Analysis of Al 2 O 3 /Al FGM as Biomaterial of Artificial Human Femoral Bone and Compare with Ti6Al4V Alloy through Computational Study

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Abstract

A finite element model of bones with accurate geometry and material properties generated in CAD softwares are being widely used to make realistic investigations on the mechanical behavior of bone structures. The aim of this study is to create a model of real proximal human femur bone for evaluating the finite element analysis (FEA) and investigate the use of Ti6Al4V and Al2O3/Al FGM for artificial femur. Here, behavior of femur bone is analyzed in ANSYS 13 workbench under physiological load conditions and compared with artificial femur composed of Ti6Al4V and Al2O3/Al FGM. The CAD model was imported in Ansys 13.0 workbench, meshed and analysed in Ansys mechanical APDL workbench under the loading conditions. It was found that both material are suitable for artificial bone material. Human femur with Al2O3/Al FGM showed better mechanical properties and less weight compared to Ti6Al4V. In the biological environment, the demands of biomaterials are challenging. This study will be useful to surgeon in femur surgeries and bone prosthesis. These better synthetic bone substitutes will most probably be commercially available for orthopaedic applications in the near future.

***Index terms*—** Al2O3 /Al FGM; Ti6Al4V; ansys 13.0; FEA; femur; solid works; CAD

1 Introduction

Mechanical properties of human bones and implant devices are of prime interests to Clinicians and engineers for decades. Researches are going on to findout a material that copes with human body well, hasgood mechanical properties and of course low price.To do this the use of three dimensional (3-D) finiteelement analysis (FEA) for orthopedic application Author ? ? : Department of Mechanical Engineering, University of Engineering and Technology, Dkaha-1000, Bangladesh. E-mail : tousif.ahmed54@gmail.com iswell accepted for more than three decades [1]. Boneexhibits elastic linear behavior at macro level for the normal range of regular daily activities [9]. As a result, although the bone is a complex biological tissue, theuse of FEA is attractive. The need for reconstructive surgery of bones is continuously increasing along with the ageing of the population as well as the increase of traumatologic injuries. In 2001 350,000 bone grafting was conducted only in USA. Nowadays, over 500,000 bone graft procedures are performed annually, and approximately 2.2 million world wide (Giannoudis et al., 2005) [10]. Per year total cost of this process excceds billions of dollers. Hence, solely donor material cannot meet this surplus amount of bone replacement. Autografts are still regarded as optimal reconstruction material, because of the lack of good enough synthetic materials. However, highly engineered structures can fulfil the demand of synthetic biomaterials to a great extent. In fact, it is possible to mimic better the structures of living materials, like bone, cartilage or teeth using substitute materials. Therefore, the search for better synthetic bone substitute is consistant.

2 II.

3 Femur's CAD Model Generation Methodology

The 3D model was generated using Solid works 12, a highly efficient and easy to use CAD modeling software. Using a reals bones sketch and dimensions the 3D model was generated using different advanced features of Solid works. Abstract -A finite element model of bones with accurate geometry and material properties generated in CAD softwares are being widely used to make realistic investigations on the mechanical behavior of bone structures. The aim of this study is to create a model of real proximal human femur bone for evaluating the finite element analysis (FEA) and investigate the use of Ti6Al4V and Al 2 O 3 /Al FGM for artificial femur. Here, behavior of femur bone is analyzed in ANSYS 13 workbench under physiological load conditions and compared with artificial femur composed of Ti6Al4V and Al 2 O 3 /Al FGM. The CAD model was imported in Ansys 13.0 workbench, meshed and analysed in Ansys mechanical APDL workbench under the loading conditions. It was found that both material are suitable for artificial bone material. Human femur with Al 2 O 3 /Al FGM showed better mechanical properties and less weight compared to Ti6Al4V. In the biological environment, the demands of biomaterials are challenging. This study will be useful to surgeon in femur surgeries and bone prosthesis. These better synthetic bone substitutes will most probably be commercially available for orthopaedic applications in the near future.

itanium alloys are considered to be the most attractive metallic materials for biomedical applications. In biomedical applications Titanium alloys specifically Ti6Al4V is mostly favoured. But a matter of great concern that this alloy has possible toxic effect resulting from released vanadium and aluminum in case of permanent implant applications [13].

T This unique study is conducted to analyze the prospect of Al 2 O 3 /Al FGM which is a relatively new * concept as biomaterials. As, FGM has relatively less decompose rate over time, this is one of the most prospective materials in permanent implant applications.

Tousif Ahmed ? & Muhammad Ziaur Rahman ? & Debasish Adhikary ? A total of five planes was created to generate different major features on the specified plane. All planes were offset of the base plane at different distances as shown in Figure 1. Figure 2 shows the drawing sketched onthe plane 40. (1)

In the equation (1) if ? is set to 0, a component fully made of ceramic will be formed. On the other hand content of metal increases as ? increases. Poisson's ratio, ? is assumed to be constant throughout the material. The stress-strain relationship can be expressed as GPa, ? = 0.25, ? = 800 kg/m . It is observed load q = 100 kN/m .The outcomes were compared 2 b) Ti6Al4V Alloy "Ti6Al4V, Ti-6Al-4V or Ti 6-4, is the most commonly used Titanium alloy. It has a chemical composition of 6% aluminium, 4% vanadium, 0.25% (maximum) iron, 0.2% (maximum) oxygen, and the remainder titanium. It is significantly stronger than commercially pure titanium while having the same stiffness and thermal properties (excluding thermal conductivity, which is about 60% lower in Grade 5 Ti than in CP Ti). Among its many advantages, it is heat This grade is an excellent combination of strength, corrosion resistance, weld and fabricability.This alpha-beta alloy is the workhorse alloy of the titanium industry. The alloy is fully heat treatable in section sizes up to 15mm and is used up to approximately 400°C (750°F). Since it is the most commonly used alloy -over 70% of all alloy grades melted are a sub-grade of Ti6Al4V, its uses span many aerospace airframe and engine component uses and also major non-aerospace applications in the marine, offshore and power generation industries in particular.Generally, Ti-6Al-4V is used in applications up to 400 degrees Celsius. It has a density of roughly 4420 kg/m3, Young's modulus of 110 GPa, and tensile strength of 1000 MPa. By comparison, annealed type 316 stainless steel has a density of 8000 kg/m3, modulus of 193 GPa, and tensile strength of only 570 MPa. And tempered 6061 aluminium alloy has 2700 kg/m3, 69 GPa, and 310 MPa, respectively." **??**11] IV.

4 A Case Study: Typical Femur Under Load

Relevance Center set to medium. A fine relevance center would yield better results but it causes very high amount of RAM consumption which was unavailable. The Inflation Option settings determine the heights of the inflation layers. Smooth Transition was set for obtaining desired mesh refinement. The Smooth Transition option uses the local tetrahedral element size to compute each local initial height and total height so that the rate of volume change is smooth. Each triangle that is being inflated will have an initial height that is computed with respect to its area, averaged at the nodes. This means that for a uniform mesh, the initial heights will be roughly the same, while for a varying mesh, the initial heights will vary. Increasing the value of the Growth Rate control reduces the total height of the inflation layer. The total height approaches an asymptotic value with respect to the number of inflation layers. Span Angle Center sets the goal for curvature based refinement. The mesh will subdivide in curved regions until the individual elements span this angle. The following choices are available: For this study Curvature Normal Angle was set to 18O. The load applied here was ramped load which was applied for 1 second varying linearly 0N to 300N.

5 A Year

To demonstrate the behavior of the femur modeled for Al 2 O 3 /Al FGM and TI6AL4V, a simple example is presented here. This example is not a best case or worst case scenario but rather just a pseudo random example to see if and how much proper the materials are for artificial bone.

? Coarse -91o to 60o ? Medium -75o to 24o ? Fine -36o to 12o6

6 Results and Discussion

It may be noted that only static load applied on Femur. Though Al 2 O 3 /Al FGM is relatively new concept compared to TI6Al4V, it has higher reliability and less weight. From the properties of Ti6Al4V and Al based FGM (i.e. Al 2 O 3 /Al FGM) we can see that FGM has slightly less strength than Ti6Al4V. But from aluminum based FGM sudden release of Al is less frequent and safe. As a result Al based FGM has become a strong competitor in the field of artificial bone material.

7 Conclusion

1

Figure 1: Figure 1 :

[1] [2] [3] [4] [5]

[2]Analysis of Al2O3 /Al FGM as Biomaterial of Artificial Human Femoral Bone and Compare with Ti6Al4V Alloy through Computational Study

[3]Analysis of Al2O3 /Al FGM as Biomaterial of Artificial Human Femoral Bone and Compare with Ti6Al4V Alloy through Computational Study

[4]Analysis of Al2O3 /Al FGM as Biomaterial of Artificial Human Femoral Bone and Compare with Ti6Al4V Alloy through Computational Study

[5]Analysis of Al2O3 /Al FGM as Biomaterial of Artificial Human Femoral Bone and Compare with Ti6Al4V Alloy through Computational Study

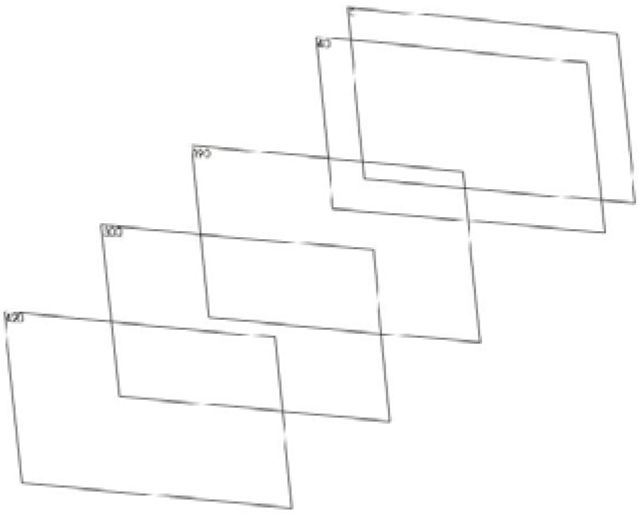

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Figure 2: Figure 2 :

