEM of implant.

| Material             | Young’s modulus (GPa) | Poisson’s Ratio | Tensile Strength (MPa) | Density (Kg/m³) |
|----------------------|-----------------------|-----------------|------------------------|-----------------|
| Ti-6Al-4V (Ti64)     | 110                   | 0.32            | 900                    | 4500            |
| Ti-15Mo-5Zr          | 78                    | 0.33            | 960                    | 5060            |
| Ti-35Nb-5Ta-7Zr-0.4O | 66                    | 0.34            | 1010                   | 5600            |
2.2 Methodology
The very initial step in preprocessing is to develop a 3D Computer aided design Model of Prosthesis in Solid works. After generating the CAD model in Solid works, it is saved in Parasolid x _t file and finally the model imported in ANSYS Workbench as shown in fig.1.

**Figure 1. CAD model of Hip Prosthesis**

Meshing in Workbench generally provide durable and easy specifically that will mainly help to facilitate the mesh generation process. The CAD model used should be segregated into a number of small pieces called as finite elements. Here we have used “Fine” mesh. Finite (3942 elements) mesh is generated using ANSYS 16.0. The von Mesh stress is checked for convergence. Fig.2.represent the meshed prosthesis hip model

**Figure 2. Meshed Model of Hip Prosthesis**
2.3 Boundary Condition.
The boundary condition is the assemblage of different constraints, forces, supports and any other condition essential for the complete analysis. After culmination of the finite element mesh model, boundary conditions and forces are defined in. The focus of study was to obtain the optimum selection of materials to analyse material with optimized results. Torsional force is not taken into account due to the anterior loading of the hip joint. Distal end of prosthesis is kept fixed to carry out the static analysis of prosthesis. A load of 3000N is applied on the surface of prosthesis. Equivalent to weight of 70 kg. A 1250 N load is applied as specified on muscle [13]. Traction intensity is expressed by force per unit area [14]. User can apply different constraints and loads in various ways.

**Figure 3.** Applied constraints on CAD Model of Hip Prosthesis

3. Result and Discussion
Through homogenous modelling, material properties like density, hardness and Poisson’s ratio were graded by using different alloy for different model. Stress distribution and total deformation for each model was obtained and represented in various figures given below under the boundary conditions mentioned earlier. Results of various models were obtained in a similar pattern due to similar boundary conditions.

**Figure 4.** Equivalent stress of Ti64
**Figure 5.** Equivalent Stress of Ti-15Mo-5Zr

**Figure 6.** Equivalent Stress of Ti-35Nb-5Ta-7Zr-0.4O (TNZTO)

**Figure 7.** Total Deformation of Ti64
The total deformation of Ti-15Mo-5Zr is shown in Figure 8.

The total deformation of Ti-35Nb-5Ta-7Zr-0.4O (TNZTO) is shown in Figure 9.

Table 2. Bio-materials with their approximate results

| Material             | Equivalent stress | Deformation  |
|----------------------|-------------------|--------------|
|                      | Min   | Max   | Min   | Max   |
| Ti-6Al-4V (Ti64)     | 0.1066 | 49.543 | 0     | 0.4543 |
| Ti-15Mo-5Zr          | 0.1080 | 50.417 | 0     | 0.6407 |
| Ti-35Nb-5Ta-7Zr-0.4O | 0.1069 | 50.297 | 0     | 0.7563 |
As no parameter to evaluate the performance of analysis is reported till now so deformation of each model could be considered to measure the output performance of the model. Model with large deformation is less stiff as compare to other models and could be more suitable for reduction in stress shielding effect, but its equivalent stress is lesser to bear the load. In table 2 result showing deformation and stress distribution have been complied and Ti-15Mo-5Zr is found to deliver optimum results by considering stress shielding effect and mechanical load bearing capabilities.

4. Conclusion and Future Scope

Hips are crucial part of our body as they help us in performing various daily activities such as getting up, walking, climbing and cycling etc. but unluckily femur bone can be fractured in an incident or impaired by any disease. The problem can be resolved by replacing femur with an implant. Insertion of implant may cause problem because implant bear more load which were originally shifted to the femur.

Titanium and its alloys are being used as implant bio-material since long. Evolution of an applicable microstructures with excellent mechanical properties is a focal point. Although titanium alloys have young’s modulus near to bone but their loading conditions are very poor. In novel application of homogeneous modelling and analysis has been implemented in this study to optimise selection of materials to reduce stress shielding and sustain mechanical loading capabilities. Homogeneous modelling of hip prosthesis using three different titanium alloys have been carried out using ANSYS 16.0. by analysing stress and deformation results generated by software Ti-15Mo-5Zr was found to deliver optimum results among three.

In future hip prosthesis would be designed with variable material and graded distribution of various materials simultaneously along with various coordinates [15-16]. Heterogeneous materials have diversified approach for systematic applications in various fields [17]. These models would be designed to diminish stress shielding and encourage bone in growth simultaneously.

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