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FINITE ELEMENT ANALYSIS OF HIP JOINT TO PREDICT THE SUITABLE BIOCOMPATIBLE IMPLANT MATERIALS FOR FEMORAL HEAD USING MSC-NASTRAN

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ABSTRACT

The fracture of the femoral head of femur bone which is situated in the hip joint is common nowadays, the reasons for fracture varies from accidents to diseases. It is one of the most important parts where whole body weight is transferred to the legs and it helps in performing daily activities. In this study, we are focused on the finite element analysis of this part to know the fracture with available bone implant material and also to understand the load-bearing capacity of these materials in real-life scenarios. We selected Natural bone, Zr–Nb alloy, Zirconia ceramic, and CF/PEK composite materials as implant materials from the literature. A three-dimensional cad model is prepared using PTC CREO 5.0 and analysis was carried out by applying the required boundary conditions using MSC-Nastran and Patran. It is observed from this study that Zirconia ceramic is best suited for the femoral head implant design in comparison with Zr-Nb alloy because Zirconia ceramic showed 0.0833 mm displacement/deformation in comparisons with 0.376mm displacement of Zr-Nb alloy. But stress distribution at the femoral shaft for both the materials is 10 MPa. As per weight saving is considered CF/PEK composite materials is good and materials properties are the same as bone, but more displacement is observed in comparison with bone, Zr–Nb alloy and Zirconia ceramic materials.

Key words: Bone Implant, Displacement, Fracture, Hip Joint, Von-mises Stress.

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1. INTRODUCTION

The biomechanical analysis helps us to understand the mechanical behavior of any part/bone of the human body. In such studies, the femur bone is one of the most important in biomedical studies to understand the mechanics of this bone such that an implant can be designed [1].

The femur bone consists of three major parts, one is the femoral head (forms hip joint), Femoral shaft, and Knee joint. The femoral head is subjected to different loading conditions and it is pron to fracture or dislocation. The femoral head is connected to the acetabulum to form the hip joint [2]. This is the most important part of the human body because it transfers loads of the body to the legs and also helps in completing the daily actives [3].

The hip joint is subjected to highly daily stresses, bearing the weight of the upper part of the body and transferring to legs [4]. Due to accidents, advancing age, and diseases like osteoarthritis, osteonecrosis, and rheumatoid hip joint is subjected to stresses. If the damage to the hip joint is severed, it is necessary to replace it with an artificial joint for reducing pain and restoring motion [5-6].

The development of the computational capabilities in the field of mechanics nowadays helped us to understand/solve the most complicated problems. In which Finite Element Analysis (FEA) is one of them, this numerical technique is widely used in almost all the fields, but there is a need to apply this method for understanding biomechanics [7].

The biomechanical study is one of the most emerging and interesting filed nowadays. It helps one to understand the biological and mechanical aspects of the bone or biological object in the body [8]. The study of the biomechanics of hip joint for analysis of load, stress-induced helps us to go for the surgical implant of an artificial hip joint which also functions as the natural joint [9]. In this work, we have analyzed the displacement/deformation and stress for a given load to suggest/ find the suitable bio implant material for the femoral head.

2. THREE-DIMENSIONAL MODELING, BOUNDARY CONDITION, AND MESHING

Three-dimensional modeling is carried out using PTC CREO 5.0 and the required dimensions for the drawing are obtained from the literature. Fig. 1 shows the three-dimensional model of the femoral head with half femoral shaft. The boundary condition is also shown in Fig. 1[11].

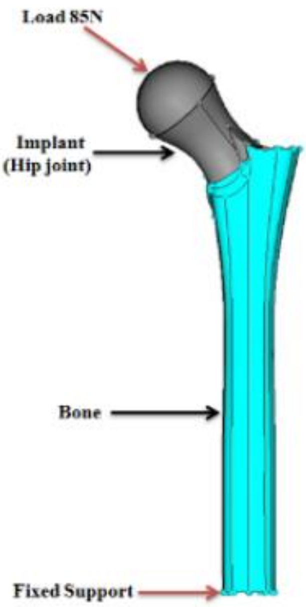

Figure 1 Three-dimensional model with Boundary conditions

We divided the model into two parts, the implant part, and the bone part and it is shown in Fig. 1. The convergence criteria are applied to know the preferred element size to get an exact solution for the FEA problem. It is found that 3.5 mm element size is optimum and also, we selected the CQUAD4 element to get accurate results. The meshed model is shown in Fig. 2.