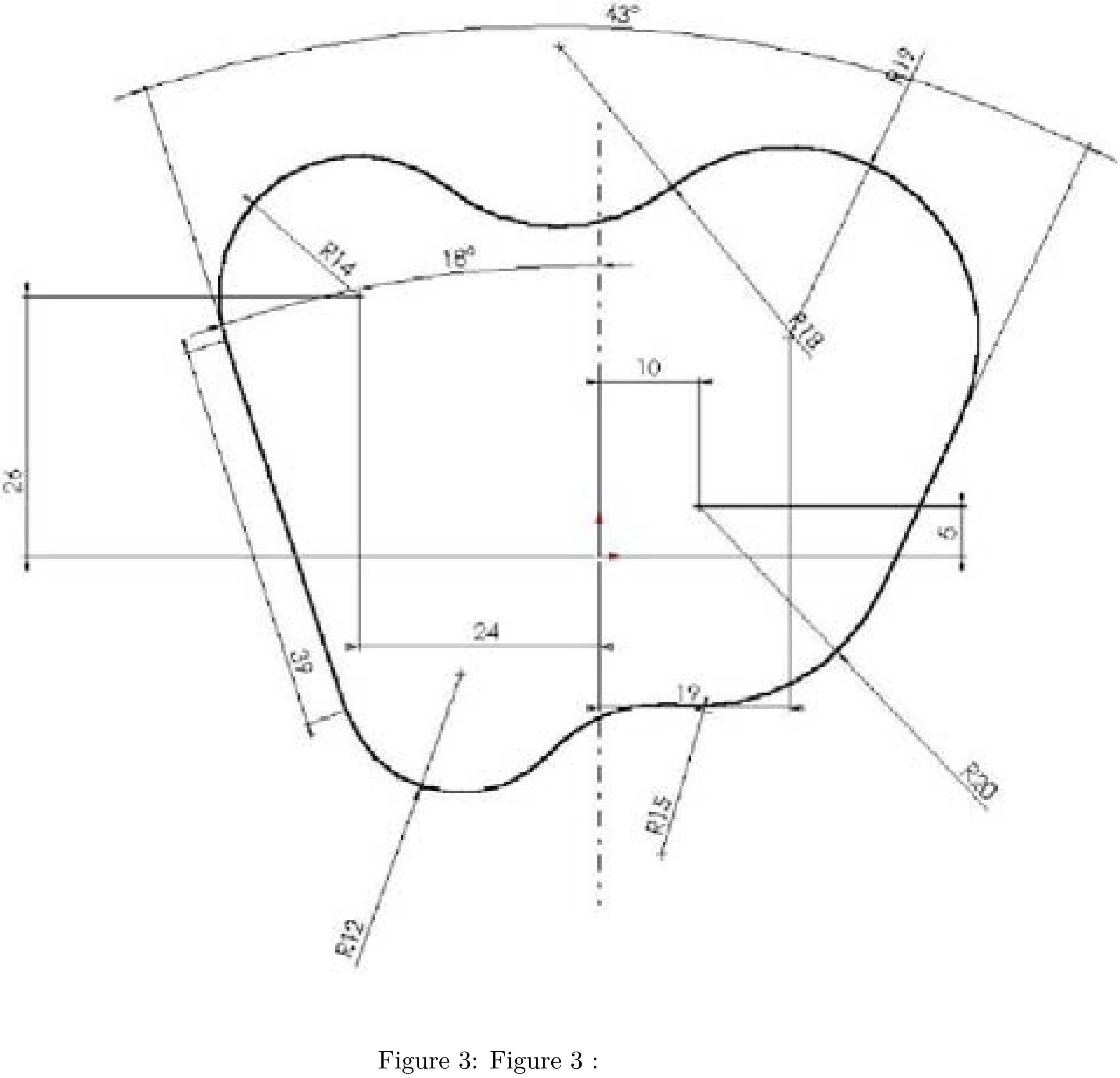

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Figure 3: Figure 3 :

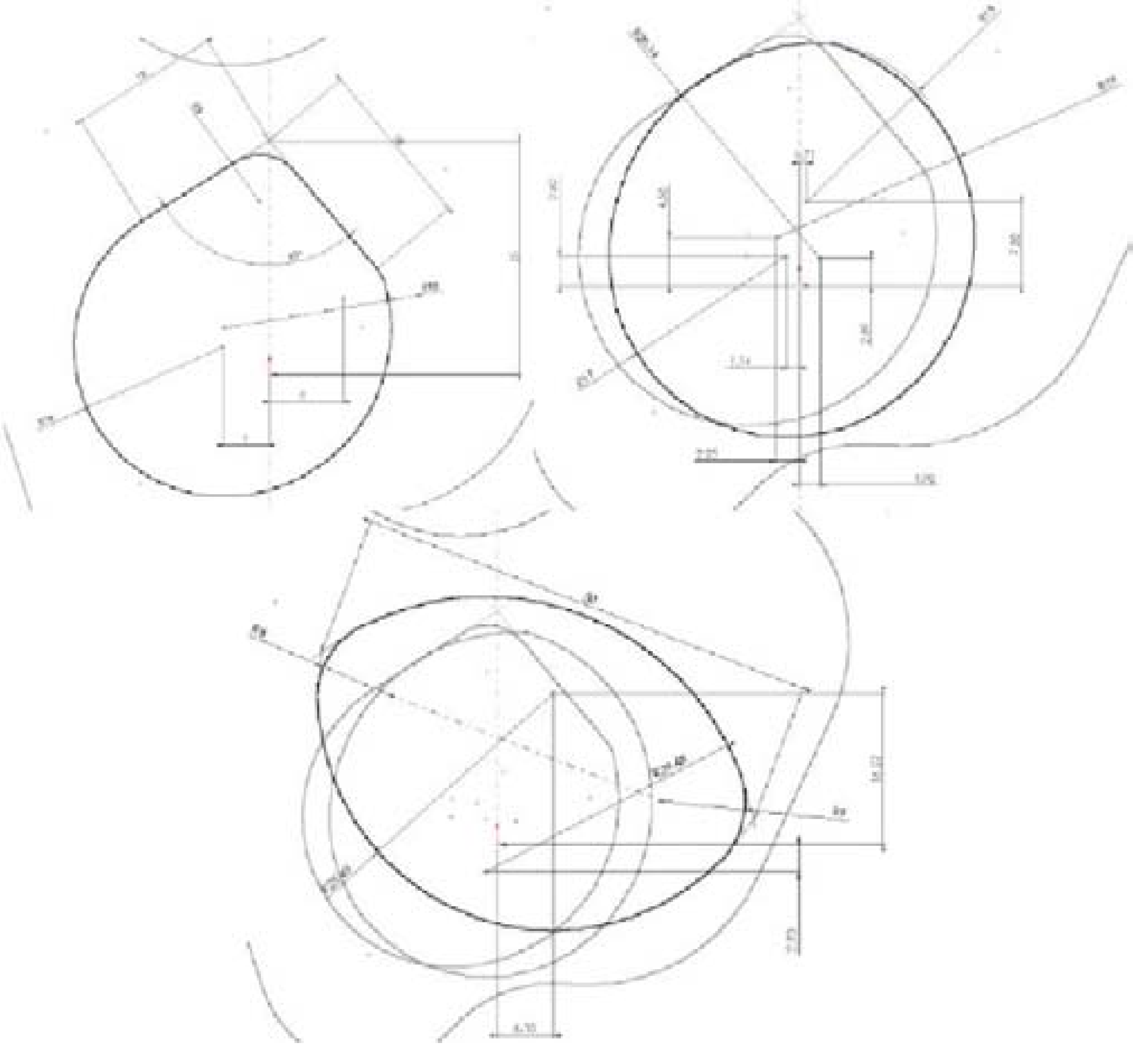

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Figure 4: Figure 4

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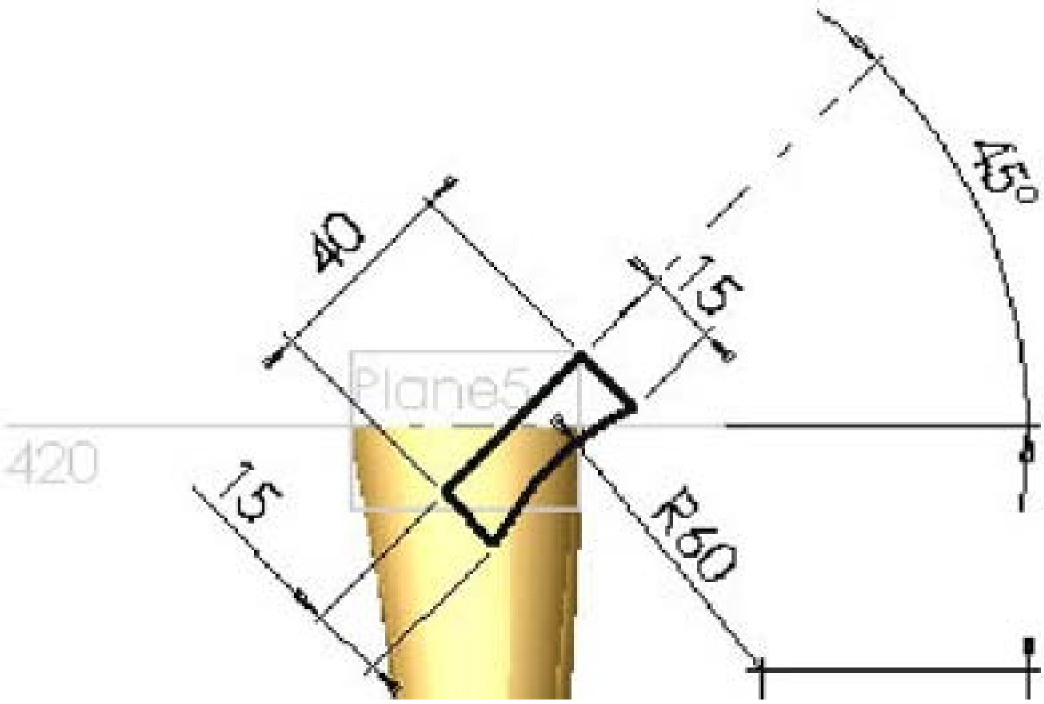

