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Design and Analysis of Artificial Hip Joint

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ABSTRACT

Artificial hip joint, either as a partial or a total replacement, has become a widely accepted solution for natural hip joint damages. To function as a replacement of a natural joint, the artificial one must fulfill the requirements of biocompatibility, stability and mobility. This project . is focused on the 3D geometrical design of a total hip joint replacement and finite element analysis to evaluate the mobility and stability of the artificial joint. First, three dimensional model was built and components were assembled. Then, assembly analysis was done to detect the stress, strain, displacement and factor of safety of the hip joint model of two different materials in five different motions at two different loads. Results depicted that the joint mobility of hip joint replacement represented by the range of motion, was not equal to the natural one. However the range of motion of the artificial joint was still satisfactory for daily activity. Finite element analysis results indicated that the strength of hip joint replacement was sufficient which is indicated by the value of the factor of safety. The most critical areas were the neck of the femoral stem and the doom of the cup inlay. From the Finite element analysis (FEA) results, it was also predicted that wear failure tend to occur in the upper periphery of the stem inlay.

Keywords— Hip-joint, abduction , extension , flexion and rotation

I. INTRODUCTION

A joint is the location at which bones connect. They are constructed to allow movement and provide mechanical support, and are classified structurally and functionally. Joints can also be classified based on their anatomy or on their biomechanical properties. According to the anatomic classification, joints are subdivided into simple and compound, depending on the number of bones involved, and into complex and combination joints

Hip Joint The hip joint is one of the largest joints in the human body and is what is known as a "ball and socket joint". In a healthy hip joint, the bones are connected to each other with bands of tissue known as ligaments. These ligaments are lubricated with fluid to reduce friction. Joints are also surrounded by a type of tissue called cartilage that is designed to help support the joints and prevent bones from rubbing against each other. The main purpose of the hip joints is to support the upper body when a person is standing, walking and running, and to help with certain movements, such as bending and stretching.

The hip joint, scientifically referred to as the acetabulofemoral joint , is the joint between the femur and acetabulum of the pelvis and its primary function is to support the weight of the body in both static (e.g. standing) and dynamic (e.g. walking or running) postures. The hip joints are the most important part in retaining balance. The pelvic innclination angle which is the single most important element of human body posture, is mostly adjusted at the hips. The ball and socket joint between the head of the fermur and the acetabulum.

Necessity for hip replacement It might be necessary for you to have a hip replacement if one (or both) of your hip joints becomes damaged and causes you persistent pain or problems with everyday activities such as walking, driving and getting dressed. Some common reasons why a hip joint can become damaged include:

- osteoarthritis – so-called "wear and tear arthritis", where the cartilage inside a hip joint becomes worn away, leading to the bones rubbing against each other
- rheumatoid arthritis – this is caused by the immune system (the body's defence against infection) mistakenly attacking the lining of the joint, resulting in pain and stiffness
- hip fracture – if a hip joint becomes severely damaged during a fall or similar accident it may be necessary to replace it.

Many of the conditions treated with a hip replacement are age-related so hip replacements are usually carried out in older adults aged between 60 and 80.However, a hip replacement may occasionally be performed in younger people. The purpose of a new hip joint is to:

- relieve pain
- improve the function of your hip
- improve your ability to move around
- improve your quality of life

What happens during hip replacement surgery?

A hip replacement can be carried out under a general anaesthetic (where you are asleep during the procedure) or an epidural (where the lower body is numbed).The surgeon makes an incision into the hip, removes the damaged hip joint and then replaces it with an artificial joint that is a metal alloy or, in some cases, ceramic. The surgery usually takes around 60-90 minutes to complete.

Recovering from hip replacement surgery:

For the first four to six weeks after the operation you will need a walking aid, such as crutches, to help support you. You may also be enrolled on an exercise programme that is designed to help you regain and then improve the use of your new hip joint. Most people are able to resume normal activities within two to three months but it can take up to a year before you experience the full benefits of your new hip.

What to expect after a hip replacement?

Since its introduction in the 1960s, hip replacement surgery has proved to be one of the most effective types of surgery in modern medical history. Most people experience a significant reduction in pain and, to a lesser extent, improvement in their range of movement.