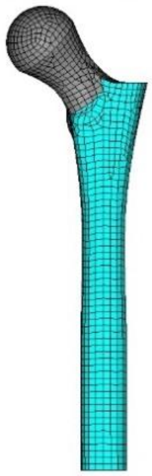

Figure 2 Meshed model

3. MATERIALS PROPERTIES

We selected Zr–Nballoy, Zirconia ceramic and CF/PEK composite and their materials properties from the literature [10-11]. In this work, we considered that femoral head is fractured and not the femoral shaft. An implant is designed for the femoral head and attached to the femoral shaft. The femur bone properties are Young's Modulus17GPa, Density is 2.0g/cm3 and Poisson's ratio is 0.33. The properties of Zr-Nb alloys are Young's Modulus 42.1GPa, Density is 8.9g/cm3 and Poisson's ratio is 0.33. For Zirconia ceramic it is, Young's Modulus 190GPa, Density is 5.81g/cm3 and Poisson's ratio is 0.31 and for CF/PEK composite Young's Modulus 23GPa, Density is 2.01g/cm3 and Poisson's ratio is 0.3.

4. RESULTS AND DISCUSSION

The results obtained in this study are discussed under the following heads.

4.1. Results for bone materials

The total displacement is 0.446 mm at the femoral head and stress is 9.99 MPa at the femoral shaft. This material is considered in the analysis to see the load-bearing capacity of the bone materials and it is shown in Fig. 3 and Fig. 4.

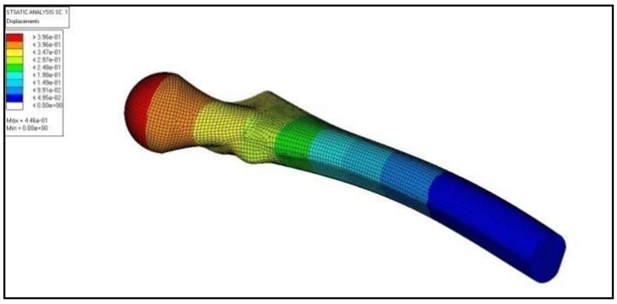

Figure 3 Displacement for Bone material

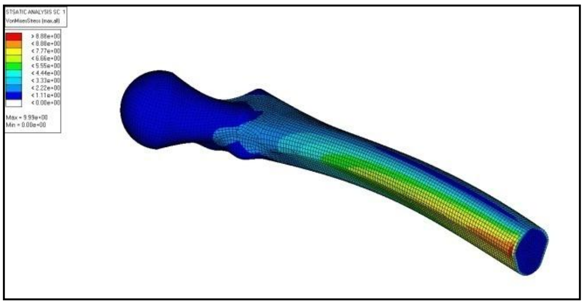

Figure 4 Stress for Bone material

4.2. Results for Zr-Nb alloy

The total displacement is 0.376mm at the femoral head and stress is 10 MPa, at the femoral shaft. This material is generally considered in the design of implants, in comparison with bone material the displacement is less and it is shown in Fig. 5 and Fig. 6.

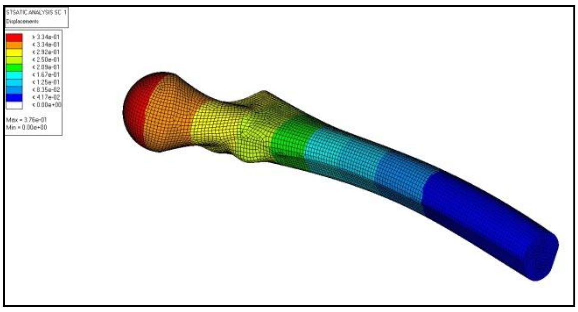

Figure 5 Displacement for Zr-Nb alloy

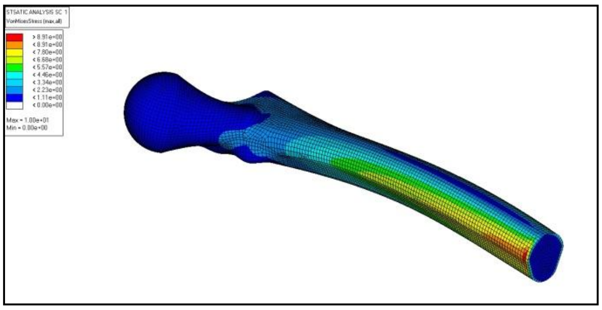

Figure 6 Stress for Zr-Nb alloy

4.3. Results for Zirconia ceramic

The total displacement is 0.0833 mm at the femoral head and stress is 10 MPa it is at the femoral shaft. This material is generally considered in the design of implants. In comparison with Zr-Nb alloy the displacement is less, but stresses is same and it is shown in Fig. 7 and Fig. 8. This is the most promising material for a bone implant.