Figure 5: Figure 4 :

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Figure 6: Figure 5 :

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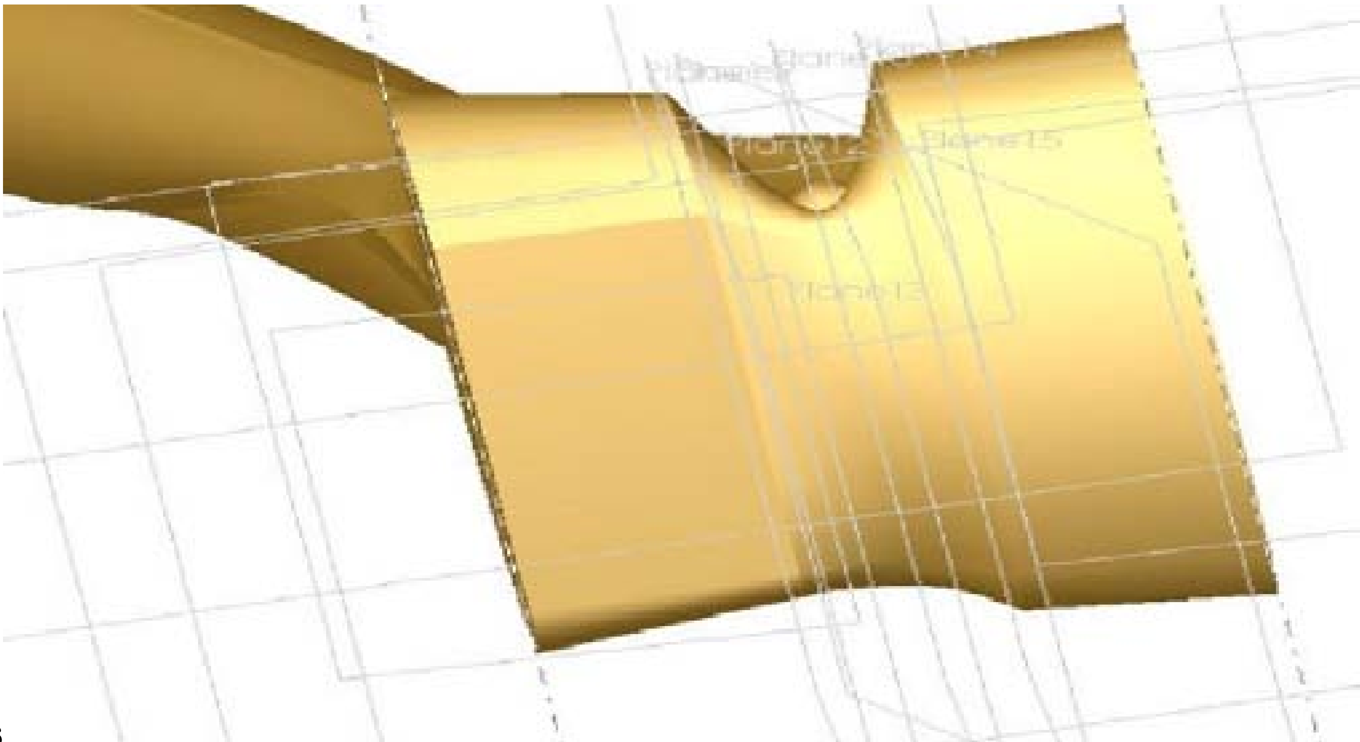

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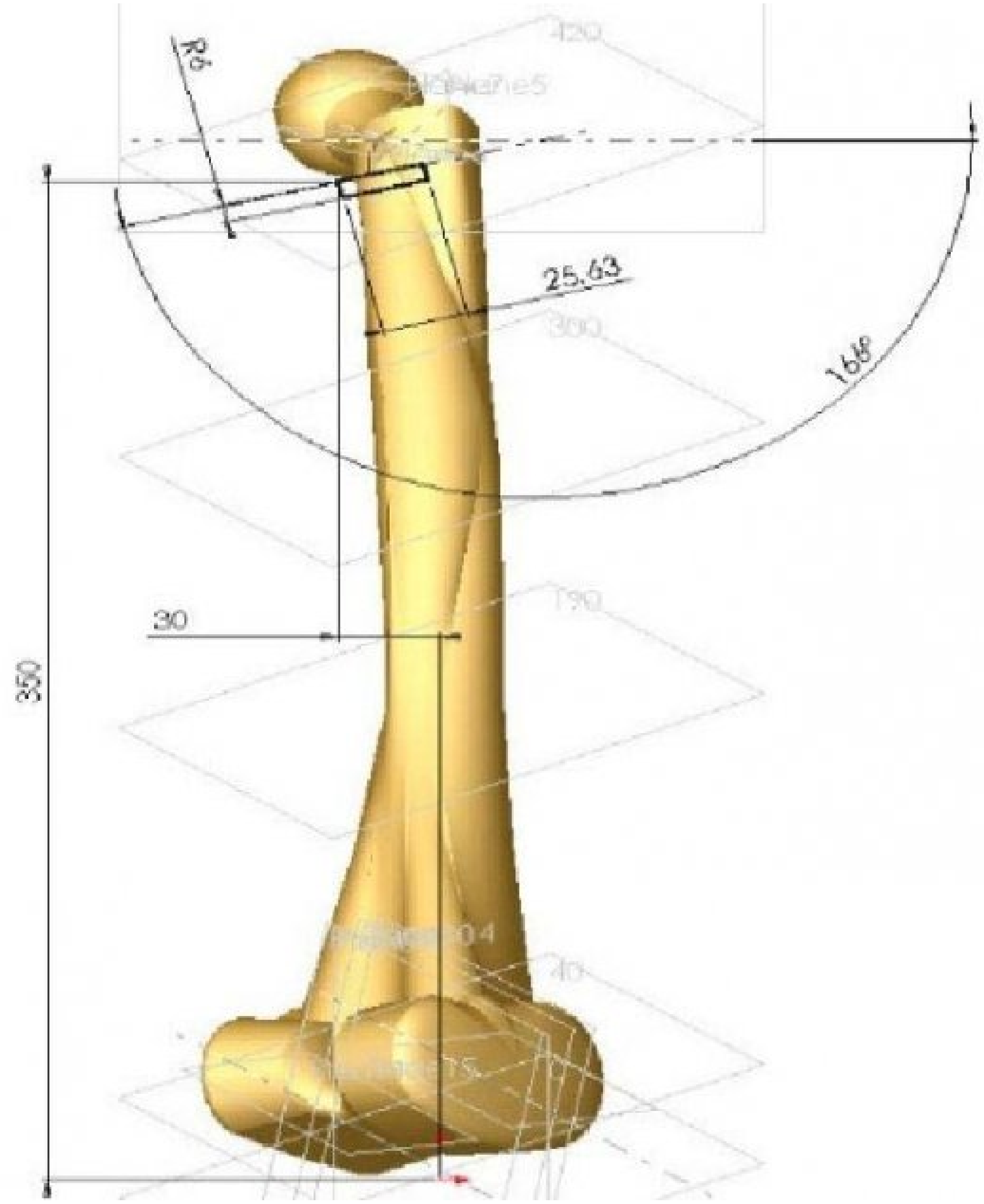

Figure 8: Figure 7 :

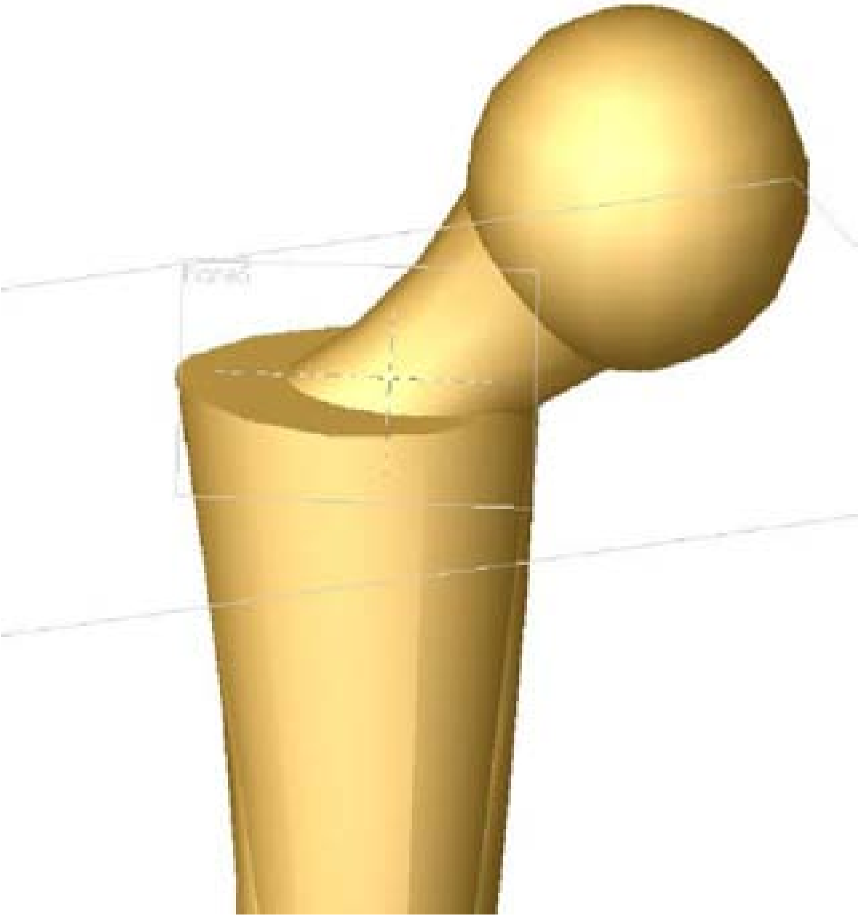

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Figure 9: Figure 8 :

