Middle-East Journal of Scientific Research
24 (Recent Innovations in Engineering, Technology, Management & Applications): 124-132, 2016
ISSN 1990-9233; © IDOSI Publications, 2016
DOI: 10.5829/idosi.mejsr.2016.24.RIETMA120

Design and Analysis of Hip Prosthesis Using Functionally Graded Material

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Abstract: Bio active material as a replacement of metallic implant. The functionally graded material use in ceramic and polymers are two kinds of lightweight materials , which shows better biocompatibility and corrosion resistance in body compared to that of composite material. Among different materials, Hydroxypatite (Hap), Ti, alumina and bio-glass are widely researched materials for implant applications and being commercially produced.Among these materials, (Hap) is the most investigated bioactive materials for compositional similarities with human bone and teeth. On the other hand different biocompatible polyethylene (PE) based materials are being used as low load bearing application in THR socket. The metallic materials such as Ti and alumina have been widely used as bone implant which is of 6-7 times stiffer then human bone. In order to minimize stress- shielding effect which High density polyethylene have been successfully reinforced with Hydroxypatite (Hap) for replacement or healing of bone.

Key words: Alumina · THA · FGM Hip Prosthesis · Composite [Hydroxypatite] · Polyethylene

INTRODUCTION

In material sciences, a Functionally Graded Material (FGM) is a type of material whose composition is designed to change continuously within the solid. The concept is to make a composite material by varying the microstructure from one material to another material with a specific gradient. This enables the material to have good specifications of both materials. If it is for thermal or corrosive resistance and malleability or toughness, both strengths of the material may be used to avoid corrosion, fatigue, fracture and stress corrosion cracking. In comparison to conventional composite materials, FGMs exhibit a progressive change in composition, structure and properties as a function of position within the material [1]. The transition between the two materials can usually be approximated by means of a power series. The aircraft and aerospace industry and the computer circuit industry are very interested in the possibility of materials that can withstand very high thermal gradients.

Bone is a natural nano composite biomaterial with a complex hierarchical structure.Bones are rigid organs that consist of osseous tissue, bone marrow, endosteum, periosteum, cartilage, nerves and vascular channels constituting the skeleton of vertebrate animals [2, 3]. Several organic – inorganic parts are encased in a strong collagen matrix with a blood circulation system the structure of a typical hip bone.The hip joint is located where the upper end of the femur meets the acetabulum. The femur, or thigh bone, looks like a long stem with a ball on the end [4]. which is strongly influenced by cortical and trabecular bone. Hip is a ball-and-socket joint where the thighbone or femur (ball) meets the pelvis (socket). This joint is surrounded by cartilage, muscles and ligaments that allow it to move smoothly. The cartilage is a smooth, shock-absorbing layer that covers the bones and allows the ball to glide easily inside the socket. Hip joint serves as one of the most important load bearing joints in human body. Studies have shown that up to5.5 times the bodyweight is tolerated by femur and pelvis during daily activities [5].

A hip joint provides, in addition to its load bearing ability, the needed mobility that includes extension, rotation and flexion. The most prevalent cause of hip joint surgical operation and hip joint replacement is osteoarthritis (OA). OA occurs when the cartilage fissuring is severe enough to a point where bone contact is initiated at the hip joint. OA is attributed to many causes that include age, overuse, excessive loading, or flaw in the hip joint geometry referred to hip dysplasia. It is estimated that about 200, 000 hip replacements occur in the United States due to hip joint OA. [6] Other hip joint problems include osteolysis, avascular necrosis, neck fracture of femur. Hip joint implant is designed to provide the same mobility and stability of the original functioning hip joint.

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Certainly, the design of hip joint implant needs to investigate all parameters such as wear, roughness, erosion, tribology, materials and also many problems caused by surgical procedure including bone replacement. Some of these factors have been studied since about 50 years ago. About 50 years ago, investigated the manufacturing of hip prostheses. Metal-on-metal hip prostheses failed in some patients due to the release of metal debris resulting in revision surgery. Symptoms such as neurological impairment, cardiomyopathy and hypothyroidism were reported in their study.Oneof the key factors that shortens the life of joint implants and increases the number of revision surgeriesis wear debris, which is primarily generated at the bearing interface [7]. Wear debris also results inmechanical instability of the joint, reduces joint mobility, increases pain with detrimental biologicresponses, results in osteolysis and, ultimately, causes component loosening and implant failure.