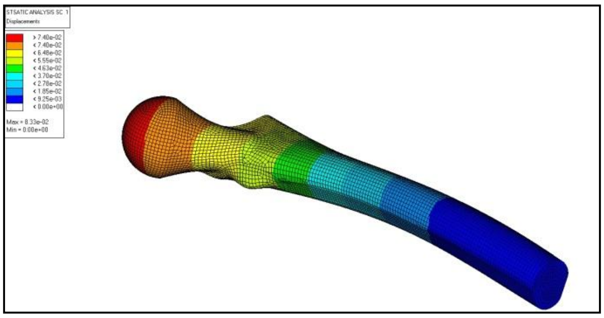

Figure 7 Displacement for Zirconia ceramic

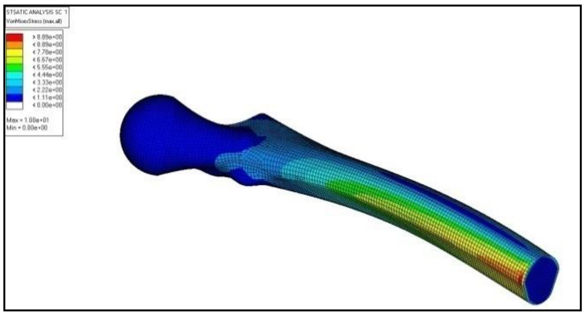

Figure 8 Stress for Zirconia ceramic

4.4. Results for CF/PEK composite

The total displacement is 0.688 mm at the femoral head and stress is 9.99 MPa it is at the femoral shaft. This material is generally considered in the design of implants, in comparison with Zr-Nb alloy and Zirconia ceramic the displacement is more and it is shown in Fig. 9 and Fig. 10. It is composite materials having less weight, but load-bearing capacity is less and also stresses are same as bone material.

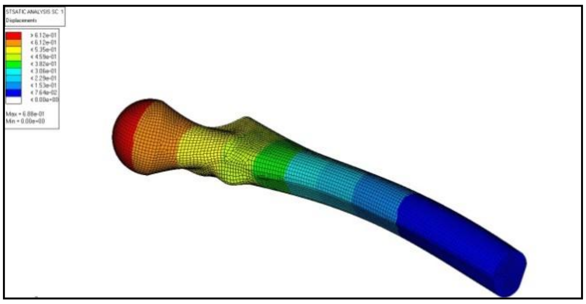

Figure 9 Displacement for CF/PEK composite

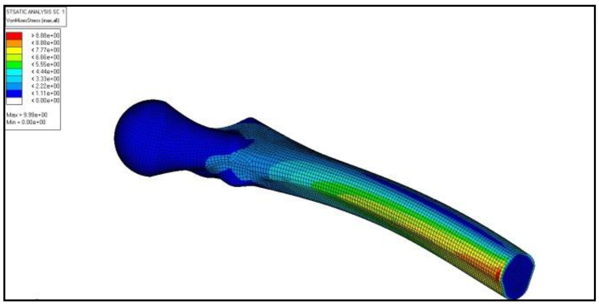

Figure 10 Stress for CF/PEK composite

5. CONCLUSIONS AND FUTURE WORK

In this work, the FEA is carried out by adopting the boundary conditions for Zr–Nb alloy, Zirconia ceramic, and CF/PEKcomposite materials. From the above study, the following conclusions are drawn.

- The stress distribution near the femoral shaft for all four materials are observed as follows,
- Bone and CF/PEK composite is 9.99MPa.
- Zr–Nb alloy and Zirconia ceramic is 10MPa.
- The variation in the displacement/ deformation is observed in all four materials. It is because each material possesses different strengths in bearing different loads.
- The Zirconia ceramic and Zr–Nb alloy is best suited for making the femoral head implant in comparison with CF/PEKcomposite material, but Zirconia ceramic is more suited because of the least displacement.
- As per the weight is considered CF/PEK composite is less weight and possesses the properties as that of bone material.

This work will help in designing a variety of hip joint implants. By considering the obtained results the implants can be modeled separately and dynamic analysis can be carried out to understand the nonlinear behavior of the considered materials.

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