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DESIGN & FEM ANALYSIS OF HIP IMPLANT FOR WALKING AND RUNNING LOADING CONDITIONS

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ABSTRACT

Hip Joint is a ball and socket assembly formed by spherical head of the femur and concave acetabulum of the pelvis in the human body. A band of tissues called ligaments connect the ball to socket in order to provide stability to the joint. Hip joint transplantation and modification are common in old aged persons as well as younger persons. The loads acts on joint are repetitive and fluctuating depending on the activities of human being, which may leads to failure of Hip joint. Also the contact pressure developed due to fluctuating loads generates wear debris particles due to rubbing of contact surfaces. In the research study linear elastic finite element study is carried out to determine Stresses developed in Jumping Loading Condition. To evaluate the stresses developed in all these conditions and to come with best material suggestions

KEYWORDS: Prosthetic implant, Ball and socket, Static analysis, Hip replacement, Hyper mesh, FEM.

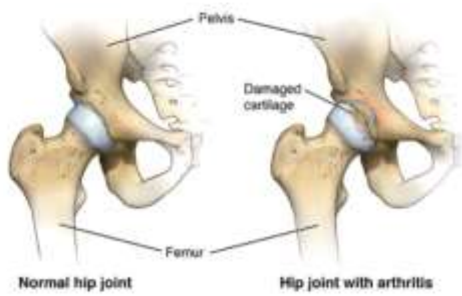
I. INTRODUCTION

The surgical procedure where hip joint is replaced by prosthetic implant is known as Hip replacement. The hip replacement surgery is usually considered to be of a total replacement or a hemi (half) replacement. In earlier day's people are suffering from Sevier pain of legs. Because of more work load.Due to running and walking the force acting on the body multiples the force acting on the hip. In earlier days Hip replacement was not possible because, the technology was not much improved though joints was not easily produced in a laboratory. The human body was rejecting the foreign materials. Although some material was introduced for prosthetic implant, sometimes due to the pains it would held the artificial joint to other bones work loose and it always required further surgery. Because of this hip joint we should be able to accommodate these extreme forces acting on body during intense physical activities. A total hip replacement consists of replacing both the acetabulum and the femoral head Joint replacement orthopedic surgery is carried out to relieve arthritis pain or in some hip fractures. Because of accident or old age if knee or hip joint breaks it wears out bone. Patient should take the advice of surgeon and it can be replaced with ball and socket which is made of engineered material metal or plastic which will duplicate the motions of human joint. Some of the joints which is artificial knee could not be worked well as they designed like hinges and just opened one way. In earlier, days designers realized that knee should be rotated slightly, then they produced a joint which can fulfill that movements.

II. HIP REPLACMENT PROCEDURE AND FEM ANALYSIS

Hip replacement surgery is a procedure in which a doctor surgically removes a painful hip joint with arthritis and replaces it with an artificial joint often made from metal and plastic components. Usually it's done when all other treatment options have failed to provide adequate pain relief. At first general anesthesia is given to muscles to relax at standard hip replacement so that patient will undergo temporary deep sleep. It will prevent from pain during surgery. A spinal anesthetic may also be given for alternative preventing pain. After that doctor will make a cut along the side of hip and muscles are moved which is connected to the top of thigh bone to expose hip joint. After that the ball portion of hip joint is removed by cutting the thigh bone with a saw. An artificial joint is attached to thighbone by using cement or some special material which allows the remaining bone to attach new joint. FEA is carried out here to determine the stress at joint area and for replacing the components at different loading conditions

Figure: 1(a)



Fem Analysis

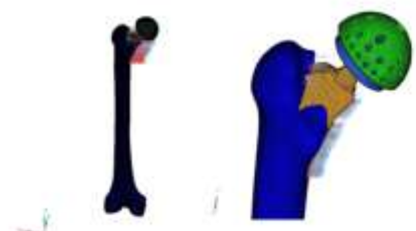
Finite element (FE) model for Hip joint considering the Femoral stem, Femoral Head, Plastic liner, The femur model was discretized into 44,714 elements using ten-node quadratic tetrahedron elements. 3D Tetrahedral element is used.