Fig. 1: Natural Hip

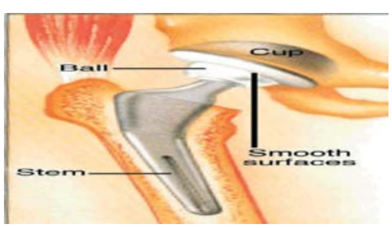

Fig. 2: Prosthesis Hip

Cortical Bone in Hip Prosthesis: Bone is a natural nano composite biomaterial with a complex hierarchical structure. Several organic – inorganic parts are encased in a strong collagen matrix with a blood circulation system the structure of a typical hip bone, where the femur is attached as a ball-and-socket arrangement through a ligament the basic adult femur, which is strongly influenced by cortical and trabecular bone. Hip is a ball-and-socket joint where the thighbone or femur (ball) meets the pelvis (socket). This joint is surrounded by cartilage, muscles and ligaments that allow it to move smoothly. The cartilage is a smooth, shock-absorbing layer that covers the bones and allows the ball to glide easily inside the socket.

Fig. 3: Femur Bone

Total Hip Replacement (THR): A total hip replacement is an operation designed to replace a hip joint which has been damaged, usually by arthritis.The hip joint is a ball and socket joint. The ball is formed by the head of the thigh bone (femur) and fits snugly into the socket (acetabulum) in the pelvis.The surfaces of the bones in the joint are coated by a smooth and compressible substance known as gristle (or articular cartilage). This causes roughening and distortion of the joint, resulting in painful and restricted movement. A limp will often develop and the leg may become wasted and shortened [1-7].

Pankaj [8] Functionally Graded Materials are those in which the volume fractionof the two or more constituent materials is varied continuously as afunction of position along certain dimension(s) of the structure.Due to the broad and rapidly developing field of FGM, these conclusions cannot encompass all significant directions, trends and needs. Nevertheless, they reflect some of the observations of the authors based on the published research and their own analysis of the subject.

Sathya Ganapathi [9] Anthropometric parameters of the human femurbone are collected from a particular age group. Theseare then used to obtain a CAD model of the bone usingCATIA. The standard Charnley hip implant, The 3D models are very useful in simulationof bone fractures and internal fixations with implants. Inthis work, the hip joint and implant model, developed in CATIA software, help to understand how these structuresadapt to external forces disturbances.

Objective of Project Work: The objective of the present work In this bio material using a composite material Ti, alumina by using FGM material the hip bone is design and analysis to get better efficiency also weight at high corrosion resistance. The aim of this paper is to investigate the functionally graded material properties of the hip prosthesis using static and dynamic loading condition and also finding out the deformation of the material are analyzed.

Polymer Composites: An alternative technique for improving polyethylene properties is the use of polymer composites. These materials have shown the ability to improve the performance of UHMWPE in artificial joints through the use of selected fillers .The final performance of these polymer composites may provide promising alternatives to Crosslinked polyethylene for orthopedic applications. Natural lubricants like hyaluroran (HA) have been added to UHMWPE to enhance lubrication and improve wear resistance of non-cross linked UHMWPE have recently developed an UHMWPE-HA micro composite. However, whether HA treatment is able to improve the wear resistance of HXLPE remains a matter of debate.Innovations using micro- and nanoparticles to improve mechanical properties of biomaterials have also been reported. Zirconium micro particles as a method to enhance the performance of UHMWPE in joint replacements. Zirconium (Zr) has been shown to have excellent corrosion resistance and biocompatibility. The results suggested a reduction in wear rates without sacrificing the impact toughness. However, the inclusion of hard particles into an UHMWPE matrix has generated several concerns, since it may increase the wear of the metal counter face. Carbon fibers have also been investigated in recent decades. In 2007, [3] carbon fiber reinforced polyetheretherketone (CFRPEEK) was introduced onto the market as an alternative bearing to UHMWPE in the hip. This composite has shown extremely low wear rates and comparable biological activity to UHMWPE . Also, multiwall carbon nana tubes (MWCNTs) have been added as a reinforcing component for UHMWPE. Carbon annotates(CNTs) have excellent mechanical properties such as high tensile strength and are ultra-light weight, which makes them an attractive alternative for reinforcing polyethylene.

