BIO-MATERIALS USED FOR ARTIFICIAL HIP PROSTHESIS

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ABSTRACT:

In last decades medical technology and development of the relocation and replacement becomes the indispensible solution for the versatile complications. The replacement finds a modernistic technique and this technique paved the way for the inception of biomechanics into the medical technology coming in these recent days. The hip joint was plays the important role in our mobility of our body. In this work mainly focus about the analysis of hip prosthesis on wear rate and flexural strength of the stem and acetabular cup of the hip prosthesis. Here the materials we used to make a hip acetabular cup (namely PMMA, PEEK and UHMWPE) and stem (namely Ti6Al4V alloy). This composition are analysed for the mechanical properties of tensile strength, ultimate tensile strength, modulus of elasticity, shear modulus to enhance its performance and lifetime. This analysis is done by sample prepared by using various elements and testing for its wear and flexural strength by using three point flexural test, impact test etc. The materials are analysed using ANSYS and best suitable recommented material is PMMA.

1. INTRODUCTION:

Hip joint is the one of the most important joints in our human body. It connects upper and lower part of the body. If the joint breaks, the person becomes almost immobile condition. So the replacement of joint is important role. In this joint replacement bio materials are employed to get ultimate efficiency. The types of fixing joints are cemented and cement less. Mostly used bio-materials are stainless steel for femur bone and the polymer materials are used for acetabulum. The ball connected to the socket by a band of tissues called ligaments can provide stability to the joint. The common reason for the fracture of hip is due to accident, dislocations and fractures were happened. This may cause the fracture of hip and may cause lifelong permanent handicap to the persons.

HIP PROTHESIS

The process to replace of total amputated hip joint into the artificial hip joint using the different bio-materials is called Hip Prosthesis. The biomaterials mostly used for the hip replacement are more biocompatibility. Biocompatibility is the general term describing the property of a material being compatible with living tissues of the human body. There is no toxic response from the biocompatible materials when exposed to the fluids in the body is the first requirement for the composites. In the common sense, a biocompatible material or device does not harm the patient for his life time. The affected ball and socket was removed and replaced by artificial metallic ball and stem. Important issues, which decide the success of hip replacement are Prosthesis Fixation and selection of Biocompatible materials

2. METHODS

2.1 SELECTION OF BIO-COMPATIBLE MATERIALS

Biocompatibility is the generally used term describing the property of a material being compatible with living tissue. Titanium Alloys (Ti6Al4V), Ultra High Molecular Weight Polyethylene (UHMWPE), Polyether ether ketone (PEEK), Poly (methyl methacrylate) (PMMA) proximally cemented, distally uncemented total hip arthroplasty with a minimum follow up time of 24 months and observed that the early rates of these prostheses were unacceptably high for a contemporary hip design.

- Scifert *et al.,* [16] was designed a convex curved acetabular lip to reduce the propensity for dislocation. For studying the dislocation phenomenon, a 3D non-linear finite element (FE) model was developed using ABACUS software. It was shown that the new design achieved 28% more resisting moment build-up during dislocation. Gross *et al.,* [12] had done a finite element analysis of hollow stemmed hip prosthesis to reduce stress shielding in the femur.
- Phillips *et al.*[28] used a 2D FE model of the acetabulum contains four layers viz., plastic, cement, graft and bone using a plane strain elements. The inside diameter of the acetabular cup was taken as 50 mm. The plastic, cement and bone were considered as linear elastic materials and the graft layer was considers as elasto-plastic material. The maximum load applied to the model was 1000% BW by (Bergmann et al., [1], [2],[3],[4],[5]) and the body weight was assumed 1000N. Implant separation from the bone tissue is a major drawback and the reason for it is the unnatural stress distribution around the implant. Stresses and motions in the bone and implant depend on the loading conditions and implant design.
- Kowalcyzk et al.,[23] used optimization of cement less femoral hip to develop the reliability of the joint prosthesis. Cheng *et al.,* [13-14] carried out design of robust total hip joint replacements under based on the environmental variables viz., joint force angle, cancellous bone elastic modulus and implant-bone interface friction.
- Senapati and Pal et al., [30] carried out FE analysis on a specified three-dimensional (Axi-symmetric) model. He showed that for a stiffer prosthesis material, the peak interface stress occurred on the distal end of the stem whereas for a flexible implant like UHMWPE-Al2O3 the peak stress occurred at the proximal end. Then concluded that a more flexible stem or less stiff materials caused more proximal load transfer.
- Katoozian [21], Katoozian [22], Katoozian and Davy [29] and Nicolella *et al.,* [15] developed a numerical optimization method to design a fibre-reinforced composite implant to minimize the potential for bone remodelling and stress shielding. In their investigations, two different design objectives (failure-based and stress shielding-based) were used.. Weisseet al.(17) did an optimization of a proof test procedure of ceramic hip joint ball heads for rejecting defective samples in the production line before implanting into human body. Prendergast (24) reviewed the Finite Element modelling in three major areas such as analysis of a skeleton, analysis and design of orthopaedic devices and analysis of tissue growth.
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2.2 Casting of TI6AL4V