However, it is important to have realistic expectations about what the operation can achieve. For example, you should be able to ride a bike but it is unlikely that you would be able to play a game of rugby safely (although, as with most things, there are always exceptions to this rule).The rehabilitation process after surgery can be a demanding time and requires commitment.

Risks of hip replacement surgery

Complications of a hip replacement can include:

- hip dislocation
- infection at the site of the surgery
- injuries to the blood vessels or nerves
- a fracture
- differences in leg length

However, the risk of serious complications is low – estimated to be less than 1 in a 100.A modern artificial hip joint is designed to last for at least 15 years, but there is always the risk that the artificial hip joint can wear out or go wrong in some way before this time, meaning that further surgery is required to repair or replace the joint. This is known as revision surgery. It is estimated that around 1 in 10 people with an artificial hip will require revision surgery at a later date.

There have been recent cases of metal-on-metal (MoM) replacements wearing quicker than would be expected, causing deterioration in the bone and tissue around the hip. There are also concerns that they could leak traces of metal into the bloodstream.

Alternatives

There is an alternative type of surgery to hip replacement, known as hip resurfacing. This involves removing the damaged surfaces of the bones inside the hip joint and replacing them with a metal surface. An advantage to this approach is that it removes less bone. However, it is usually only effective in younger adults who have relatively strong bones. Resurfacing is much less popular now due to concerns about the metal surface causing damage to soft tissues around the hip.

Future developments

Hip replacement surgery is being improved in several ways:

- New, stronger materials for prosthetics are being developed that will allow longer wear and better joint mobility.
- Enhancements are being made to new "cementless" implants. Patients can be recommended for newer types of joints, such as ceramic-on-ceramic and ceramic-on-plastic. Computer-assisted surgery is being used to generate an image of the hip joint to allow greater precision.

II. PROBLEM FORMULATION

Need for the work. In the present scenario,a hip replacement is a common type of surgery where a damaged hip joint is replaced with an artificial one (known as a prosthesis).Today there are increased demands on artificial hip joints because of increase in number of accidents, damage due to obesity and so on.

The artificial hip joint design in general is a very complex methodology and to arrive at a solution, which yields, a good performance a tedious task. Analytical methods are available to provide closed form of solutions to a simple problems. But the components have a complex geometry and loading patterns, there is no well defined analytical procedure available for a model with different thicknesses and orientations. Experimental method of analysis involves huge amount of labour and material and also the time consumption is tremendous as a pilot model need to be built each time.so to overcome all these hindrances, numerical method of analysis is adopted. Finite element method is the most widely used numerical technique because of its versatility.

In the finite element analysis many variations can be tried out on the model with reasonable time period. The model can be analyzed for static and dynamic conditions and the critical regions can be found out. Any modifications can be made on the part, which is in the range of failure; thus any part can be modified to the required shape and sizes.

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Objectives: The main objectives of this work is to evaluate the static characteristics of a truck chassis under different load conditions ,different motions and different materials. Static analysis is carried out on model with varying positions, material and loads. the loading patters remain the same and the analysis is carried out.

Scope of Work: The scope of work is out lined below

- Solid modelling of artificial hip parts and estimation of their properties.
- Static analysis of model for

1. different load conditions.
2. different motions and
3. differnt materials.

III. DESIGN CONSIDERATION OF HIP JOINT

Components of artificial hip joint:

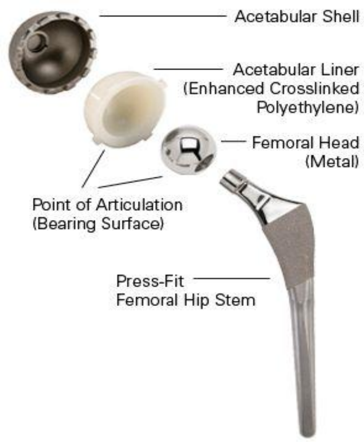


Fig 3.1 : Components of Artificial Hip Joint

ACETABULAR SHELL: The acetabular shell is the component which is placed into the acetabulum (hip socket).

