EFFECT OF HOLES IN THE FEMORAL STEM MADE OF Ti6AI4V ON THE STRENGTH OF THE MATERIAL

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Abstract

The hip joint or hip joint is a very important joint in the human skeletal system because it is the connection between the legs and the body. Stage joints often experience damage caused by many factors. Damage to the hip joint usually causes the patient to have to use an artificial hip joint or what is usually called an artificial hip joint. Hip Prosthesis takes into account the anatomical shape in terms of patient size. The focus of this research is modeling the femoral stem using Ti6AI4V titanium material through simulation software. Analysis of variables in the form of offset length, stem length, hole and magnitude of force on the implant. The results of the stress analysis simulation can be concluded that the femoral stem design in terms of the largest Von Mises stress distribution is size 7 at 448.4 Mpa. The greatest strain in femoral stem size 3 is 1.672 10^{-3}. The largest total deformation in femoral stem size 7 was 1.768 mm.

***Keywords**: Hip joint, hip prosthesis, femoral stem, Von Mises stress*

Introduction

Osteoarthritis (OA) is chronic inflammation of the joints caused by damage to cartilage which causes the joints to feel painful, stiff and swollen. This disease can attack all joints, but most often occurs in the joints of the fingers, knees, hips and spine. Hip osteoarthritis is a type of inflammation of the hip joint (ball-and-socket joint) with the femoral head. One way to treat hip osteoarthritis is by replacing the implant material in the hip joint by an orthopedic doctor, which is called a hip prosthesis.

The artificial hip bone consists of an acetabular and femoral system. The acetabular system consists of the acetabular shell and acetabular liner, while the femoral system consists of the femoral head and femoral stem. Various combinations of materials, such as metal, ceramic, and polymer are the materials used to manufacture hip implants. Biomaterials are materials that have direct contact with biological systems in living creatures. These materials must have characteristics, including not having a negative impact on the body, having good corrosion resistance, and having good strength, especially physical strength and toughness [1].

The materials that are widely used for these components are mostly acetabular liners using UHMWPE, while the acetabular shell, femoral head and femoral stem use Ti6Al4V, CoCrMo or 316L stainless steel alloys. Permanent damage to the hip joint due to calcification, aging or accidents requires artificial hip joint replacement or what is usually called artificial hip joint replacement [5]. In developed countries, the number of patients using artificial hip joints is very large. On the European continent there were 600,000 cases of artificial hip joint replacement in 2005, then there were also 230,000 cases found in America in 2004 and at least 150,000 cases were found in Japan over the last few years. Therefore, this research is needed to model a femoral stem that is suitable and tough for patients. To obtain a femoral stem that has low metal stiffness and does not have much effect on the maximum stress, a hollow femoral stem is designed. Porous metals have lower stiffness than solid implants [2].

Simulation is needed to analyze the performance of the model that has been created. One technique that is often used for simulation is using the finite element method (FEM). Analysis using FEM is very useful to determine the effect of changes in parameters such as load, speed, geometry, material properties and others. FEM analysis was carried out because the femoral stem model was quite complex so it would be very difficult to calculate manually. By carrying out FEM simulations, it can be seen whether the femoral stem is safe to use under loading conditions.

Table 1. Types of Materials and Their Applications [3]

Material	Superiority	Weakness	application
Metal: stainless steel, titanium alloy, cobalt-chrome	Strong, tough, tenacious	Non bioactive	Orthopedic implants, dental implants, artificial

alloy, etc			joints, heart rings (stents), etc
Ceramics: zirconia, alumina, bioglass, Hydroxyapatite	Bioactive, inert	Brittle	Orthopedic implants, dental implants
Polymers: nylon, polyactide, polyethylene, polyester, etc	Bioactive, elastic	Not strong enough	Blood vessel grafts, suture threads, sockets, artificial joints, etc
Composite: amalgam, fiber reinforced bone cement, etc.	Custom made.	Relatively difficult to make.	Bone cement, dental resin, etc

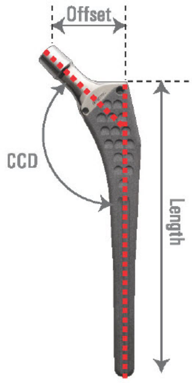


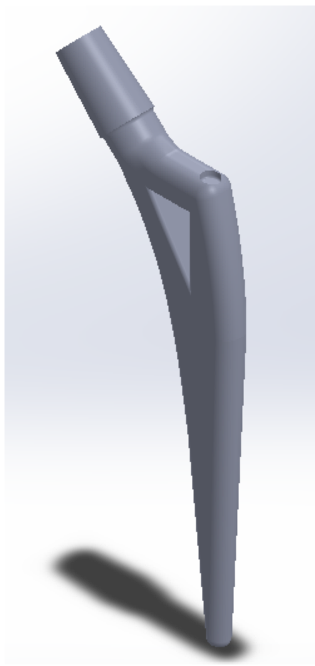
Figure 1. Femoral Stem [7]

Methode

This research focuses on the design of a hollow femoral stem that suits the patient's anatomy. The femoral stem geometry is in accordance with Indonesian anatomy with 3 main parameters, namely CCD angle (centrum-collum-diaphysis angles), stem length, and offset.