The general properties of Ti6Al4V has shown that it is mostly suitable for making stem .For the synthesis of Ti6Al4V we have to go for investment casting method. The Ti6Al4V is used for the stem.

2.3 Water Jet Machining

The PEEK, PMMA, UHMWPE are machined using un-conventional machining to make acetabular cup.

In water jet machining uses a high velocity stream of Ultra High Pressure Water 30,000–90,000 psi (210–620 MPa) which is produced by a high pressure pump with possible abrasive particles suspended in to the stream is used for machining a large number of materials, including heat-sensitive, subtle or hard materials. In this machining does not produce heat damage to the surface or edges of the workpiece. Nozzles are typically made of composite tungsten carbide or sintered boride. Distance of nozzle from work piece affects the size of the kerf and the removal rate of material is .125 in (3.2 mm).

2.4 Testing Methods:

Impact tests are designed to measure the resistance to failure of a material. The test measures energy absorbed by the materials. The most common methods of measuring the impact energy are:

- Charpy Test
- Izod Test

Impact Energy:

It is the measure of the work to fracture a test specimen. This specimen absorbs energy produced by striker and which undergoes deformation. The maximum energy at which striker absorbs and fracture occurs is known as impact energy.

The specimens used in Charpy test normally measures 55x10x10mm and have a notch machined across one of the larger faces. The notches may be:

• V-notch – A V-shaped notch, 2mm deep, with 45° angle and 0.25mm radius along the base

• U-notch or keyhole notch – A notch with 5mm depth and 1mm radius at the base.

Operation:

The Charpy test involves striking a test piece with a striker, mounted at the end of a pendulum. The test piece is fixed at both ends and the striker impacts the test piece immediately. The pointer is attached in it the movement of pendulum is proportional to the pointer. From the pointer we taken the measurement.

2.5 THREE-POINT FLEXURAL TEST

The Three-point bending flexural test provides values for the Young's modulus in bending and the flexural stress–strain response of the materials. The sample is placed on two supporting pins at a distance apart. The calculations are done from the following equatios.

Calculation of the flexural strain £_f

$$£\_f=6Dd/L^2$$

Calculation of flexural modulus E_f

$$E\_\{f\}=(L3m/4bd^3)$$

In these formulas the following parameters are used:

£_{f} = Strain in the outer surface, (mm/mm)

E_{f} = flexural Modulus of elasticity, (MPa)

F = point load on the load deflection curve, (N)

L = Support span, (mm)

b = Width of test beam, (mm)

d = Thickness or Depth of tested beam, (mm)

D = maximum deflection of the canter of the beam, (mm)

m = The slope (i.e., gradient) of the initial straight-line portion of the load deflection curve,(F/D), (N/mm)

R = The radius of the beam, (mm)

2.6 EXPERIMENTAL PROCEDURE OF WEAR TEST

Dry sliding wear tests for different number of specimens was conducted by using a pin-on-disc machine (Model: Wear & Friction Monitor TR-20) supplied by DUCOM.

In this experiment, the test was conducted with the following parameters: the parameters are load, speed and distance.