ACETABULAR LINER: Acetabular liner is one piece (monobloc) shells are either UHMWPE (ultra-high-molecular-weight polyethylene) or metal, they have their articular surface machined on the inside surface of the cup and do not rely on a locking mechanism to hold a liner in place.

FEMORAL HEAD: The femoral component is the component that fits in the femur (thigh bone). Bone is removed and the femur is shaped to accept the femoral stem with attached prosthetic femoral head (ball).

Mobility of artificial hip joint:

The mobility of human joint is indicated by the relative motion between bones connected by the joint. This relative motion depends on the contact between bones and also the maximum strains of tissues surrounding the joint. If a natural joint is replaced, the joint replacement should be able to achieve the minimum movement of the natural one. The types of joint movement are flexion, extension, abduction, adduction and rotation.

Flexion is the movement to bend the joint and extension is to straighten the joint. Abduction is the movement of joint member outward the body axis and adduction is the movement toward the body axis. Rotation is the movement of joint member around its center. The maximum angle of flexion movement was 125^0 illustrated by bending the right leg forward. The maximum angle of extension was 30^0 illustrated by pushing the left leg downward. The limit of rotation angle was 45^0, the maximum abduction angle was 45^0 and the maximum adduction angle was 30^0 obtained by crossing a leg in front of another.

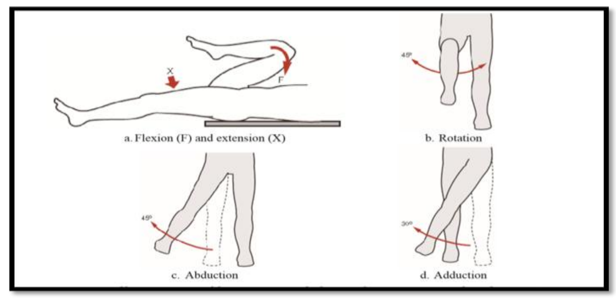


Fig 3.2: Illustration of hip joint mobility

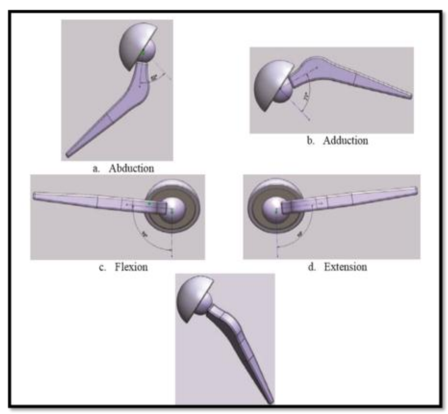


Fig 3.3 : Relative movement of the assembly model of artificial hip joint

Stability:

Stability in joint is defined by its ability to maintain position of the members during body movement. A stable joint manages to perform movement in its range of motion while carrying load. From biomechanics point of view, hip joint is one of lower extremities parts those bear high load. Mostly, hip joint is subjected to moment loading, except for rotation motion, the load is torsion. As moment and torsion loads depend on the distance or radius from center of axis, the longer the distance the higher the load on the joint. During normal body movements, such as: walking, running, stair climbing, the load on a hip joint was about 2.5 to 3.0 times of the body weight. While running, the joint load might reach 6 times of the body weight because legs position during running was farther from joint center

Geometrical model of joint replacement:

Geometry and material Based on hip anatomy and the average body size of the human population, the geometrical criteria for hip joint replacement are represented in Table 3.1.

Geometrical criteria of artificial hip joint:

Table 3.1: Geometrical criteria of artificial hip joint

Criteria	**Value**
Length of fermoral stem	1500mm
Neck length of fermaral stem	20-30mm(adjustable)
Neck shaft length of fermoral stem	135^0
Diameter of fermoral head	30-40mm(adjustable)
Diameter of acetabular socket	25-30mm
Range of motion between head and socket	$45\text{-}50^0$
Materials	Biocompatible

Range of motion of assembly model:

Type of Movement	**ROM**
Adduction	Max 52^0
Abduction	Max 71^0
Flexion	Max 95^0
Extension	Max 92^0
Rotation	360^0

Table 3.2: Range of motion of assembly model

Using the above criteria, 3D geometrical model of artificial hip joint were divided into 4 main parts, namely: femoral stem, femoral head, acetabular socket and cup inlay. Figure 5 shows 3D model and dimension of the joint replacement in details.