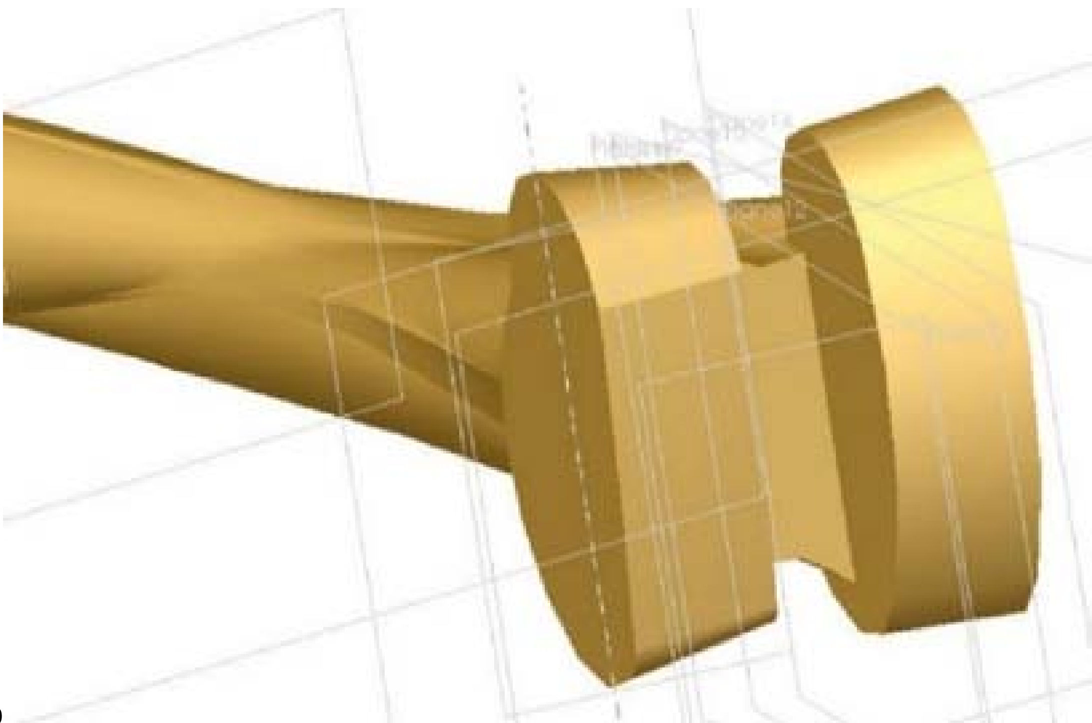

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Figure 10: Figure 9 :

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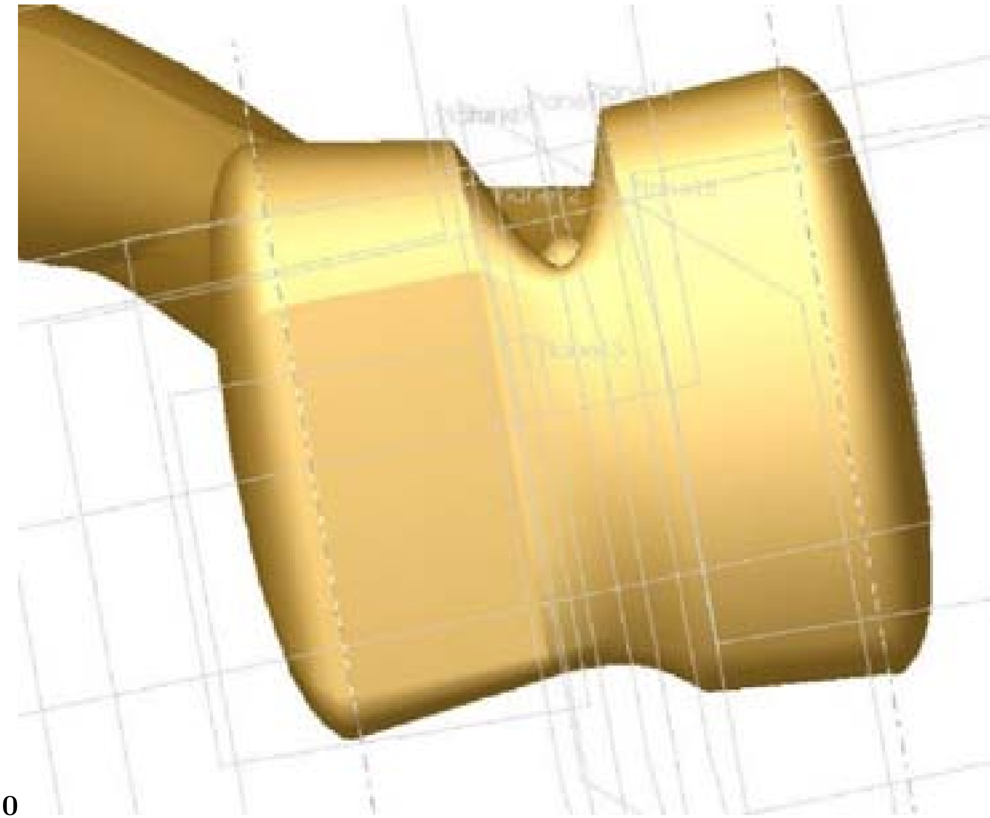

Figure 11: Figure 10 :

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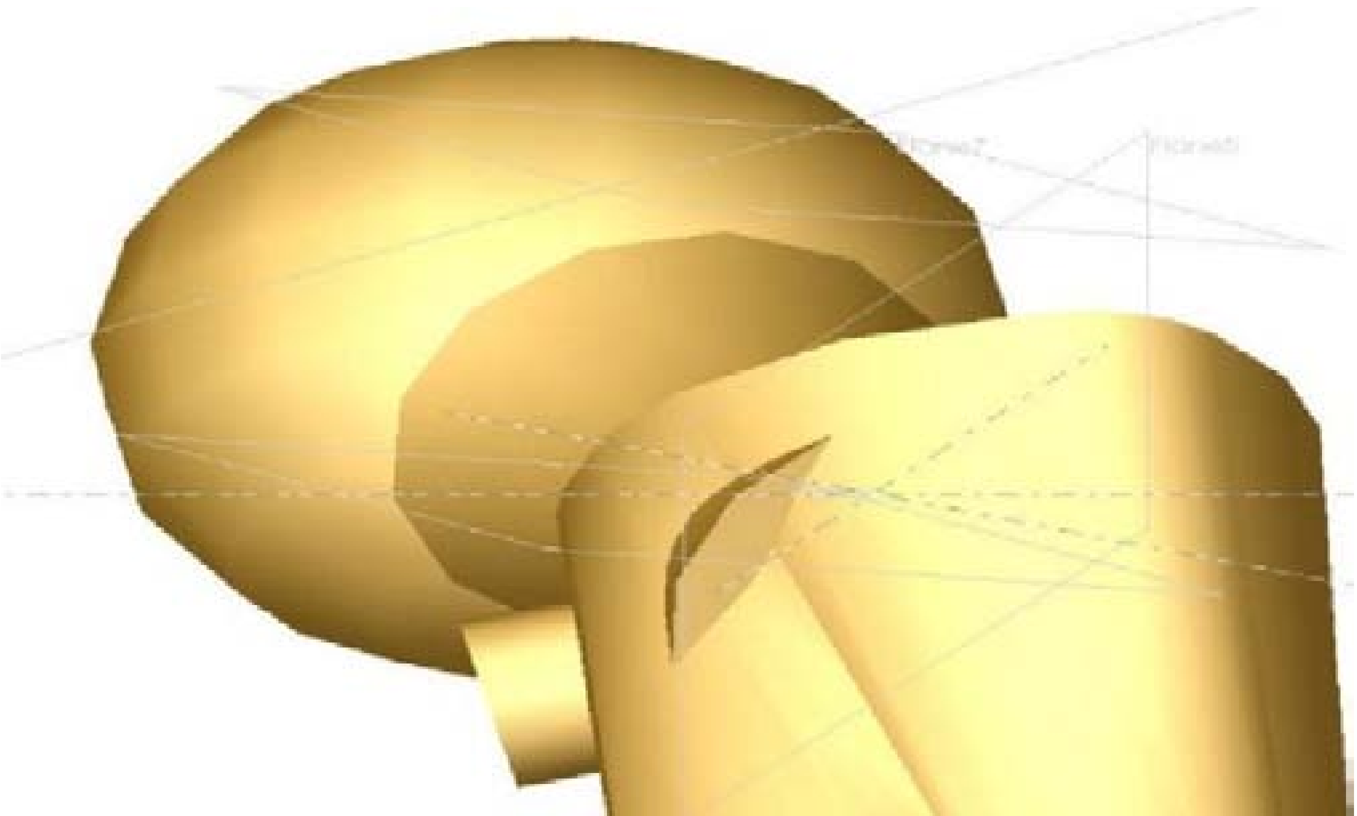


Figure 12: Figure 12 :