2.7 PIN-ON-DISC TEST

In this experiment, Pin-on-Disc was used for tribological characterization. The test procedure is as follows: Initially, pin surface is made flat so that it will support the load over its entire cross-section called first stage. This was achieved by the surfaces of the pin sample ground used emery paper (80 grit size) prior to testing Run-in-wear is performed in the next stage/ second stage. Third stage is the actual testing called as constant/ steady state wear. This stage is a dynamic competition between material transfer processes (transfer of material from pin into the disc and formation of wear debris and their subsequent removal).

Weight Loss: The alloy and the composite samples are cleaned thoroughly with acetone. Each sample is then weighed using a digital balance which has an accuracy of ± 0.1 mg.

The specific wear rates of the materials were obtained by the following relations.

$W=\Delta w/dxF$

Where,

W denotes specific wear rates in mm^3 /N-m,
Δw is the weight loss measured in grams,
d is the density of the worn material in g/mm^3
And F is the applied load in N.

2.8 WEAR CALCULATION

1. Area
Cross sectional Area $A = \pi r^2$

2. Volume loss (V_{loss})

V_{loss} = A* Height loss.

3. Wear rate (W_R)
$W_R = V_{loss}$/ Sliding distance

4. Wear resistance (β)

$\beta = 1/ W_R$.

5. Specific wear rate
Specific wear rate = W_R/load

Velocity 1m/s, Track Diameter 100mm,

2.9 SCANNING ELECTRON MICROSCOPE (SEM)

A scanning electron microscope scans the surface of the samples and produces the images with the help of focused beam of electrons.

SAMPLE PREPARATION

Samples for SEM were prepared to withstand the vacuum conditions and high energy beam of electrons and the suitable size that will fit on the specimen stage. Specimen holder uses to mount the samples. The semiconductor wafers (usually of 300mm) are measured using the instrument capable of tilting the object with the suitable limit up to 45° and provide 360° rotation. This method is used for analysing the defects of the samples.

SCANNING AND IMAGE FORMATION

In a distinctive SEM, an electron beam was emitted as thermions from an electron gun fitted with a tungsten filament cathode. Due to high melting point and low vapour pressure tungsten is preferred for electron gun.

MAGNIFICATION

The magnification lies between the ranges of 10 to 500,000 times. Unlike optical and transmission electron microscopes uses, image magnification in an SEM is not a property of the objective lens power.

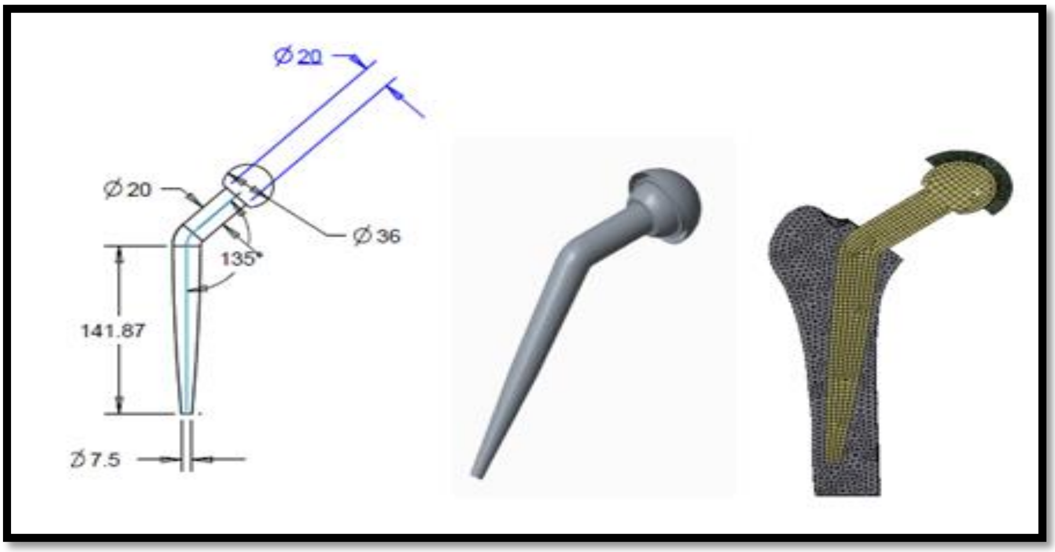

Fig 1: 2D and 3D Models of Specimen

Fig 1 shows the 2D and 3D models of the specimen taken for the experimental analysis.