Femoral stem, femoral head and acetabular socket were made from Titanium alloy Ti6Al4V which was a biocompatible material. Titanium ions were non-toxic and it has an excellent corrosion resistance in general environment and in human body fluids .From mechanics point of view, Titanium had a high ratio of strength to weight and a very good ductility as well.

The cup inlay was made from ultra-high molecular weight polyethylene (UHMWPE) which had much higher ultimate strength, ductility and toughness than ordinary polyethylene. UHMWPE was also biocompatible material due to its inertness and its wear resistance. Combination of Titanium-UHMWPE has self-lubricating contact properties with a very low coefficient of friction.

Materials

In general, titanium, stainless steel and UHMWPE(Ultra high molecular weight polyethylene) are in use. But titanium due to its high cost it is not being used that frequently. It is being used for higher end purposes such as for sports persons. Stainless steel and UHMWPE are in use frequently.

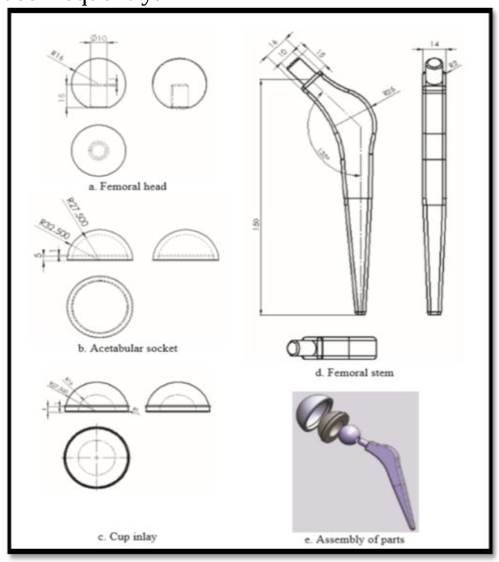


Fig 3.4: Main parts and dimension of the 3D model of hip joint replacement

UHMWPE has a self-lubricating, nonstick, light weight, and wear-resistant characteristics, it has been used for many years in the bulk handling (grain, cement, gravel, and aggregate) and ore/coal mining industries. Typical applications include liners for silos, hoppers, dump truck rail cars, and chutes; conveyor troughs and flights; wear strips; slide plates; and unlubricated bearings and bushings Few modular prosthesis uses whole prosthesis made up of material stainless steel 316 L i.e. stem and ball of same material (stainless steel 316 L). Main problem arises by using steel is Metollosis . Attempt has been made in this work to use polyethylene as an alternative material to avoid possibilities of Metollosis. The polyethylene material is Ultra-high molecular weight polyethylene (UHMWPE).

IV. RESULTS AND DISCUSSION

Once hip joint is simulated for different materials like Stainless steel & UHMWPE for different mations like abduction , extension , flexion and rotation when a load consideration of 700N is considered the analysis is carried out for finding static stress and displacement stress..