More recently, grapheme has generated great interest as reinforcement for polymer matrices due to its excellent in-plane strength and high surface area, which might lead to enhanced load transfer sites between the polymeric matrix and reinforcement. A recent study performed showed the ability of grapheme oxide to improve the friction and wear behavior of conventional UHMWPE. Clearly, new alternatives for orthopedic applications are being investigated. However, due to the limited clinical experience of these new materials in joint replacement components, caution and more research is required in order to establish the biological consequences of the use of these materials in this clinical application.

Prosthesis Material

Ceramic – Polymer Composite As Bone: The human femur bone is a classical example of a nano-composite material, having strength that is higher than either of its components, apatite or collagen [1, 2, 4, 5]. The introductory part of the paper illustrated the anisotropic mechanical response of bone Shortly, the failure mode of bone under circumstances of catastrophic over load is directly related to the loading mode of the bone. Hence, elastic modulus is an important aspect of a bone or implant when it is placed under load. Interestingly, the tensile strength of hard tissue bone does not match its compressive strength. Because compact and trabecular bones are different in structure, they have very different values for Young’s Modulus of elasticity.

Failures of Hip Implant: MetallosisAfter Metal-On-Polyethylene: Metal debris should not be generated in a well-fixed, well-functioning metal-on-polyethylene total hip arthroplasty. However, surgeons sometimes encounter per prosthetic metallosis during revision hip surgery. Insert wear, fracture, or dislodgment in modular components may lead to articulation of the prosthetic head with the metallic shell and subsequent metallosis. Metallosis may occur with loose acetabular components as a consequence of fretting of the screws and shell screw holes or shedding of the in growth surface of the component. The femoral component can also be a source of metallosis: Wear of a titanium femoral head, loosening of rough surface finish from the femoral stem and stem fracture all may result in metallic particles being deposited in periarticular tissues. Specific clinical and radiographic findings can help in differentiating these forms of failure and in planning surgery. When metallic debris-induced bone loss is recognized early, surgical intervention may limit its progression. with third-body particles interposed), or mode 4 wear (2 secondary surfaces rubbing together). In the acetabular component, wear-through, fracture, or dislodgment of the insert can lead to articulation of the prosthetic head with the metallic shell and subsequent metallosis. If the acetabular component loosens, metallosis can develop as a consequence of fretting of the screws and the screw holes12 or shedding of the in growth surface of the cup—which can become embedded in the articulating surface, generate third-body wear and damage the head.17, 18 Metallosis also results from femoral stem failure: Wear of a titanium femoral head or stem, 5 loosening of rough surface finish from the femoral stem, 14, 19-23 and stem fracture24 all can generate a large volume of metallic debris.