Table-1: Mechanical properties of different materials.

Properties	**Ti6Al4V**	**UHMWPE**	**PEEK**	**PMMA**	**Cortical Bone**
Tensile Yield Strength (MPa)	800	19	103	70	90-131
Ultimate Tensile Strength(MPa)	900-1200	40	110	94	90
Modulus of Elasticity (GPa)	110	0.725	3.95	3	12.4
Shear Modulus (GPa)	42	4.5-6.2	1.425	1.7	4.5-6.2
Hardness (Rockwell)	-	-	126	92	-
Density (g/cc)	4.5	.95	1.32	1.185	1.7
Poisson's Ratio	0.33	-	.3931	-	0.22

Table1 shows the mechanical properties of the different materials. The different material are Ti6Al4V, UHMWPE, PEEK, PMMA, Cortical bone. The material PMMA shows the overall better mechanical properties.

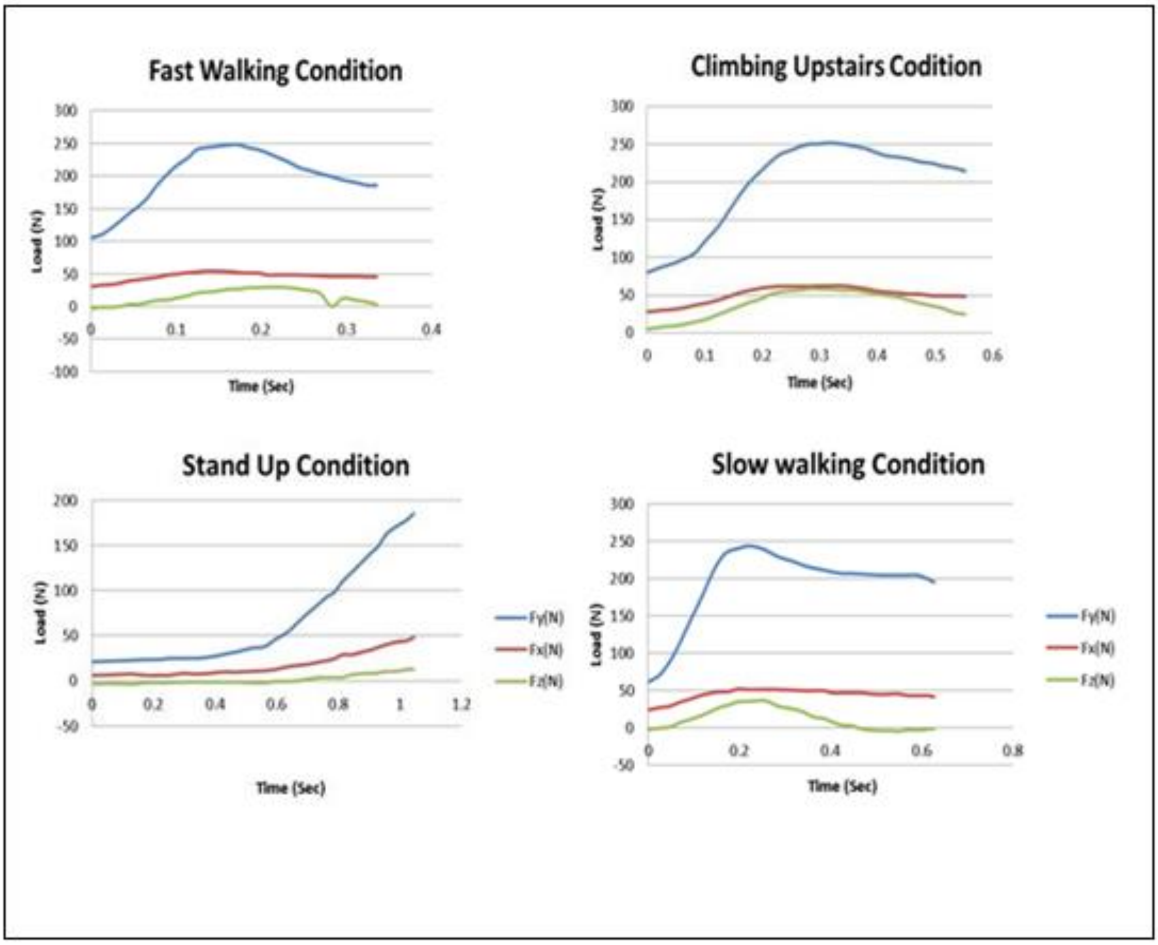

Fig 2: Change in Loads with respect to time for the following conditions: a) Fast walking b) Climbing Stairs c) Standing up d) Slow walking.

Fig 2 shows the relationship between change in load with respect to time for the different movement of the body. The different movements are fast walking, climbing stairs, standing up and slow walking.