Material: stainless steel, load consideration: 700N

Motion: Abduction

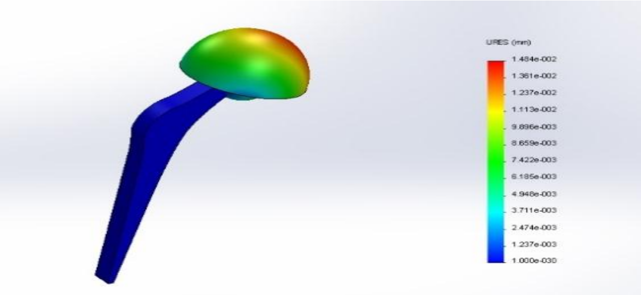


Fig 4.1: Static displacement

Motion: Extension

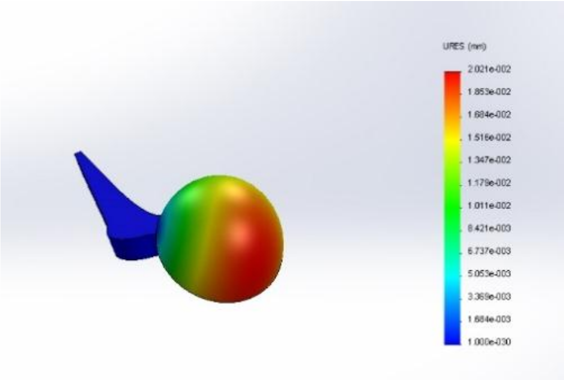


Fig 4.2: Static displacement

Motion: Flexion

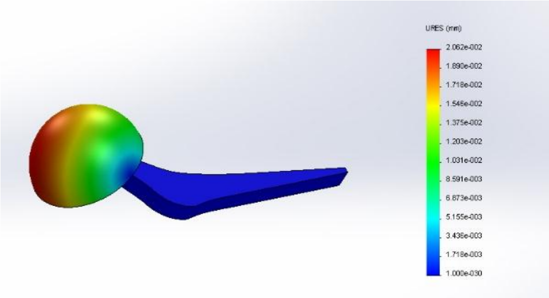


Fig 4.3: Static displacement

Motion: Rotation

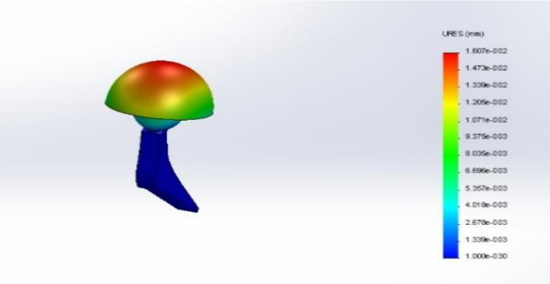


Fig 4.4: Static displacement

Material : Stainless steel & UHMWPE(cup lining) , Load consideration: 700N

Motion: abduction

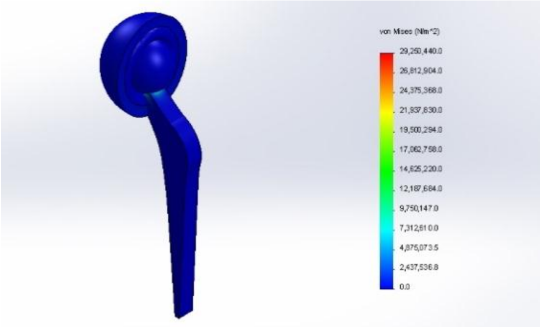


Fig 4.5: Static stress

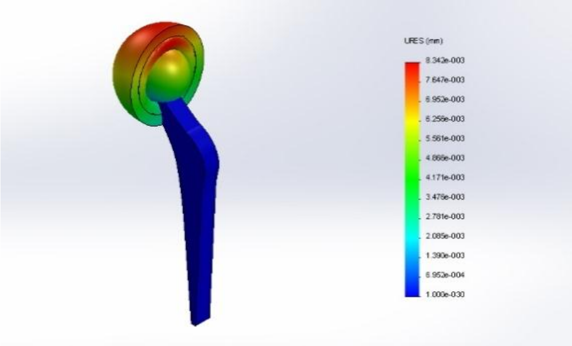


Fig 4.6: Static displacement

Motion: Adduction

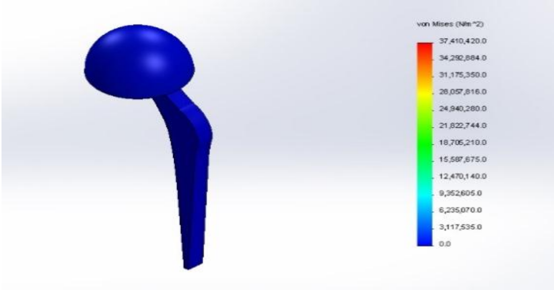


Fig 4.7: Static stress

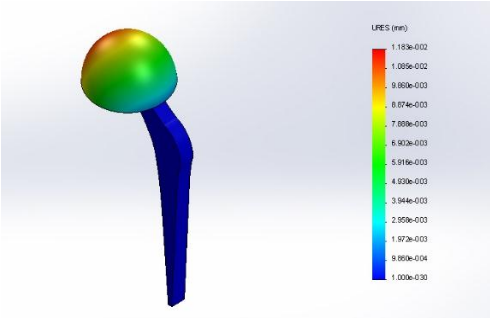


Fig 4.8: Static displacement

Motion: extension

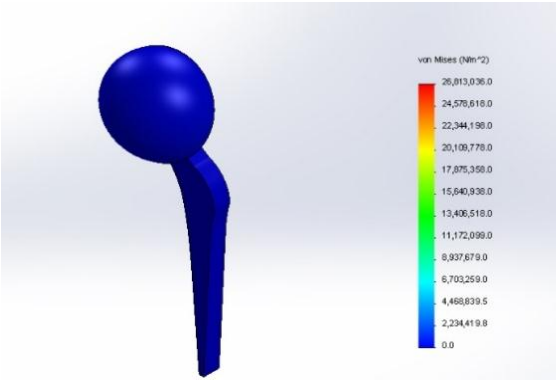


Fig 4.9: Static stress

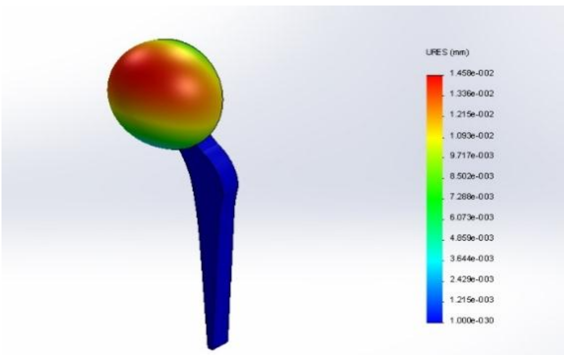


Fig 4.10: Static displacement

Motion: flexion

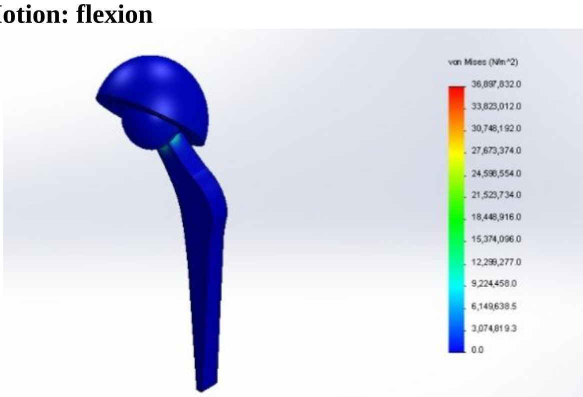


Fig 4.11: Static stress

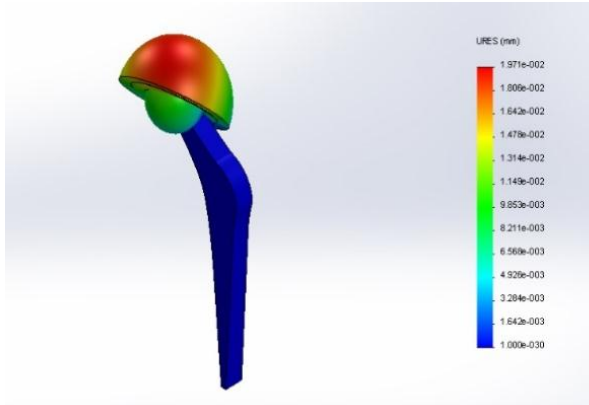


Fig 4.12: Static displacement