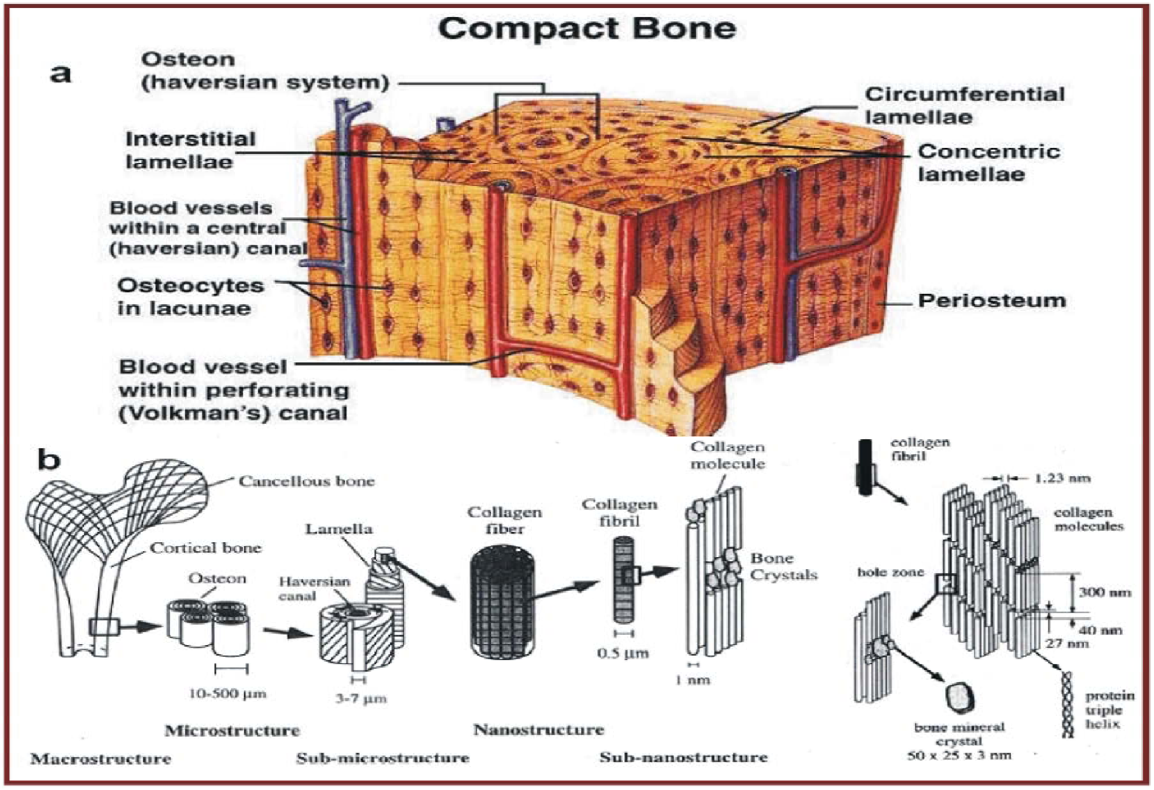

Fig. 4: Polymer Composite

Table 1: Material Composition

Material	Tensile Strength (Mpa)	Compression Strength (Mpa)	Elastic Modulus (Mpa)	Fracture Toughness (Mpa/m)
Cortical bone	345	250-600	117	60
Ti	345	250-600	117	60
Alumina	270-500	3000-5000	380-410	3
Hap	40-300	300-900	80-120	0.6-1

Failures Overcome: The metallic materials such as stainless steels alloys, Ti alloys and cobalt-chromium alloys have been widely used as bone implant which is of 6-7 times stiffer then human bone they were replaced by composite materials. Composites are engineered materials made from two or more constituent materials with significantly different physical or chemical properties. More recently, a HAp reinforced HDPE composite was produced through a conventional powder processing and compression molding technique and exhibits acceptable mechanical properties when compared with bone.

Preparation of Composite Hip Prosthesis: Ultra High Molecular Weight Polyethylene is used as matrix or base material and is used as reinforcing material in this present work. The UHMWPE powder was chosen as polymer material to prepare the composite due to its unique combinations of physical and chemical properties, which includes self lubricating, excellent chemical and corrosion resistance, light weight, good mach inability, high fatigue resistance &excellent biocompatibility. Alumina ceramic was used in this composite preparation because of its excellent biocompatibility due to chemical inertness. Alumina has been used in the area of orthopedics for more than a quarter of a century20. [3] Alumina is preferred materials for application of bearing surfaces because of its extreme hardness should result in greater durability. Al2O3 powders are stable oxides, chemically inert and well tolerated by the body. The ultra high molecular weight polyethylene used in the present work was Host lain GUR 4220 (GUR 4120 with heat stabilizer) supplied by Ticino (Belgium). The molecular weight was in the range of 3.6 to 5.6 million as per the manufacturer's data. The apparent density was measured to be 0.94 to

0.96 gm/cc for the powder samples and as well as compressed molded samples. High purity alumina of particle size (74µ) obtained from.Alcoa through Central Glass & Ceramic Research Institute, Kolkata, was used are in forcing material for composite preparation. Polymer and ceramic powder are weighed accurately in weight percent of65:35 and mixed in a high-speed rotary mixing machine.

The nearly uniform powder mixture (60 gm) is charged into the properly lubricated 3 piece mould using compression moldings technique. Initially by pressing the top part of the mould over the powder, thesestructure of hip prosthesis was made and the top part kept intact. The total assembly was placed between the two plates of a compression machine (ALMIL hydraulic presser/c of capacity 2000kN) [9]. The powder was cold compressed repeatedly for 5-10 a pressure of (10 MPa) in order toexpel the air entrapped between the mixtures. Cooling is the most important part in compression molding, otherwise shrink marks and voids will appear in the final product. As the shrinkage of the material progresses, pressure is gradually increased and brought up to 8-10MPa (load300KN). This load is maintained constant until the total mass came back to ambient temperature. The mould is taken out from the press and the desired composite prostheses is was removed from the mould.