Solid 95 is used for the tetrahedral element and Mass21 is used for representing the negligible mass at Cerig elements

Number of nodes 72516

Number of elements 307267

Figure: 2(a)



(a) Finite element model of hip replacement assembly

Loading and Boundary Conditions

Walking and running activities are investigated. These loads represent combination of joint contact forces and muscles forces that are equilibrated by the forces in the joint. These values are derived from previous work involving in-vitro tests of hip joints for a person with nominal body weight of 700 N. The corresponding loads are applied at various points on the model while the bottom section of the bone is assumed to be a fixed end of the model. Boundary condition means the application of a constraint. For simulation, it is necessary to give proper boundary conditions to the model so that the results obtained match or give better results than the calculated one. The main function of boundary condition is to create and define constraints and loads on finite element models, it can be applied to the elements or the nodes of the structure. In Hyper mesh software, conditions can be entered and stored in a collector called load collectors.

Figure: 3(a) & 3(b)

(a) Load applied

(b) Boundary condition (fixed in all DOF)

Material Properties

Static analysis is carried out with two different materials for socket

Table 1: Material Details with Stainless Steel (Head & Stem)

SL. No	Property	Value	Unit
1	Density	7.87×10^{-9}	Tonnes/ mm^3
2	Tensile strength	220	MPa
3	Young's Modulus	2.05×10^5	MPa
4	Shear Modulus	80×10^3	MPa
5	Poisson's Ratio	0.29	

Table 2: Material Details with Cobalt Chromium(Head & Stem)

SL. No	Property	Value	Unit
1	Density	8.4x 10-6	Tonnes/ mm3
2	Tensile strength	330	MPa
3	Young's Modulus	2.45×10^5	MPa
4	Shear Modulus	80×10^3	MPa
5	Poisson's Ratio	0.3	

Table 3: Material Details of Bone

SL. No	Property	Value	Unit
1	Density	7.85 x 10-6	Tonnes/ mm3
2	Tensile strength	60	Mpa
3	Young's Modulus	80×10^3	Mpa
4	Shear Modulus	20 x 103	Mpa
5	Poisson's Ratio	0.28	

III. RESULT AND DISCUSSION

Results of the analysis are presented and discussed in terms of Von-mises Stress distribution

Contour plots for Material with Stainless Steel during Walking: Deformation and stress of the material is obtained and plotted in below figure .the red color in the given figure(a) indicates the maximum stress acting on element. figure(b) indicates the stress acting on the bone material. figure(c) and figure(d) indicates the deformation and stress acting on bone. figure(e) indicates stress acting an each component.

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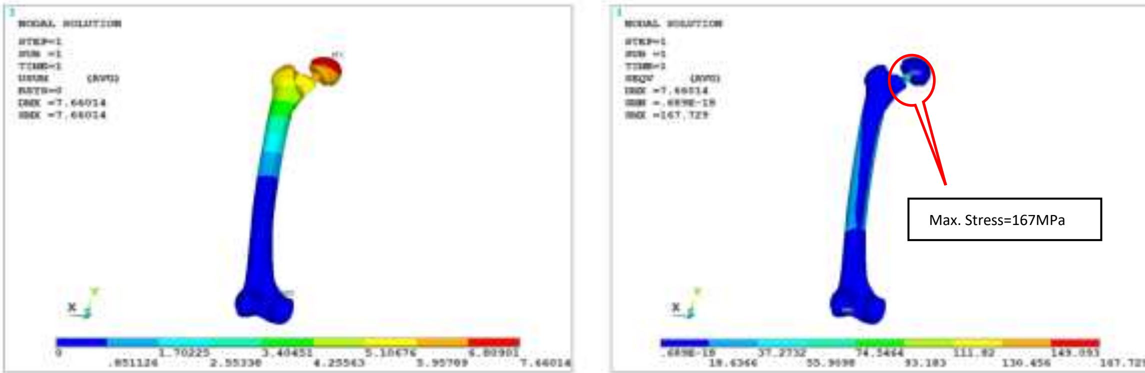
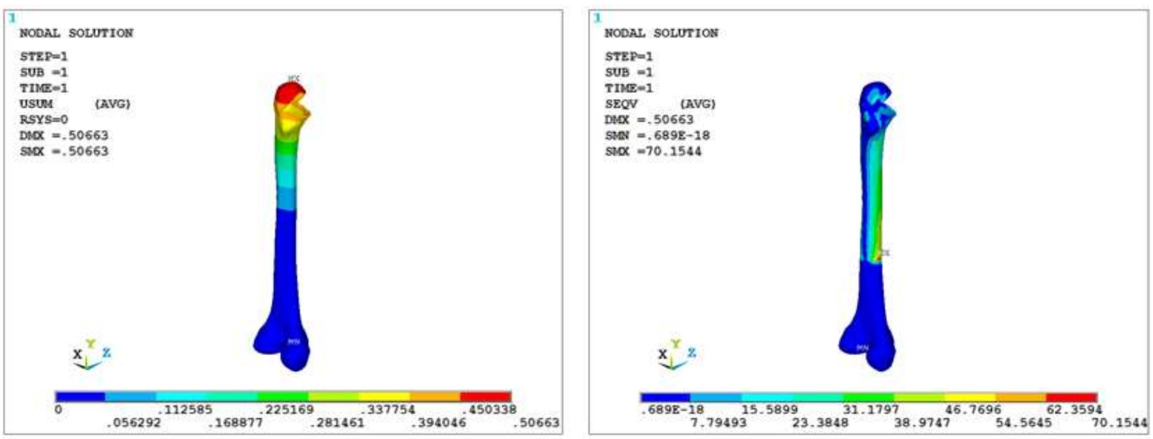
Figure: 4(a),4(b), 4(c),4(d) , 4(e),4(f) & 4(g)