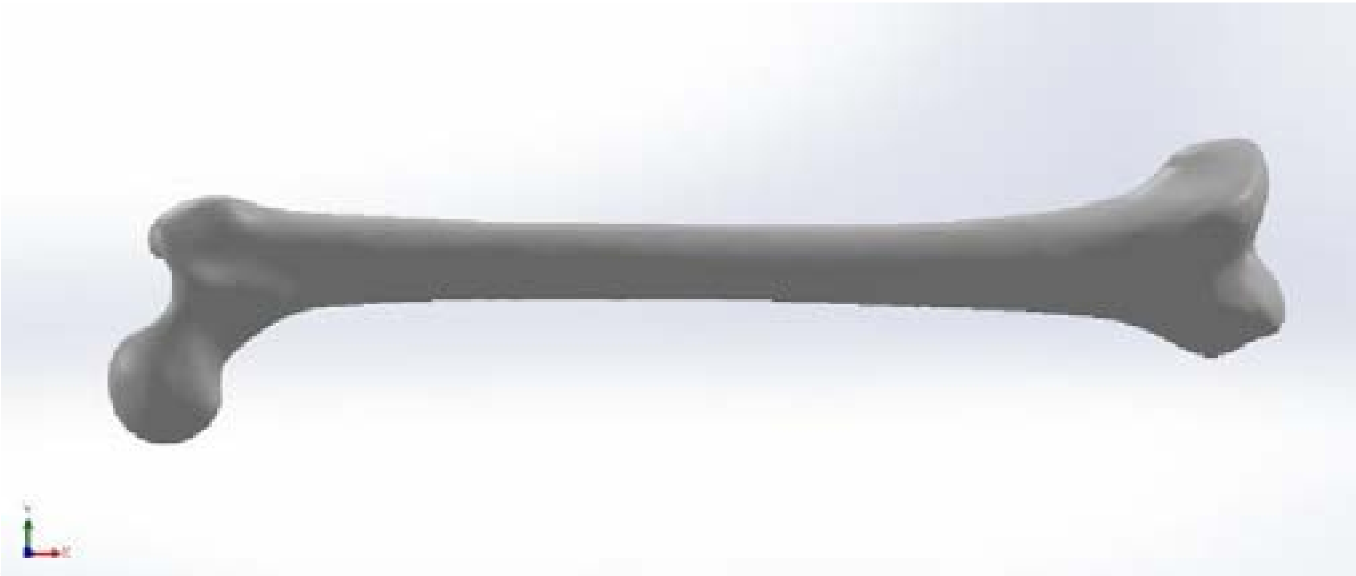
13 

Figure 13: Figure 13 :

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{zx} \end{Bmatrix} = \begin{bmatrix} 1 & \nu & 0 & 0 & 0 \\ \nu & 1 & 0 & 0 & 0 \\ 0 & 0 & \frac{1-\nu}{2} & 0 & 0 \\ 0 & 0 & 0 & \frac{1-\nu}{2} & 0 \\ 0 & 0 & 0 & 0 & \frac{1-\nu}{2} \end{bmatrix} \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{Bmatrix}$$

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Figure 14: Figure 11 : 3 Figure 14 :

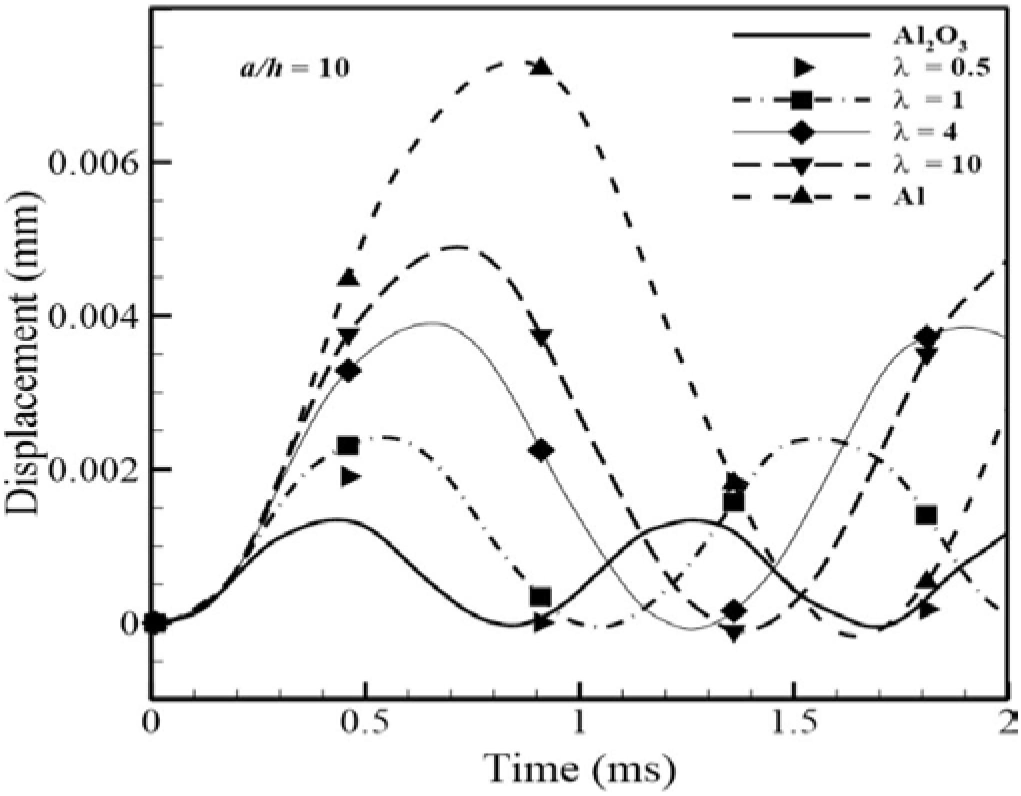

Figure 15:

$$P(z) = P_t - P_b \left\{ \frac{2z + h}{2h} \right\}^{\lambda} + P_b$$

15

Figure 16: Figure 15 :