Design of FGM Hip Prosthesis: The material used for the femoral component with comprises [7] of the femoral stem and head was designed and developed by using a per the standard size and shape of metallic hip prosthesis in composite materials.

Components Of Hip Prosthesis: The hip prosthesis consists of following components:

- Femoral stem.
- Acetabular cup.
- Acetabular Liner.
- Ball.

They are of different types of composite hip models according to the arrangements of composites and metals [4]. The load act on the prosthesis is based on the human body weight, In this analysis we modeled different types of composite hip prosthesis and applying different loads to the model and analyses the various models.According to the design they are of eight different models which is designed according to the standards by using Pro-E software.

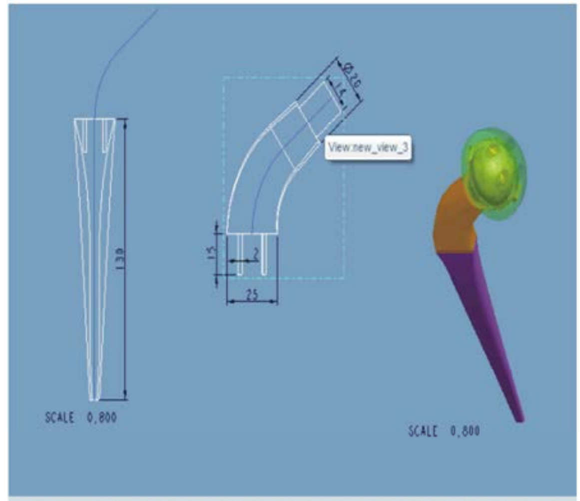

Fig. 5: Partial of Hip Prosthesis

Problem Indentification: A fracture of the hip bone can occur in severe accidents; usually associated with rupture of urethra or bladder. Fracture of patella is common, which affects the movement at the knee joint. Upper end has a head, neck, greater and lesser trochanters, intertrochanteric line interochantericcrest, the fracture of in the neck of femur is common over the age of 60 years, especially in males, females due to thinning of bone. Biomaterial as replacement of metallic implant. The socket usually affect the tibia at the junction of middle and inferior thirds during infancy and childhood.

Movement of femur are do primary to ration accruing at the hip joint, the pelvic girdle has a in positioning to that of the shoulder girdle in positioning the hip joint for effective limb movement.

- Determination of leg length, Establishment of aspirateabducators muscle tension and femoral offset.
- Determination of the anticipate component size.
- Theanatomic parameter which will allow accurate surface analysis of the removed femoral components analysis of the excited tissue, introperative replacement of the femoral implant.

The roughenedbone, head, teeth, together the bone irregular with surface, socent when you move your leg, causing pain and stiffness. the metallic material such as Ti alloy, stainless steel have been widely used as bone implant is 6-7 stiffer then human bone, they are were replaced by composite material by using Ti, alumina intropertative replacement of the femoral implant.

A composite material consist two are more mechanically distinct phase (metallic, polymer or polymeric) which are separated by interface .a composite is designed to have combination of the best characteristics of each component material, the composite material is based on the matrix material (Ti, alumina) are on the reinforcement dimension and shape , the material lt his type of irregular shape is preferred to the spherical shape as molten polymer can penetrated in to trough on the particle surface during high temperature composite processing and thus form mechanical with the particle at the at body temperature where as the smooth . are developed you provided unique mechanical properties, such as a strength, stiffeness, toughness and fatigue resistance for biomedical composite even though excellent mechanical performance and often targeted for improvement, the bio compatibility of the material is paramount concern.

Introduction about Ansys Software: ANSYS is a complete FEA simulation software package developed by ANSYS Inc- USA. It is used by engineers worldwide in virtually all fields of engineering.

- Structural
- Thermal
- Fluid (CFD, Acoustics and other fluid analyses)
- Low-and High-Frequency Electromagnetic.