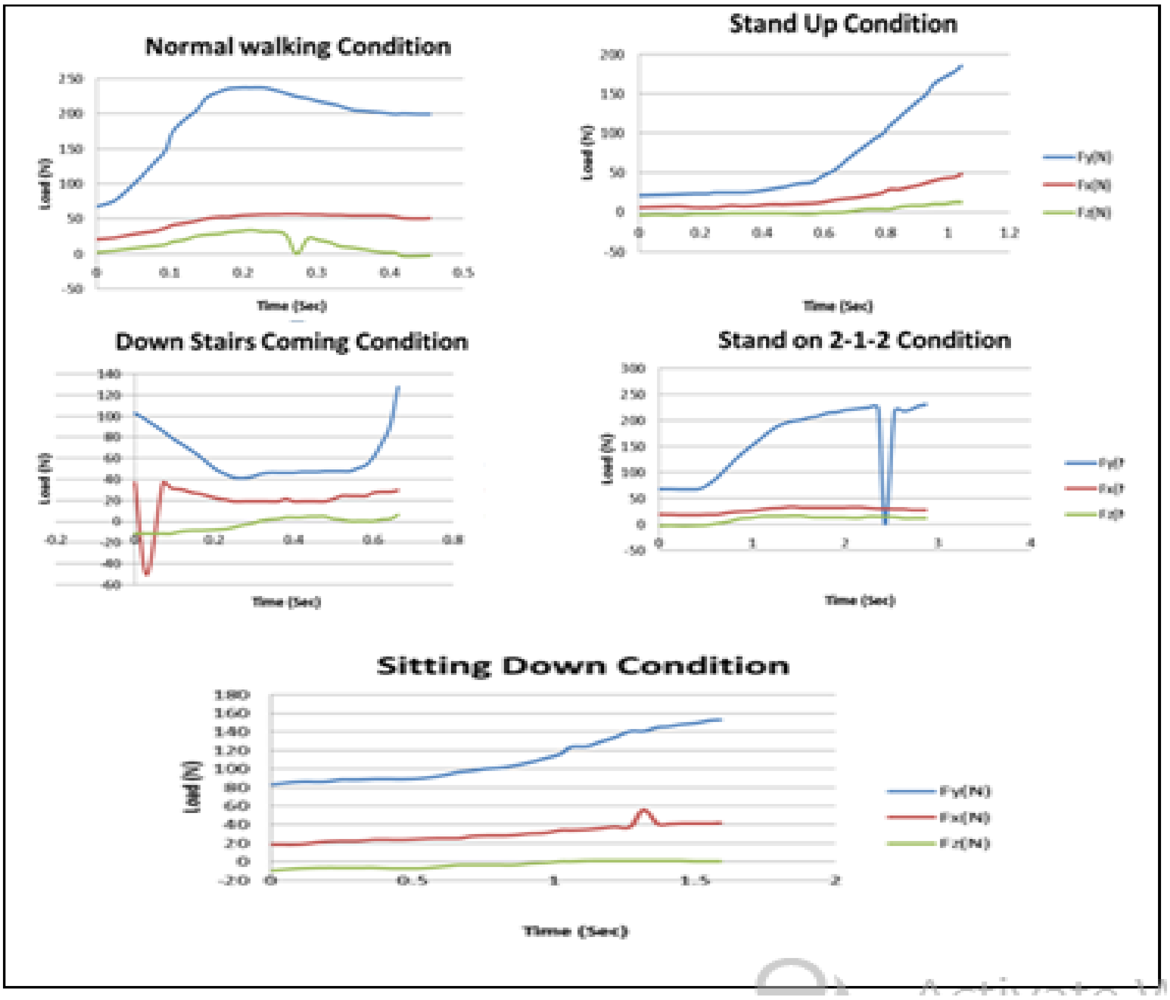

Fig 3 : Change in loads with respect to time for the following conditions: e)Normal walking f) Stand up g) Coming Down stairs h) Standing on 2-1-2 i) Sitting down.

Fig. 3 movement. The movements are normal walking, stand up, coming down in the stairs, standing on and sitting down.3 shows the change in load with respect to time for the following of the human body

Table-2: Working conditions followed for Analysis

SL.NO	ACTIVITY	DESCRIPTION
1	Slow walking (SW)	Walking at slow speed on level ground. Average speed of all patients=3.5kmph
2	Normal walking (NW)	Walking at normal speed on level ground. Average speed of all patients=3.9kmph
3	Fast walking (FW)	Walking at fast speed on level ground. Average speed of all patients=5.3kmph
4	Upstairs (US)	Walking upstairs, stair length 17cm, no support at hand rail.
5	Downstairs (DS)	Walking downstairs, stair length 17cm, no support at hand rail.

6	Standing up (SU)	Standing up, Chair height 50cm, arms hold at chest height
7	Standing down (SD)	Sitting down, Chair height 50cm, arms hold at chest height.
8	Standing on 2-1-2 legs (SL)	Two legged stance- One legged stance_ Two legged stance
9	Knee bend (KB)	Two legged stance Bending knees Two legged stance

3. EXPERIMENTAL RESULTS

Finite element analysis is a computerised method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow and other physical effects([20] C. F. Scifert et al.,)In this analysis, Solid 92 and Contac 52 elements will be used for finding the maximum stresses and the contact stresses.

3.1 Finite element analysis of polymer materials

Here the finite element analysis is done with the help of the ANSYS software.