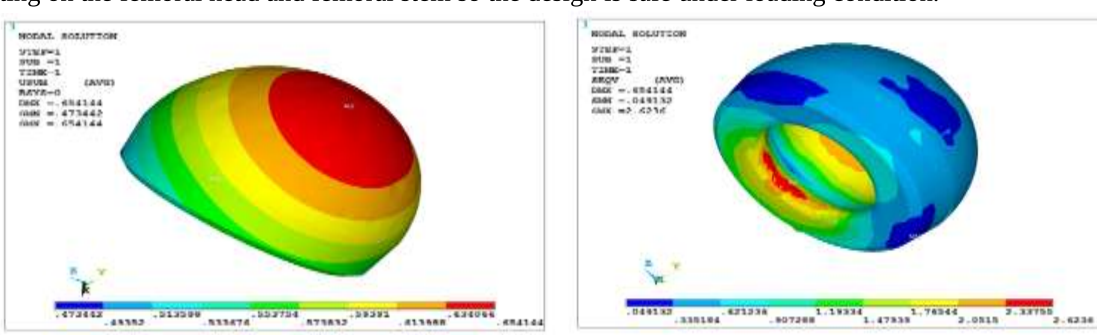
(a) Deformation plot during walking ***(b) stress plot during walking***

Figure 4(a) and 4(b) shows the deformation and stress plot of stainless steel during walking. Initially 29.9kg of load is applied on Acetabular component and femoral head. And 69.9kg of load is applied on femoral stem. For this condition maximum stress obtained during deformation is -7.66×10^{-6}mm and maximum stress is 167Mpa.In this condition there is not much stress observed in bone component and other components. All components are safe under this loading condition. But however these stresses observed with stainless steel are higher than the stress observed with cobalt chromium alloy.



(c)Deformation Plot for Bone during walking (d) Stress Plot for Bone during walking

Figure 4(c) & 4 (d) shows stress and deformation obtained in the bone. The force acting on bone is less than the force acting on the femoral head and femoral stem so the design is safe under loading condition.



(e) Deformation & stress plot of Acetabular component

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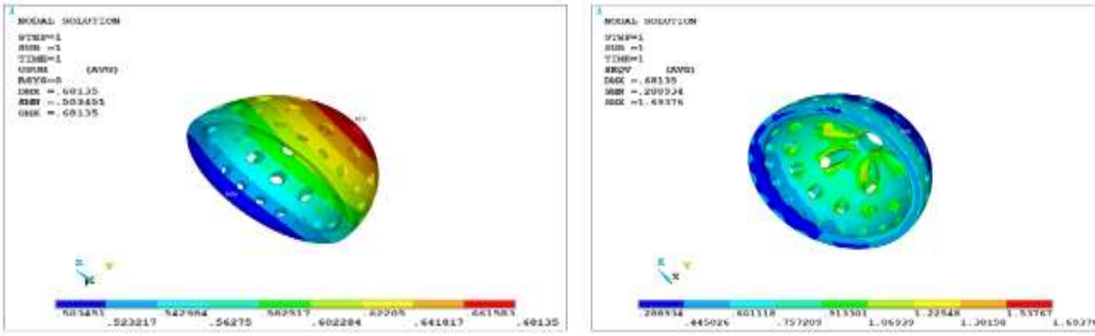
Figure (e) shows the deformation and stress acting on component of acetabular component. The maximum deformation acting on this is -6.54×10^{-6}mm and stress is 2.62Mpa.