Motion: Rotation

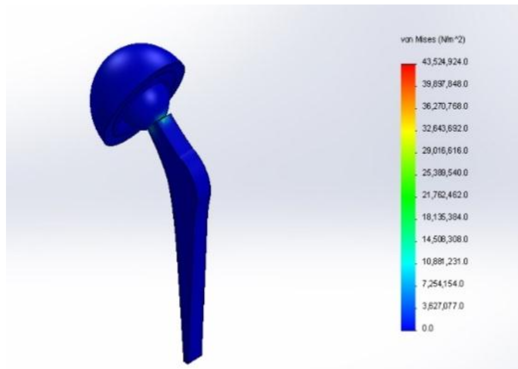


Fig 4.13: Static stress

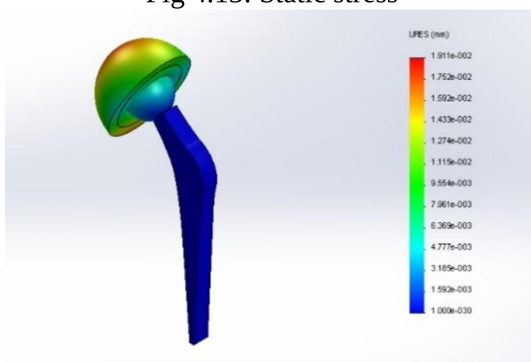
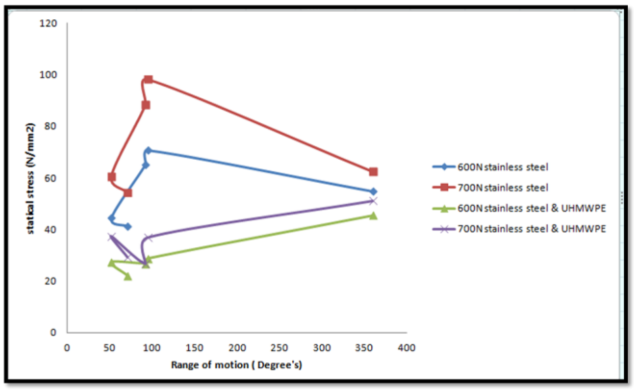


Fig 4.14: Static displacement

1. Summary of Von misses Stress (N/mm^2) results for different materials ,different body loadings at different positions:

	Material	Stainless steel		Stainless steel & UHMWPE	
ROM	Load/motion	600 MPa	700 MPa	600 MPa	700 MPa
Max 71^0	Abduction	41.35	54.33	22.06	29.25
Max 52^0	Adduction	44.61	60.65	27.33	37.41
Max 92^0	Extension	65.33	88.41	26.81	26.87
Max 95^0	Flexion	70.76	98.21	28.73	36.89
360^0	Rotation	54.88	62.39	45.52	51.11

Table 4.1: Stress results in Mpa (N/mm^2)



Graph 4.1 : Range of motion Vs stress

The maximum stress of 98.21MPa occurs when the hip joint undergoes flexion under the load of 700Nand when the entire hip is made up of stainless steel. The minimum stress of 22.06MPa occurs when the hip joint undergoes abduction under the load of 600Nand when the cup inlay is made up UPMWPE and remaining portion of the joint is made up of stainless steel. Under a load of 600N, the maximum stress occurs when the hip joint is made up of stainless steel and it undergoes flexion.