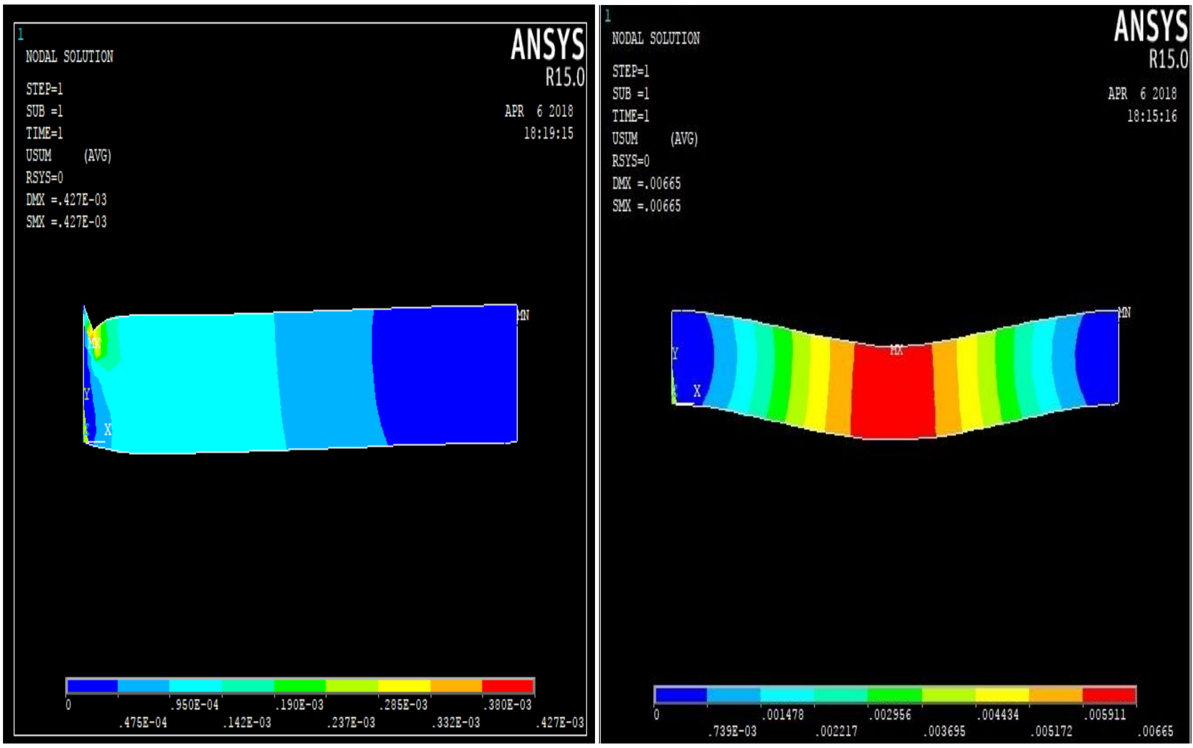

Fig.4: Impact & Flexural analysis of UHMWPE using ANSYS

Fig4 shows the impact and flexural analysis of UHMWPE materials.