(f) Deformation & stress plot of femoral head

Figure (f) shows the deformation and stress acting on component of femoral head. The maximum deformation obtained is -6.01×10^{-6}mm and stress is 2.6Mpa.

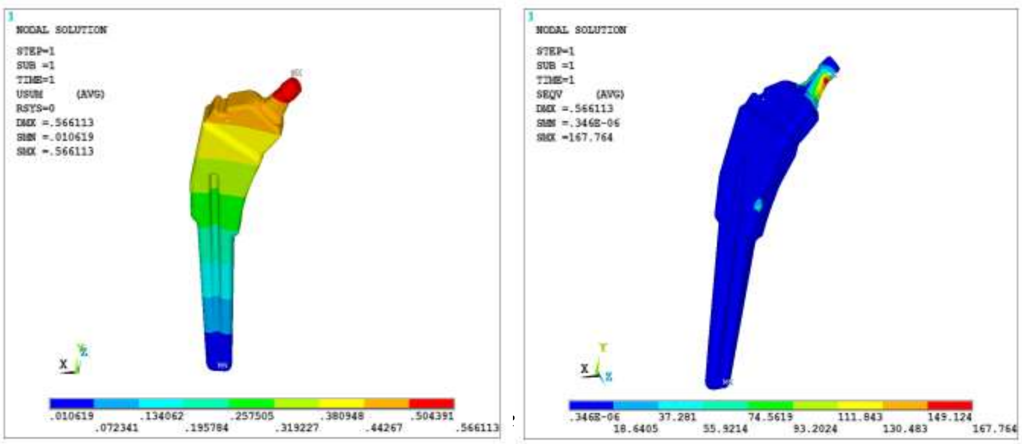
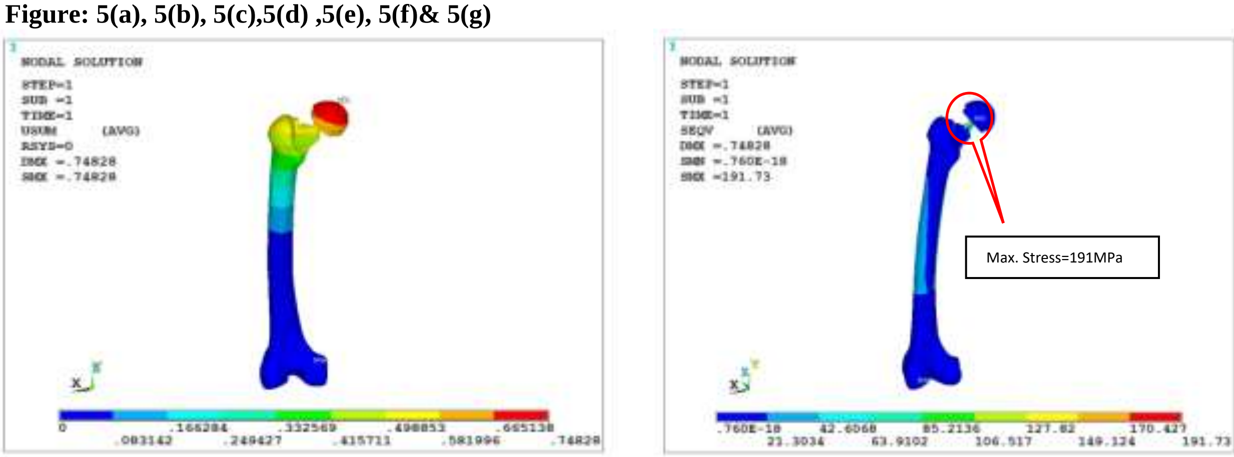


Figure (g) shows the deformation and stress acting on component of femoral stem. The maximum deformation obtained is -5.66×10^{-6}mm and stress is 167Mpa.