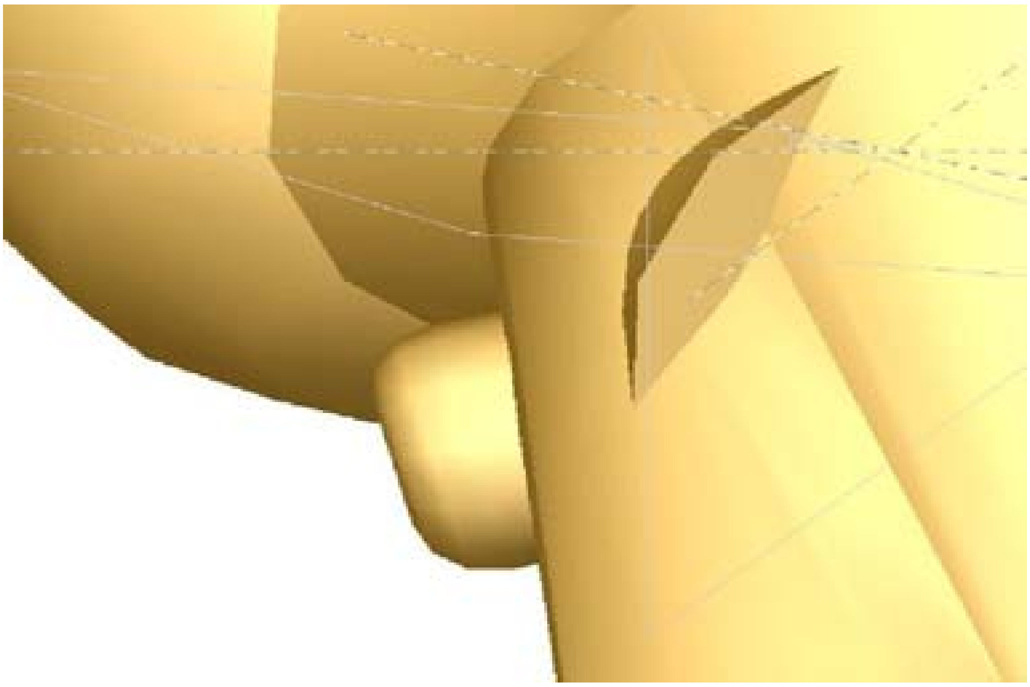

Figure 17: Figure

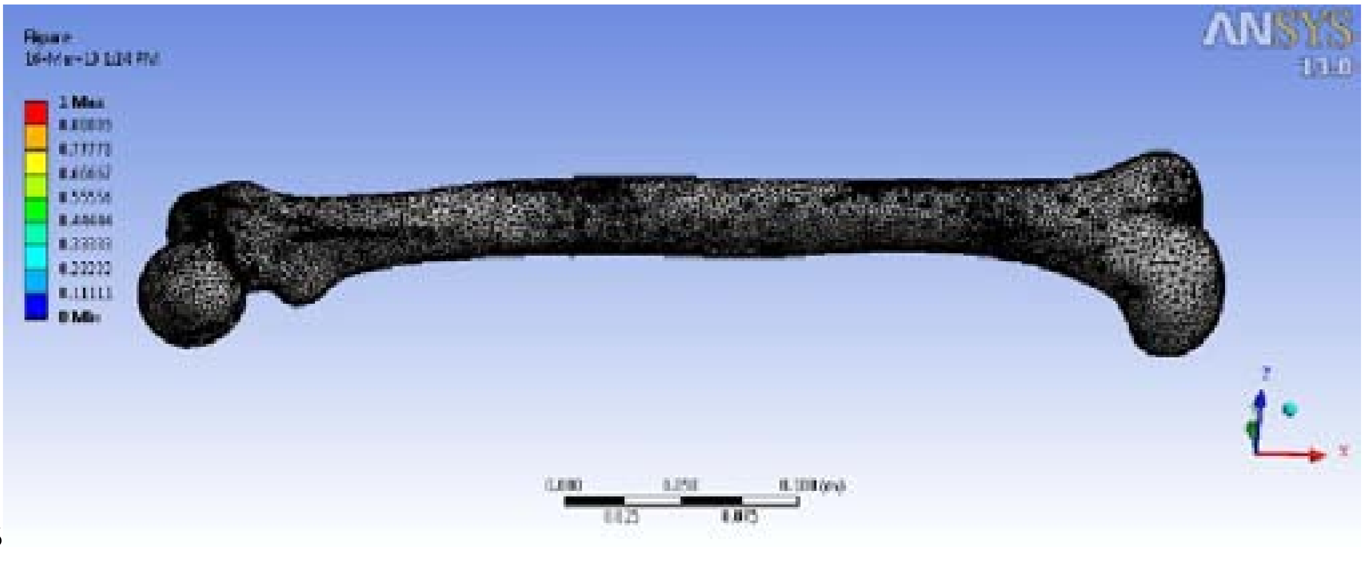

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Figure 18: Figure. 5

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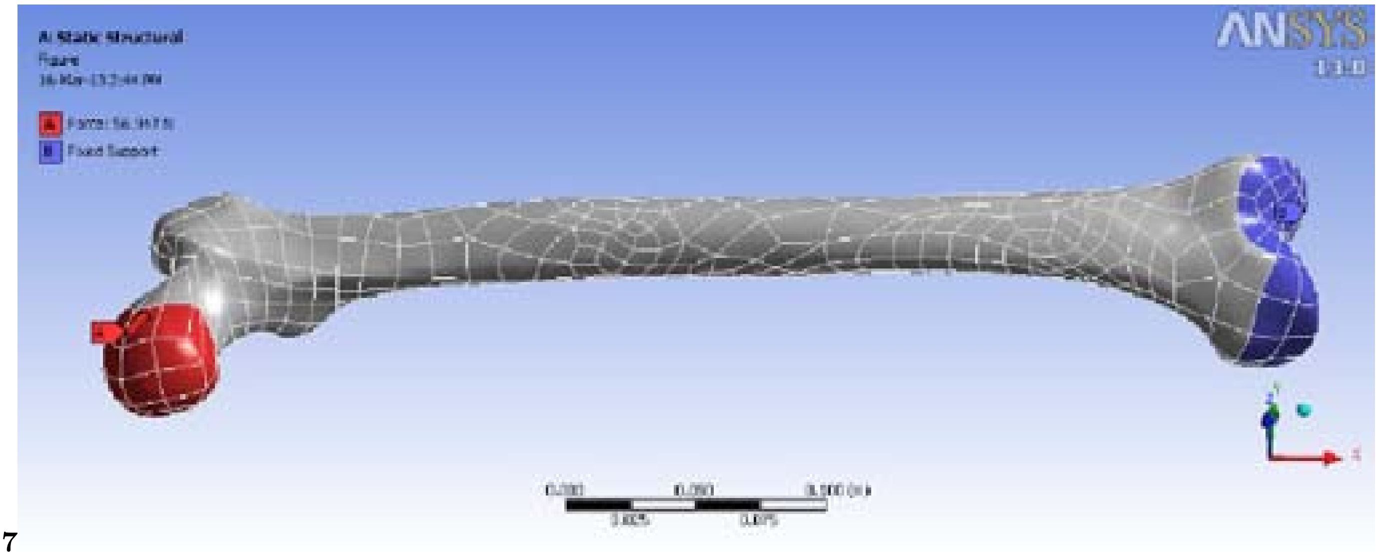

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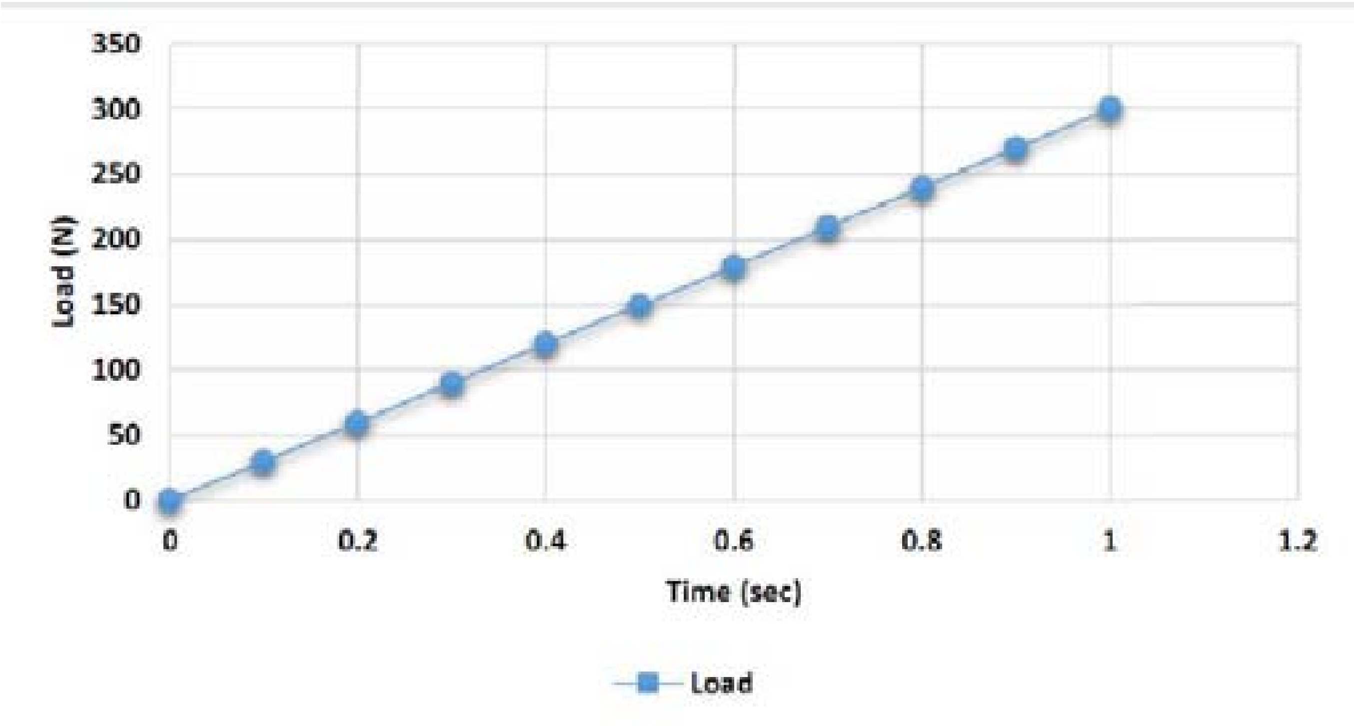

Figure 20:

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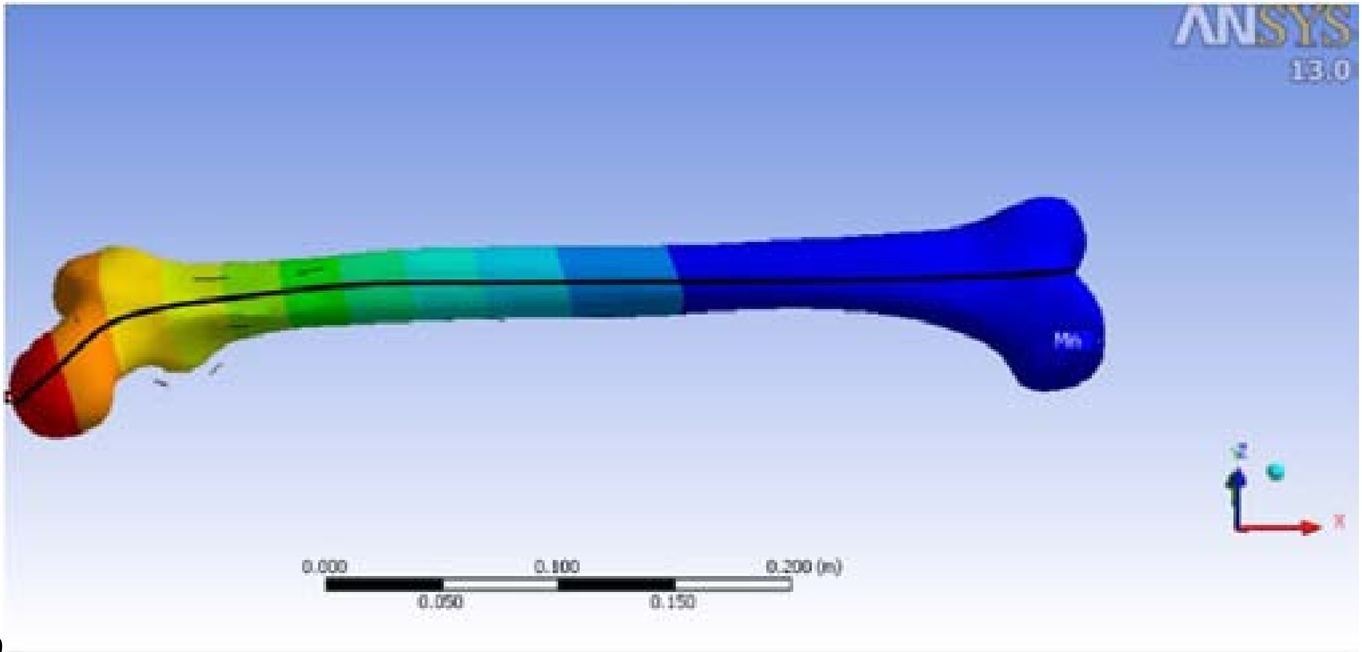

Figure 21: Figure 20 :