Introduction to General Analysis Procedure in Ansys: Ansys is a high-performance finite element pre- and postprocessor for popular finite element solvers - allowing engineers to analyze product design performance in a highly interactive and visual environment. Advanced functionality within ansys allows users to efficiently mesh high fidelity models. This functionality includes user defined quality criteria and controls, morphing technology to update existing meshes to new design proposals and automatic mid-surface generation for complex designs with of varying wall thicknesses.

ANSYS: Finite Element analysis, the core of Computer Aided Engineering dictates the modern mechanical industry and plays a decisive role in cost cutting technology. ANSYS the leading FEA simulation software, with its robust capabilities guides the Engineers to arrive at a perfect design solution.

General Analysis Procedure: This explains the general analysis procedure to be used to solve a simulation. Regardless of the physics of the problem, the same general procedure can be followed.

Every analysis involves four main steps:

- Preliminary Decisions
- Preprocessing
- Solution
- Post processer

Benefits:

- Reduce time and engineering analysis cost through high- performance finite element modeling and post-processing
- The industry's broadest and most comprehensive CAD and CAE solver direct interface support.
- Reduce overhead costs of maintaining multiple pre- and post- processing tools, minimize "new user" learning curves and increase staff efficiency with a powerful, intuitive, consistent finite element analysis environment
- Open-architecture design and customization functionality allows to Ansys fit seamlessly in any environm.

HIP Prothesis Analyses
Pro-E Model:

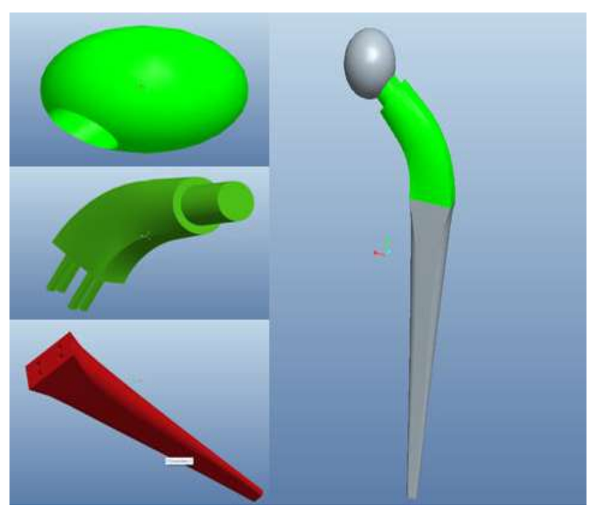

Fig. 6: Pro-E Hip Prosthesis Model

Mesh: Mesh type: Triangle Surface Meshed.

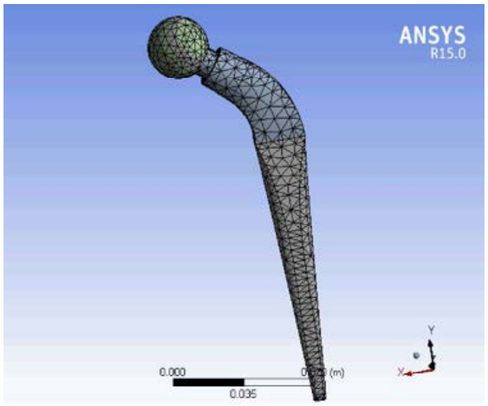

Fig. 7: Meshed Model

Load Application And Constraints: The femoral stem is fixed to the bone by using bone cement pressure acts at ball surface during mobility and load is due to the body weight.

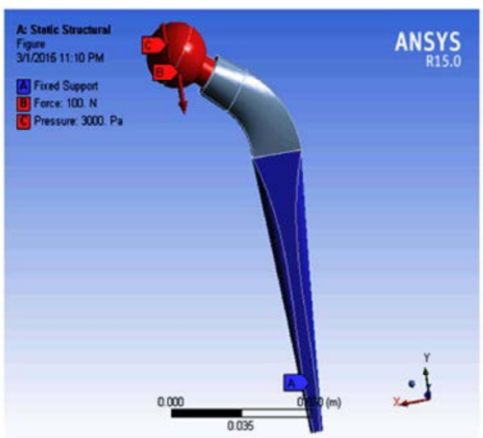

Fig. 8: Load and Constraints

Static Analysis:

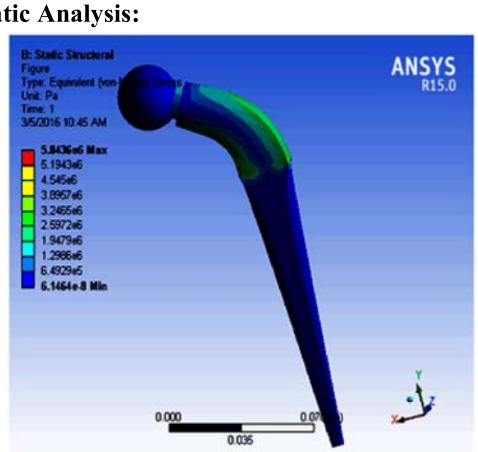

Fig. 9: Von-Mises Strain for Model 1

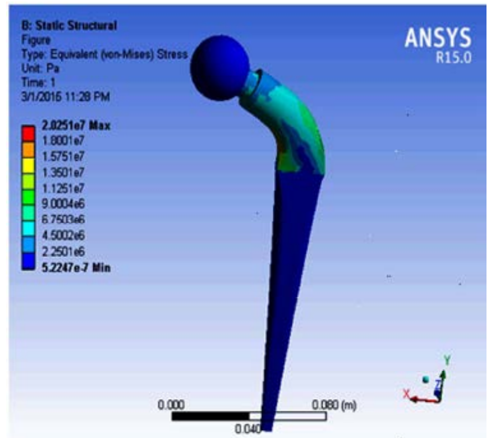

Fig. 10: Von-Mises Stress for Model 1

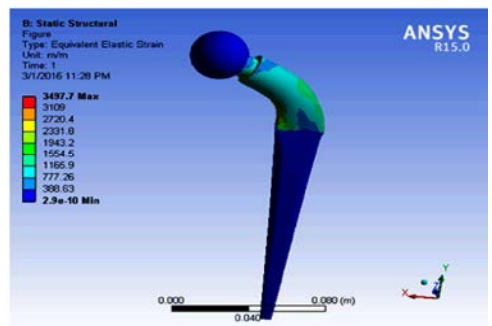

Fig. 11: Von-Misses Stress for Model 2

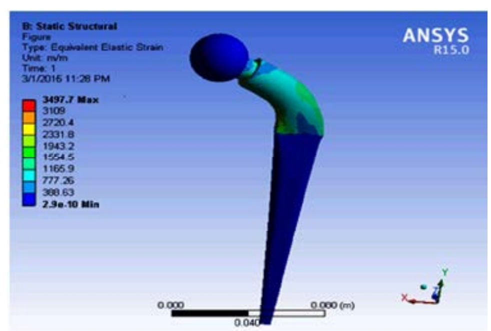

Fig. 12: Von-Mises Strain for Model 2

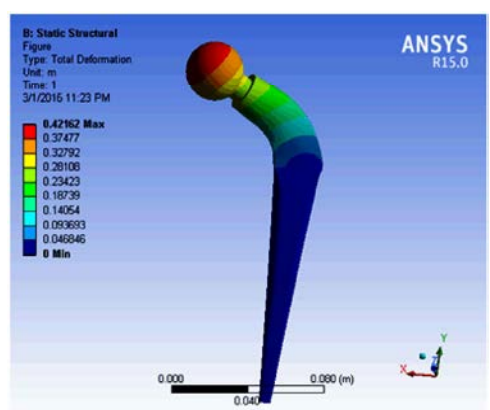

Fig. 13: Total Deformation for Model 2

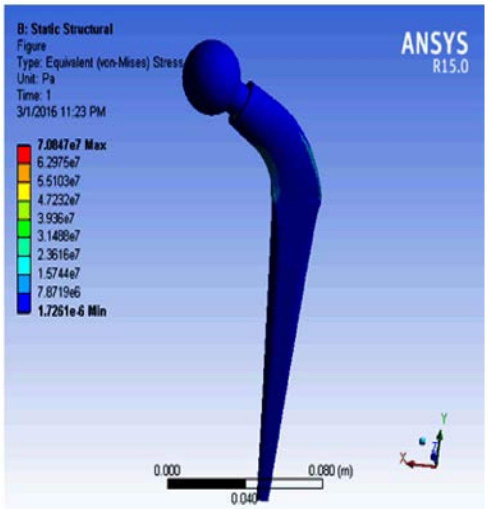

Fig. 14: Von-Mises Stress for Model 3

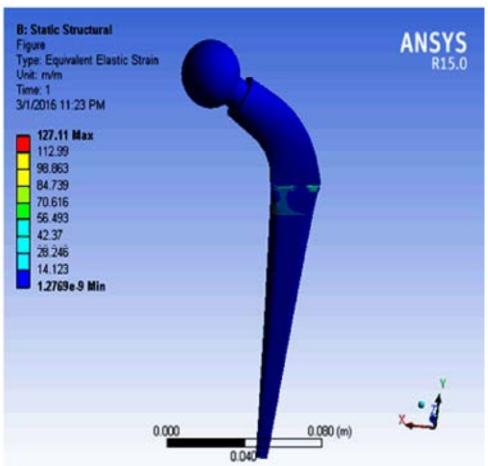

Fig. 15: Von-Mises strain for Model 3

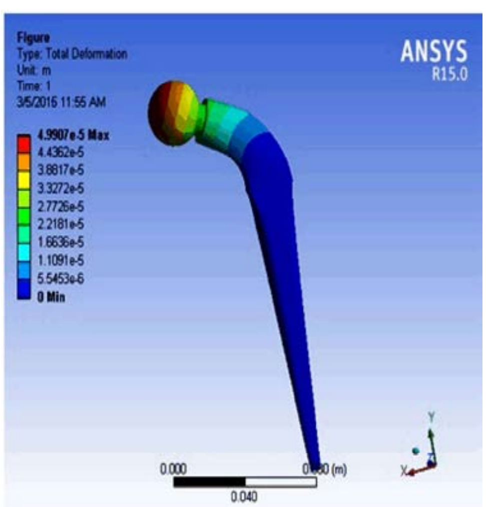

Fig. 16: TotalDeformation for Model 3

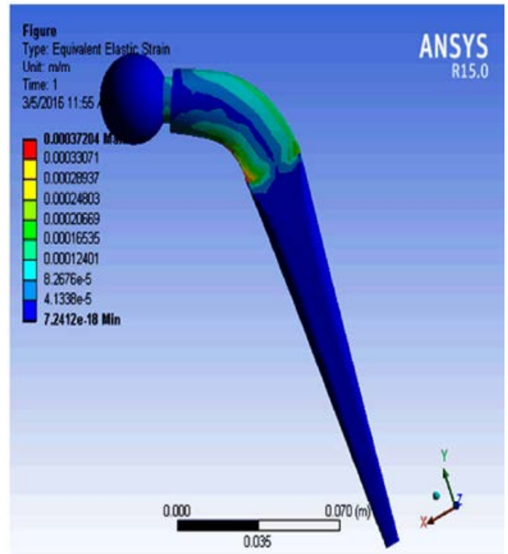