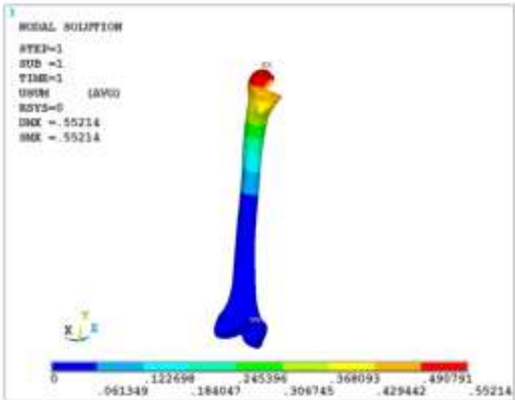
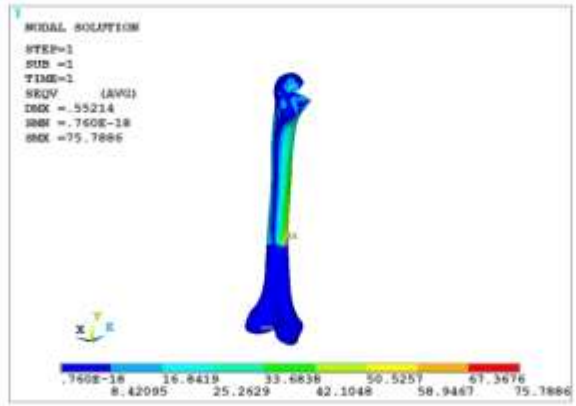
Contour plots for Material with Stainless Steel during running

Figure: 5(a), 5(b), 5(c),5(d) ,5(e), 5(f)& 5(g)



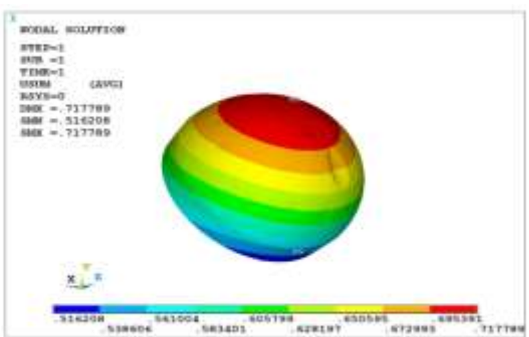
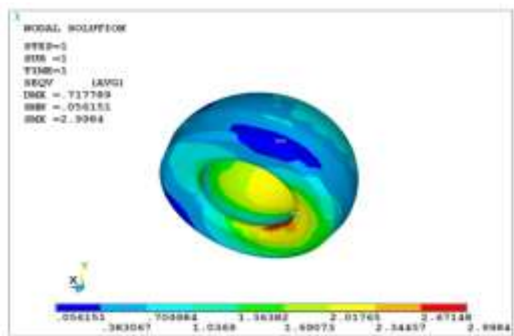
(a) Deformation plot during running ***(b) stress plot during running***

Figure 5(a) and 5(b) shows the deformation and stress plot of stainless steel during running. Initially 48kg of load is applied on Acetabular component and femoral head. And 53.6kg of load is applied on femoral stem. For this condition maximum stress obtained during deformation is -7.48×10^{-6}mm and maximum stress is 191Mpa. In this condition there is not much stress observed in bone component and other components. All components are safe under this loading condition. But however these stresses observed with stainless steel are higher than the stress observed with cobalt chromium alloy.

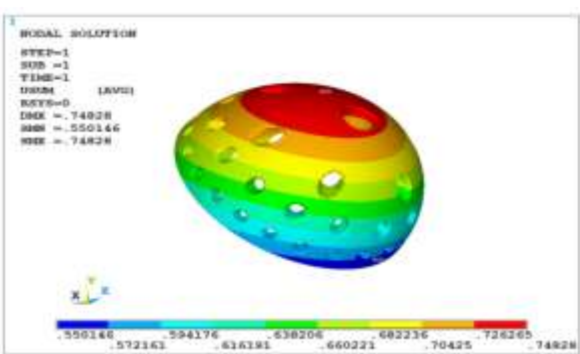
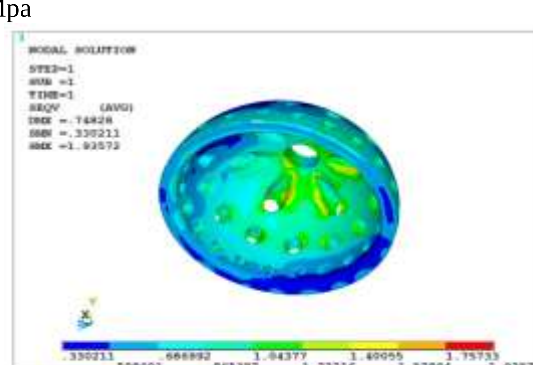
(c)Deformation Plot for Bone during Running ***(d) Stress Plot for Bone during Running***

Figure 5(c) & 5(d) shows stress and deformation obtained on the bone during running. The force acting on bone is less than the force acting on the femoral head and femoral stem so the design is safe under loading condition.