Under a load of 600N,the minimum stress occurs when the hip joint inlay linning is made up of UHMWPE . Under a load of 700N,the maximum stress occurs when the hip joint is made up of stainless steel and it undergoes flexion. Under a load of 700N,the minimum stress occurs when the is made up of stainless steel and it undergoes abduction.

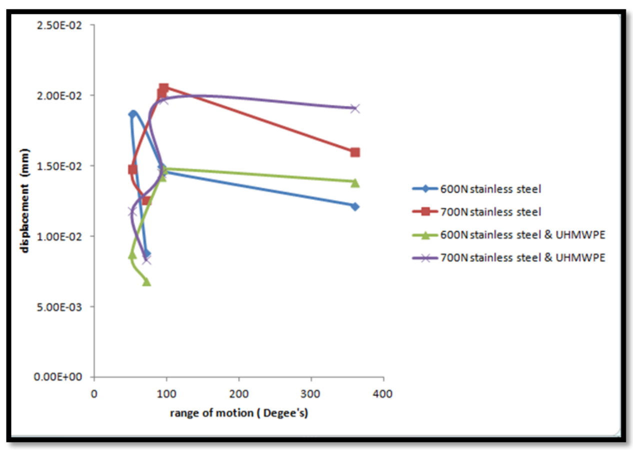
In case of abduction, adduction, extension, flexion and rotation the maximum stresses occurs when the entire hip is made up of stainless steel at a load of 700N. Minimum stresses occurs when the inlay is made up of UHMWPE and remaining portion is made up of stainless steel. As the load increases on the body ,the von misses stresses also increases proportionately for stainless steel hip material, whereas for the body containing UHMWPE as inner lining the stresses do not increase proportionately. They increase in a lower proportion which indicates that the UHMWPE serves as better lining and prevents wear and tear of the joint.