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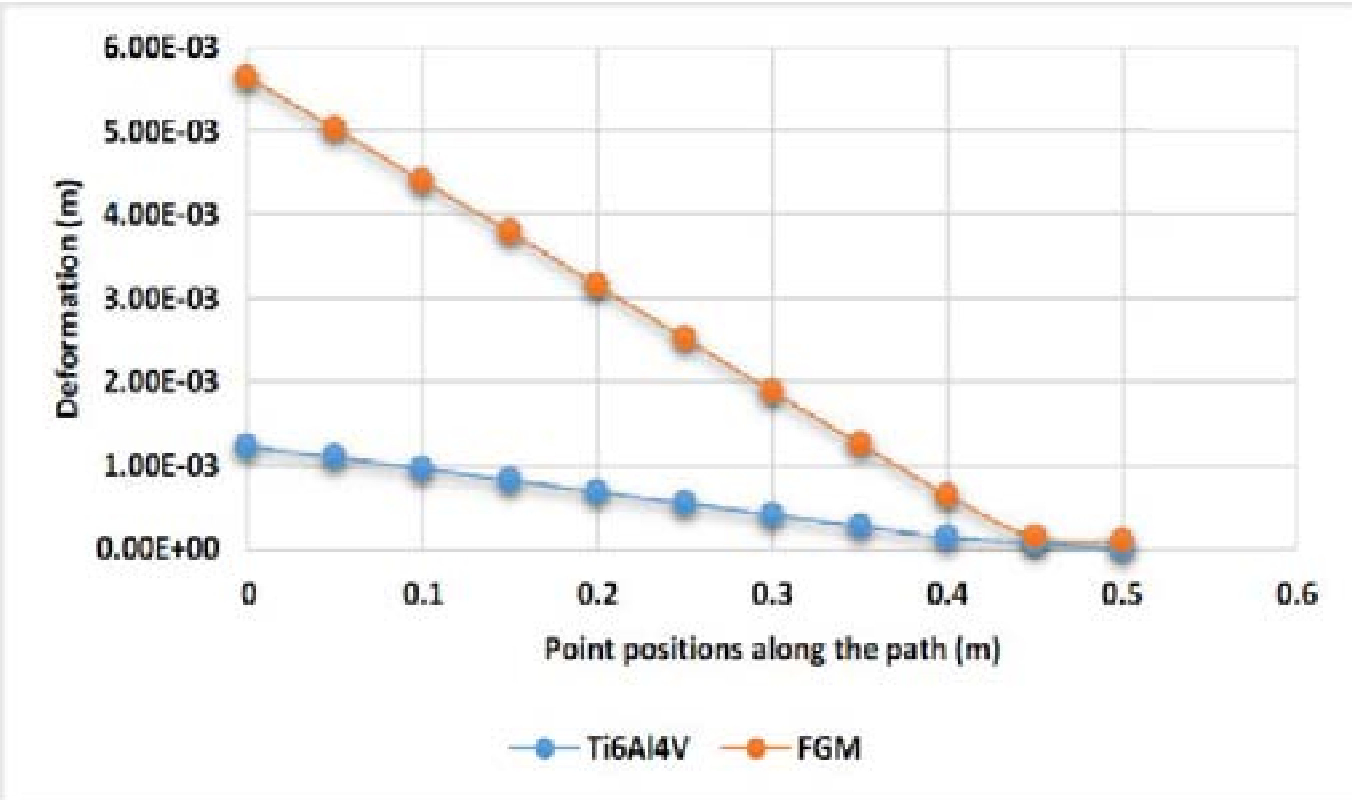

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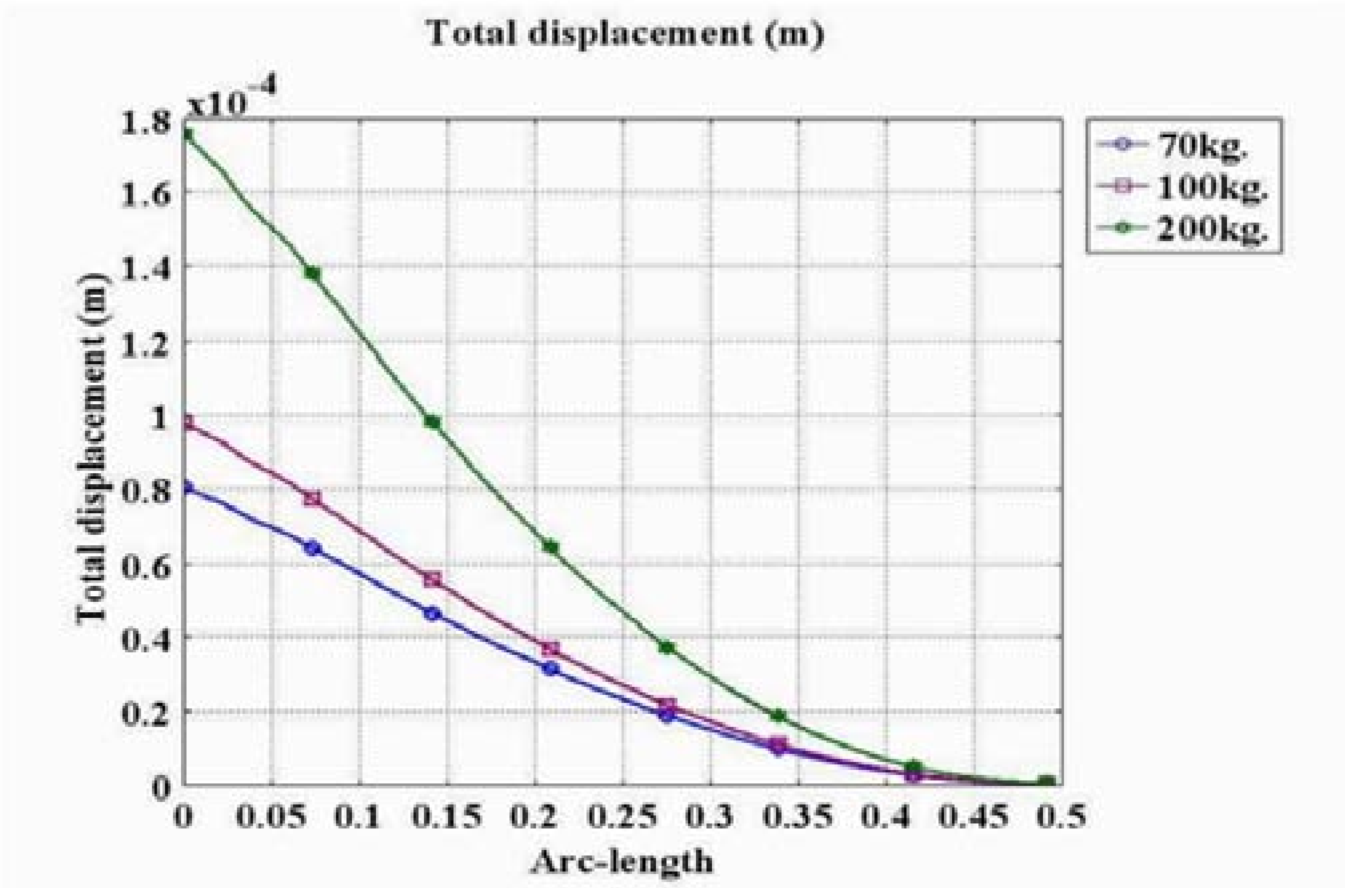

Figure 23:

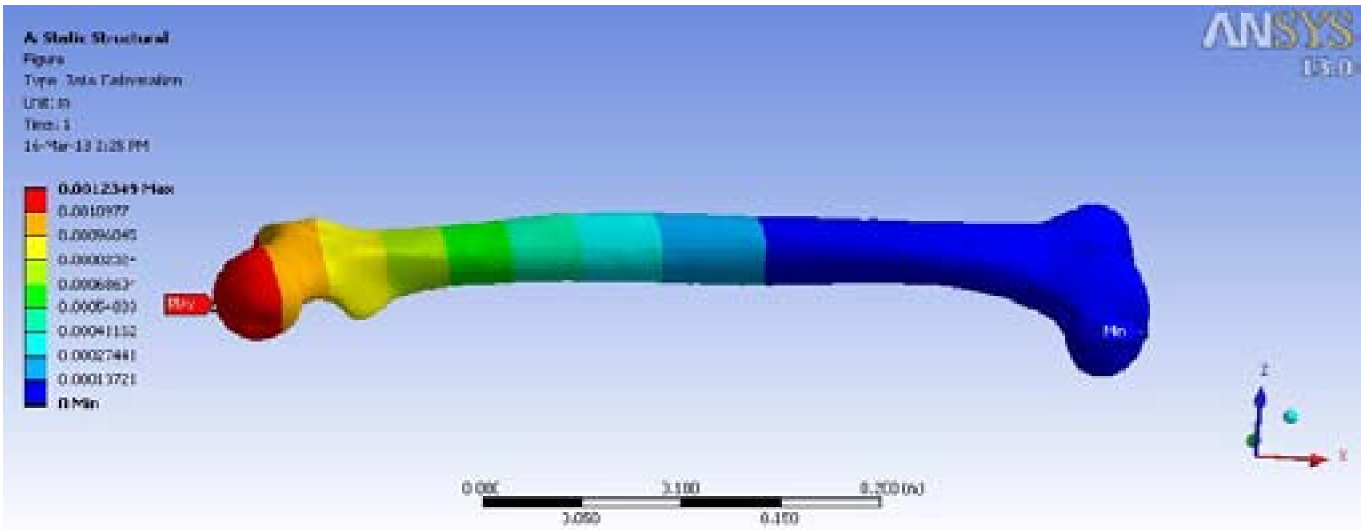

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Figure 24: Figure 18 :