(e) Deformation & stress plot of Acetabular component

Figure (e) shows the deformation and stress acting on component of acetabular component. The maximum deformation acting on this is -7.1×10^{-6}mm and stress is 2.99Mpa

(f) Deformation & stress plot of femoral head

Figure (f) shows the deformation and stress acting on component of femoral head. The maximum deformation obtained is -6.01×10-6mm and stress is 2.6Mpa.

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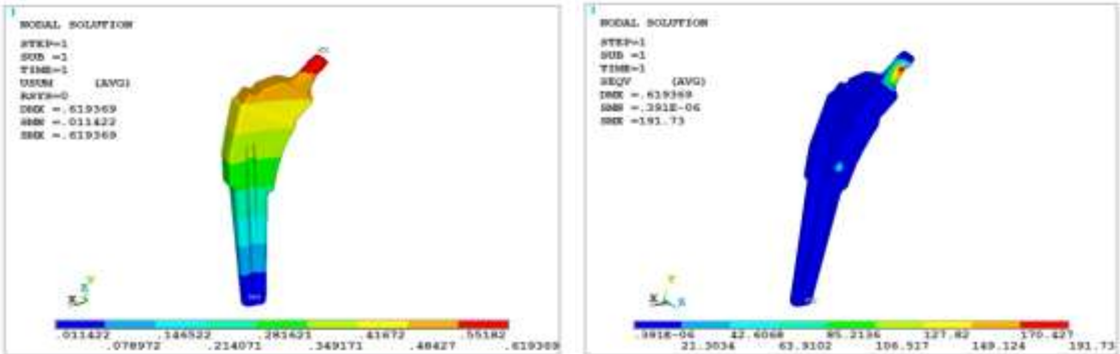
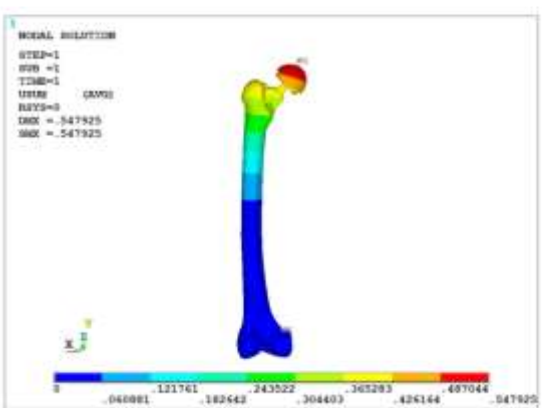


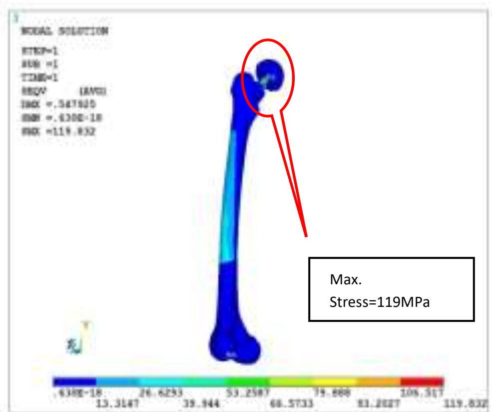
(g) Deformation & stress plot of femoral stem

Figure (g) shows the deformation and stress acting on component of femoral stem. The maximum deformation obtained is -6.19×10^{-6}mm and stress is 191Mpa

Contour plots for Material with Cobalt Chromium Alloy during walking

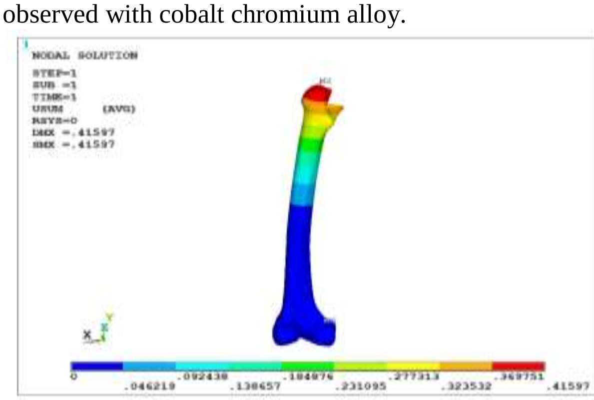
Figure: 6(a), 6(b), 6(c), 6(d), 6(e), 6(f) & (g)