2. Summary of deformations for different materials at different body conditions under two different loads:

	Material	Stainless steel		Stainless steel & UHMWPE	
ROM	Load/motion	600N	700N	600N	700N
Max 71^0	Abduction	8.87 e-003	1.26 e-002	6.88 e-003	8.34 e-003
Max 52^0	Adduction	1.87 e-002	1.48 e-002	8.79 e-003	1.18 e-002
Max 92^0	Extension	1.50 e-002	2.02 e-002	1.43 e-002	1.45 e-002
Max 95^0	Flexion	1.46 e-002	2.06 e-002	1.48 e-002	1.97 e-002
360^0	Rotation	1.22 e-002	1.60 e-002	1.39 e-002	1.91 e-002

Table 8.2:deformations in mm

From the analysis it is seen that as the load on a body increases the displacement of the body also increases in different motions of the hip joint.For the body composed of only stainless steel the variation in displacement is more compared to body having combination of stainless steel and UHMWPE.



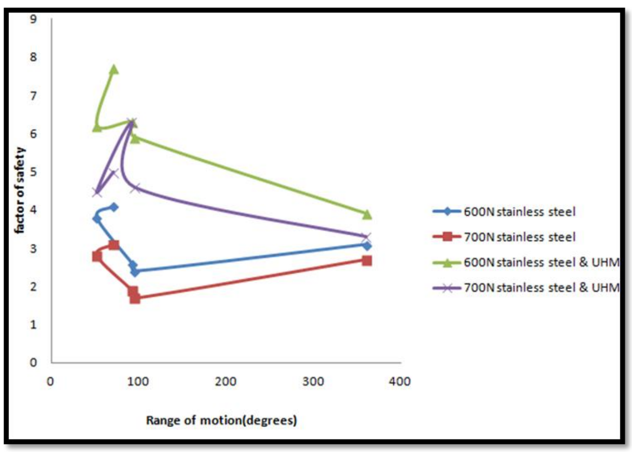
Graph 4.2: Range of motion Vs displacement

3. Summary of Factor of safety results under the action of two different loads for two materials:

	Material	Stainless steel		Stainless steel & UHMWPE	
ROM	Load/motion	600 N	700 N	600 N	700 N
Max 71⁰	Abduction	4.1	3.1	7.7	5.0
Max 52⁰	Adduction	3.8	2.8	6.2	4.5
Max 92⁰	Extension	2.6	1.9	6.3	6.3
Max 95⁰	Flexion	2.4	1.7	5.9	4.6
360⁰	Rotation	3.1	2.7	3.9	3.3

Table 4.3: Factor of safety results

From the analysis it is seen that the factor of safety is more for body having UHMWPE lining rather than stainless steel lining. Therefore it is better to use an UHMWPE lining rather than a stainless steel lining for higher loadings.



Graph 4.3: Range of motion Vs Factor of Safety

V. CONCLUSION AND FUTURE SCOPE

A modern artificial hip joint is designed to last for atleast 15 years, but there is always the risk that the artificial hip joint can wear out or go wrong in some way before this time ,that is further surgery is required to repair or replace the joint .

From the simulation analysis it is seen the maximum stress is obtained at the neck of the femoral hip stem in all motions of the hip joint. From the study it is seen that maximum stress is obtained for stainless steel during flexion under the action of maximum load on the hip and minimum stress is obtained on the joint when UHMWPE lining is used in the joint. The factor of safety is also more when UHMWPE lining is used instead of stainless steel lining.

Stronger materials for prosthetics are being developed that will allow longer wear and better join mobility. Enhancements are being made to new cement less implants. Patients can be recommended for newer types of joints, such as ceramic –on-ceramic and ceramic -on –plastic. Computer assisted surgery is being used to generate an image of the hip joint to allow greater precision.

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