Fig. 17: TotalDeformation for Cortical Bone

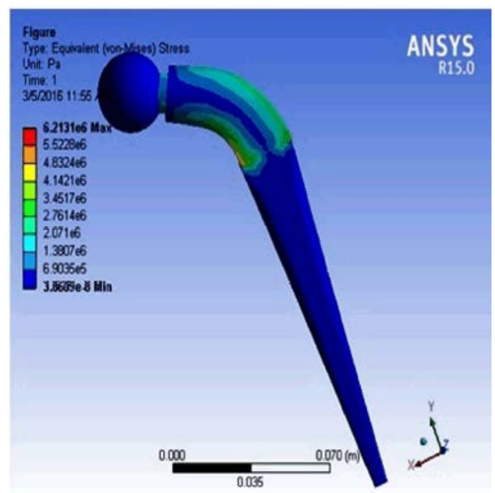

Fig. 18: Von-Mises Stress for Cortical Bone

Comparison of Results:

Table 2: Comparison of Results for Different Prosthesis Model

Properties	Cortical bone	Model1	Model2	Model3
Von-mises stress(mpa)	6.213	5.843	2.02	7.732
Von-mises strain(mpa)	0.3e-5	0.4e-5	3.4e-5	0.8e-5
Total Deformation (mm)	885	499	602	425

CONCLUSION

Finally the analysis of artificially metallic composite femur bone is successfully done. The partially metallic hip prosthesis can also used for total hip replacements HDPE causes more displacements it can be replaced by composite similar to the bone.

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