Femoral Stem Modeling

The results of modeling for various femoral stem sizes can be seen in the image below.



Gambar 2. *Femoral stem*

Material Selection

This research uses titanium material Ti-6Al-4V. The composition of titanium Ti-6Al-4V is 90% titanium atoms, 6% aluminum atoms, and 4%

vanadium atoms and is included in the classification of titanium alloys which have an alpha-beta phase. Providing holes in the femoral stem design aims to reduce the material used and reduce the stiffness of the metal. The results of the femoral stem modeling can be seen in Figure 2. Using 3 femoral stem sizes, namely size 3, 5 and 7 [6], the load simulation was then analyzed. By using a load variation of 700 N, the femoral stem stress distribution, strain and total deformation will be known and analyzed.

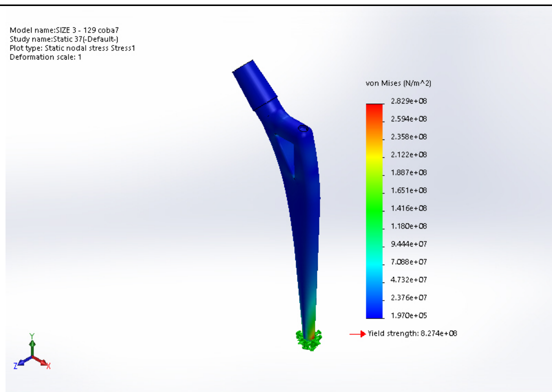
Tabel 2. Mechanical Properties Material Titanium Ti6A14V

Properties	Unit	Titanium Ti6A14V
Yield strength	MPa	1100
Ultimate tensile strength	MPa	1170
Modulus of elasticity	GPa	114
Poisson ratio	-	0,33

Discussion

Modeling and simulation of femoral stem using Ti6A14V material with static loading. The simulation is carried out statically. The load used for patients weighing 700 N. The output results from the overall simulation are von Mises stress, strain and displacement values in the form of images. Based on the results of the hip prosthesis simulation, maximum von Mises stress and strain data were obtained with the steam body concentration area at the bottom as can be seen in the table below.

Table 3. Results of analysis of Maximum Von Mises Stem Stress with a load of 700 N

Size Femoral Stem	Von Mises (Mpa)	Stress Distribution
3	282,9	

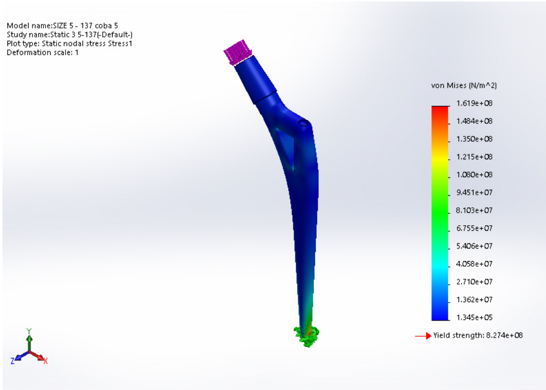
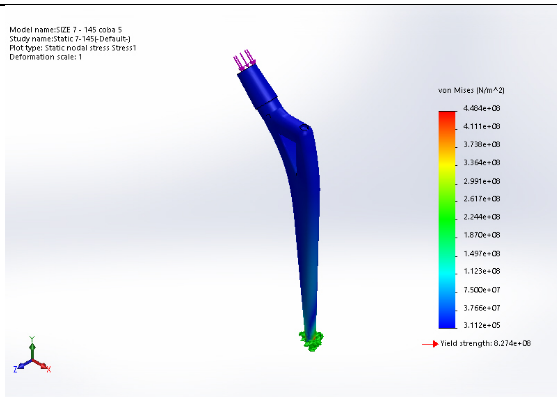
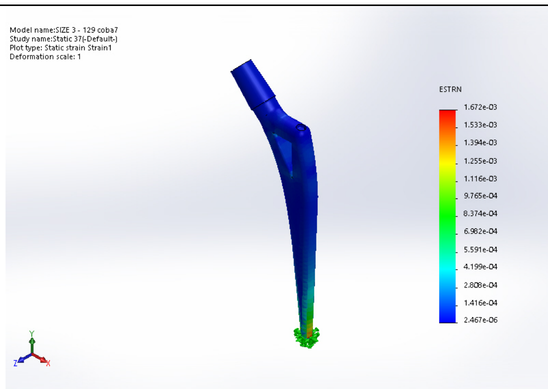
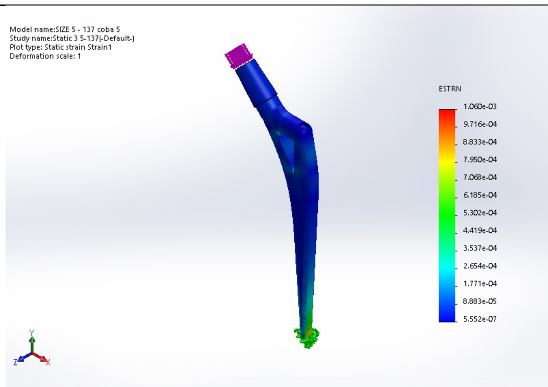
5	161,9	
7	448,4	