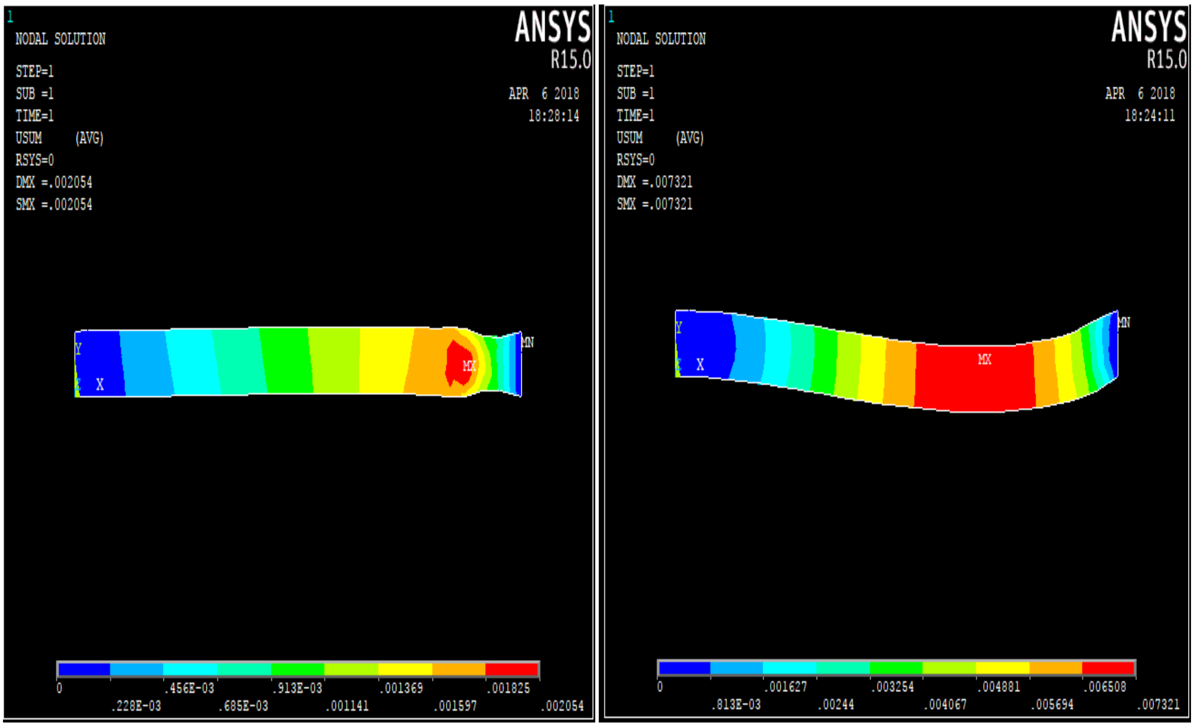

Fig. 5: Impact & Flexural analysis of PEEK using ANSYS

Fig5. Shows the impact and flexural analysis of PEEK materials.