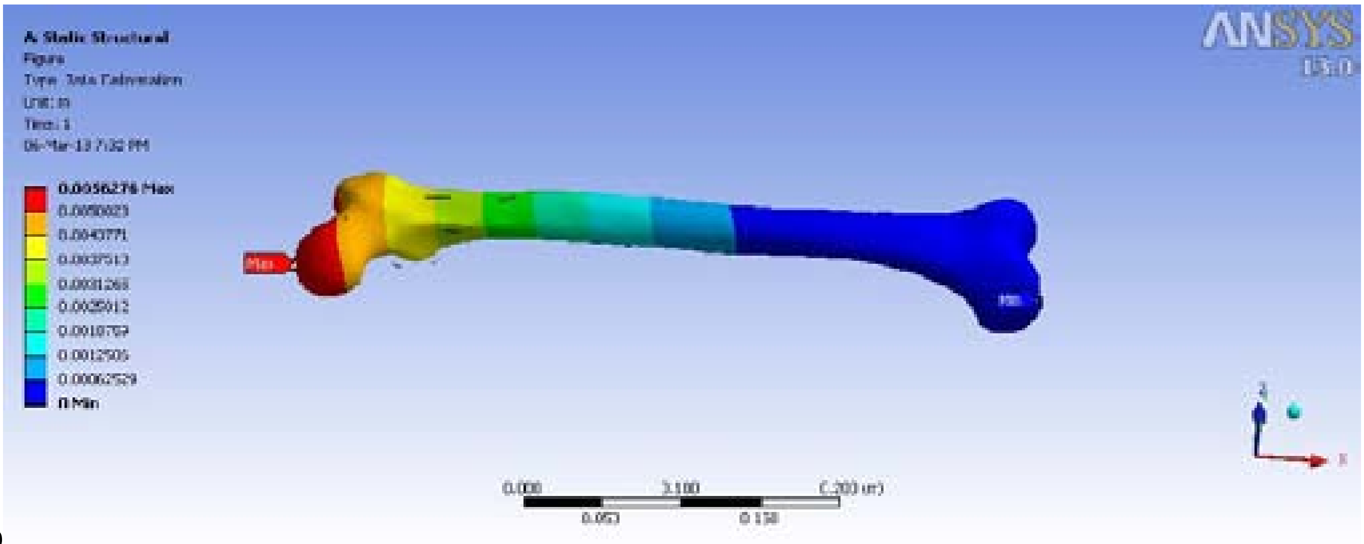

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Figure 25: Figure 19 :

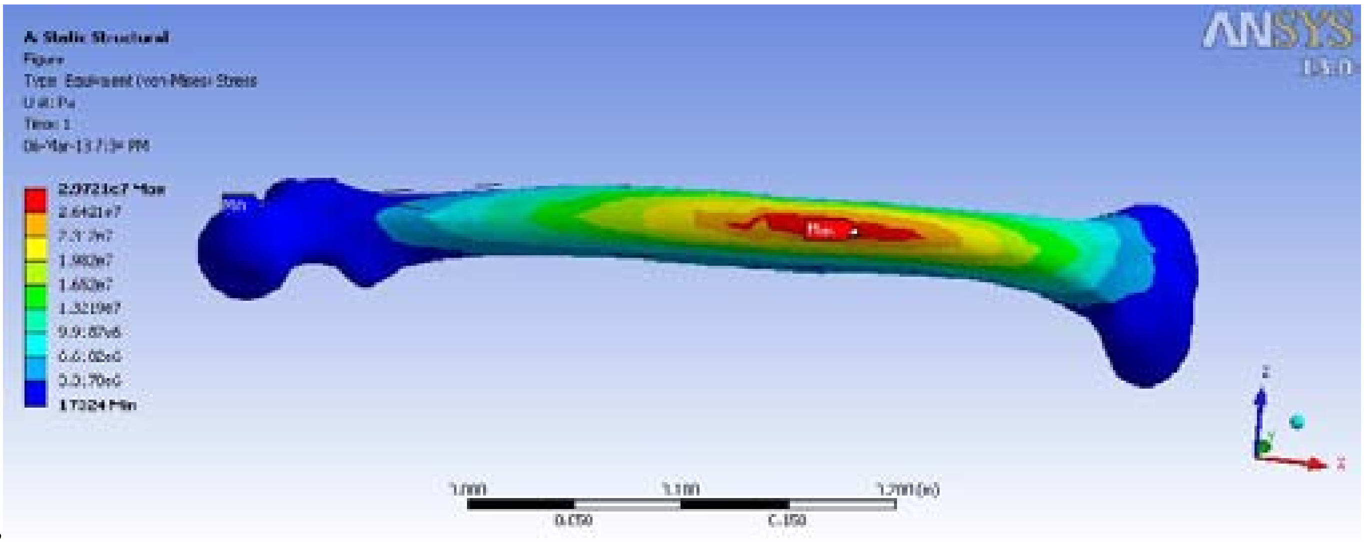

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Figure 26: Figure 23 :

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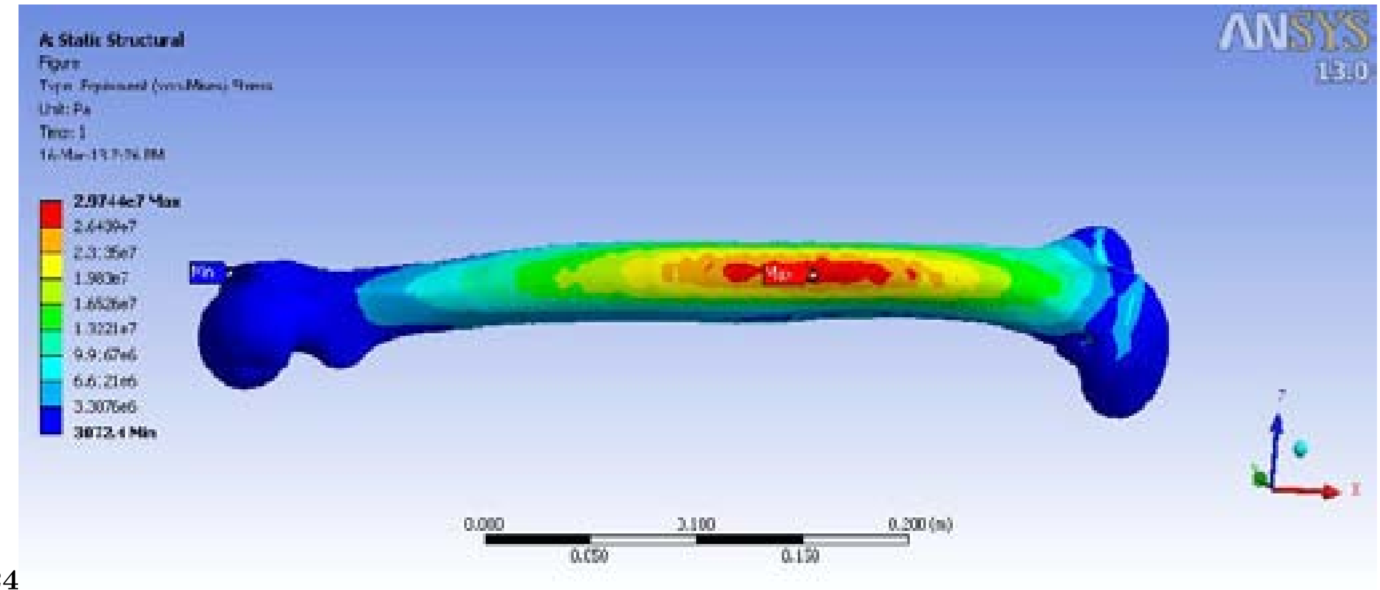

Figure 27: Figure 24 :

1

Figure 28: Table 1 :

2

Figure 29: Table 2 :

.1 Acknowledgments

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In the field of biomedical, research on biomaterial is of utmost important. Typically, in the reconstruction of bone defects, clinicians use autograft bone, based on the fact that the commercially available synthetic materials are not optimal for the reconstruction of bone. Moreover, as stated earlier for total bone replacement the need for specialized biomaterial is of utmost importance. This study deals with Ti6Al4V and Al 2 O 3 /Al FGM as prospective candidate of femur bone material. Both of these materials has friendly behavior with MRI. This computational study reveals mechanical characteristics of Ti6Al4V and Al 2 O 3/ Al FGM under a random loading. Overall study shows that Al2O3/Al is more suitable than TI6AL4V in case of both strength and weight of the bone. This study will be useful to surgeon in femur surgeries and bone prosthesis. These better synthetic bone substitutes will most probably be commercially available for orthopaedic applications in the near future.

[Informations] , `http://en.wikipedia.org/wiki/Femur` *Informations*

[Informations] , `http://education.yahoo.com/reference/gray/subjects/subject/59` *Informations*

[Sinha et al. (2009)] , A Sinha , A Kumar , A Garg , A Bhargava , A K Mishra , B Sharma , B Mishra , S S Thakur , V Kumar . *International Journal of Computer Science and System Analysis* January-June 2009. 3 (1) p. . Finite Element Method of Femur Bone

[Viceconti et al. ()] 'Acomparative study on di®erentmetho ds of automatic meshgeneration of human femurs'. M Viceconti , L Bellingeri , L Cristofolini , A Toni . *Medical Engineering &Physics* 1998. 20 p. .

[Nareliya and Kumar] 'Biomechanical Analysis of human femur bone'. Raji Nareliya , Veerendra Kumar . *International Journal of Engineering Science and Technology* IJEST.

[Elias et al.] 'Biomedical Applications of Titanium and its Alloys'. C N Elias , J H C Lima , R Valiev , M A Meyers . *Biological Materials Science*

[Giannoudis et al. ()] 'Bone substitutes: an update'. P V Giannoudis , H Dinopoulos , E Tsiridis . *Injury* 0020-1383. 2005. 36 (3) p. . (Suppl)

[Chakraborty et al.] *Dynamic Analysis Of Functionally Graded Shell Structure Using Finite Element Method*, Debabrata Chakraborty , Manish Ranjan , Anil Kumar . (space 1: 2)

[Kant et al. ()] 'Finite element transient dynamic analysis of isotropic and fibre reinforced composite plates using a higher-order theory'. T Kant , R V Ravichandran , B N Pandya , B N Mallikarjuna . *Composite Structures* 1988. 9 (4) p. .

[Amornsamankul et al.] *Three-Dimensional Simulation of the Femur Bone Using Finite Element Method*, Somkid Amornsamankul , Benchawan Wiwatanapataphee , Kamonchat Kaorapapong . (Selected Topics in APPLIED COMPUTER SCIENCE)

[Keaveny et al. ()] 'Trabecular bone exhibits fully linear elastic behavior and yields at low strains'. T M Keaveny , E Guo , E F Wachtel , T A Mcmahon , W C Hayes . *J. Biomechanics* 1994. 27 p. .