Table 4. Stem strain analysis results with a load of 700 N

Size Femoral Stem	Strain	Strain Distribution
3	$1{,}672\ 10^{-3}$	
5	$1{,}060\ 10^{-3}$	

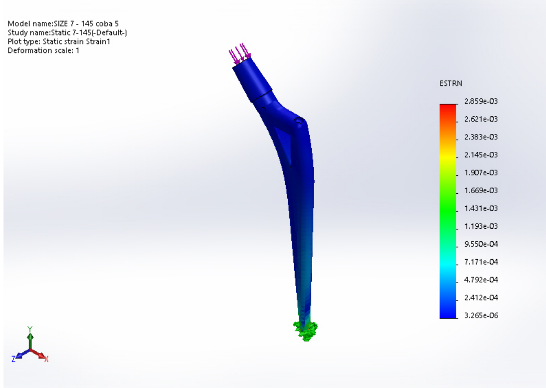
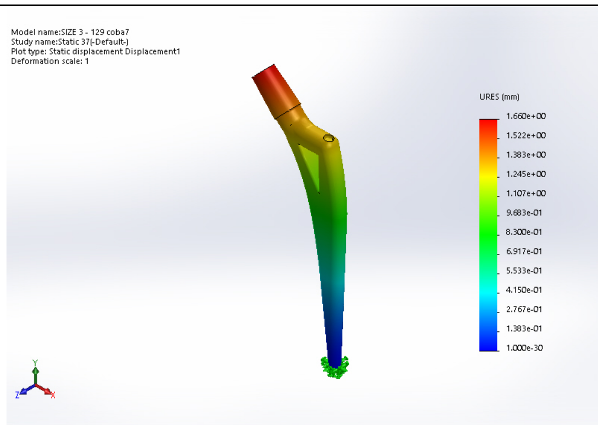
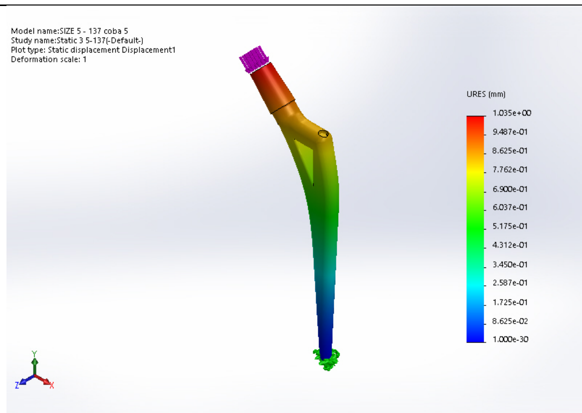
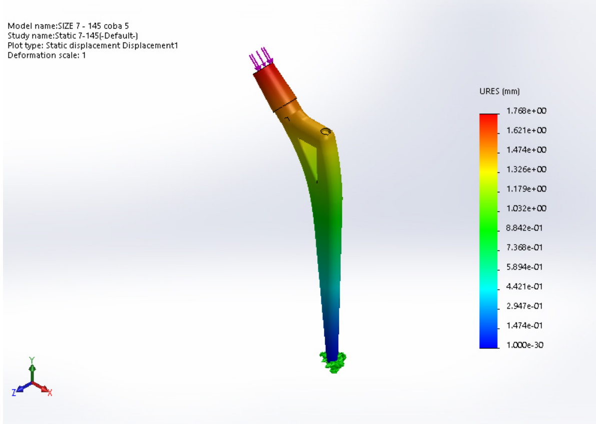
7	2,859 10^{-3}	

Table 5. Results of Total Deformation analysis with a load of 700 N

Size Femoral Stem	Total Deformation (mm)	Deformation
3	1,66	
5	1,035	

7	1,768	

The figure above shows that the maximum von Mises stress on the femoral stem tends to be stable and does not change much for various sizes. Among these sizes, the largest von Mises stress occurs in size 7 at 448.4 MPa. Providing a hole in the femoral stem causes the larger the size, the greater the von Mises stress and total deformation. . If viewed based on the area that experiences deformation under all loads, it shows that the neck area of the femoral stem experiences maximum deformation.

Conclusion

1. The results of the stress analysis simulation can be concluded that the femoral stem design in terms of Von Mises stress distribution is the largest in size 7 at 448.4 Mpa.
2. The largest strain in femoral stem size 3 is $1.672.10^{-3}$.
3. The largest total deformation in femoral stem size 7 was 1.768 mm.

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