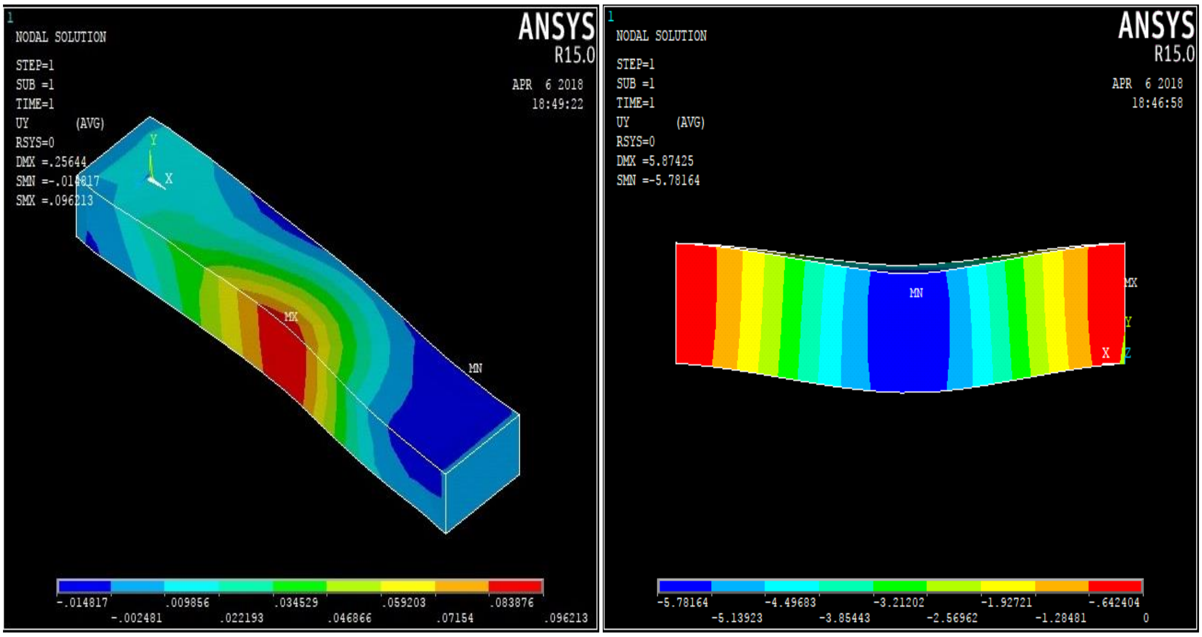

Fig. 6: Impact& Flexural analysis of PMMA using ANSYS

Fig.6 shows the impact and flexural analysis of PMMA using ANSYS.

3.2 DISCUSSIONS AND CONCLUSION

The main objective of this experiment was to develop a three dimensional finite element models for Failure analysis of Hip prosthesis. Failure of the stem due to stress induced in fatigue loading, and the failure of the acetabular cup due to gradual wear at the interface of the cup and the spherical head was analysed. In order to understand the implications of different daily activities on the life of hip prosthesis, nine different most commonly used activities such as fast walking, slow walking, normal walking, upstairs climbing, downstairs climbing, standing on 2-1-2 legs, knee bend, standing up and sitting down have been considered. Importance of choosing a prosthesis material has been studied by considering different prosthesis materials such as **UHMWPE, PMMA, PEEK**, and **Ti6Al4V** alloy in the present analysis. Based on the results PMMA has much better flexural strength than that of UHMWPE and PEEK and the wear properties of PMMA is also acceptable. So the usage of **PMMA** is recommended over UHMWPE and PEEK for acetabular cup in combination with Ti6Al4V for femoral stem which is similar to the weight of cortical bone and much less than stainless steel.

3.3 FUTURE WORK

- Fatigue analysis of prosthesis by numerical method and experimental method for various postures. Corrosion analysis of prosthesis by experimental method. Experiments could be conducted for simulating the gait movement and estimating. Fatigue life and wear of the acetabular cup. Cement less prosthesis could be studied for fatigue life and wear analysis. More advanced materials like functionally graded materials could be studied as possible prosthesis materials.

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