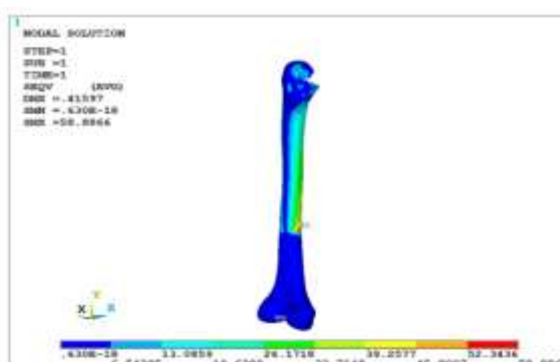




(a)Deformation Plot during Walking. ***(b)Stress Plot during Walking***

Figure 6(a) and 6(b) shows the deformation and stress plot of stainless steel during walking. Initially 29.9kg of load is applied on Acetabular component and femoral head. And 69.9kg of load is applied on femoral stem. For this condition maximum stress obtained during deformation is -5.47×10^{-6}mm and maximum stress is 199Mpa.In this condition there is not much stress observed in bone component and other components. All components are safe under this loading condition. But however these stresses observed with stainless steel are higher than the stress observed with cobalt chromium alloy.





(c)Deformation Plot for Bone during walking

(d) Stress Plot for Bone during walking

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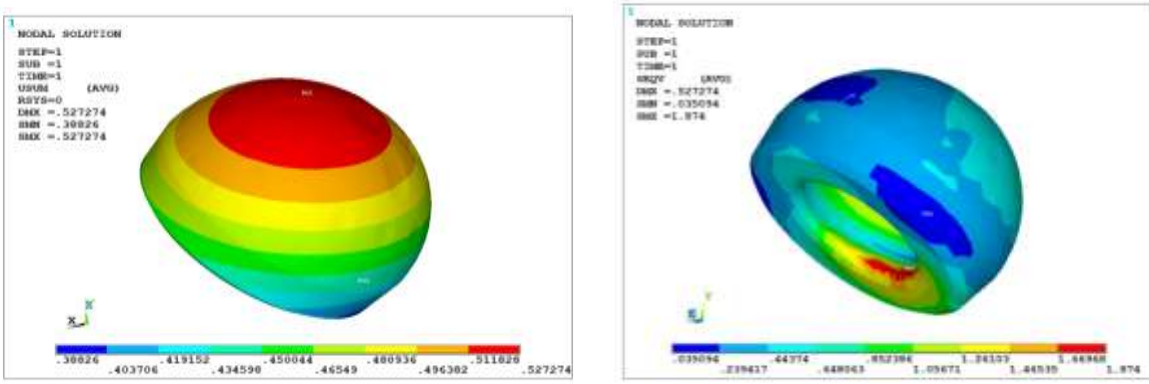
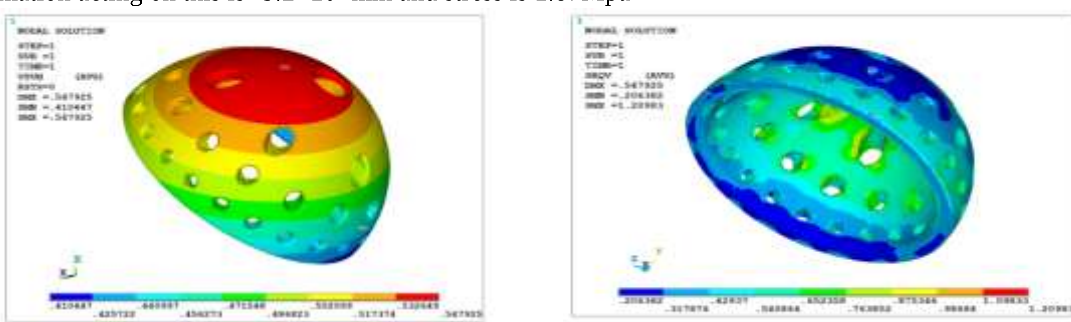
Figure 6(c) & 6(d) shows stress and deformation obtained on the bone during running. The force acting on bone is less than the force acting on the femoral head and femoral stem so the design is safe under loading condition.



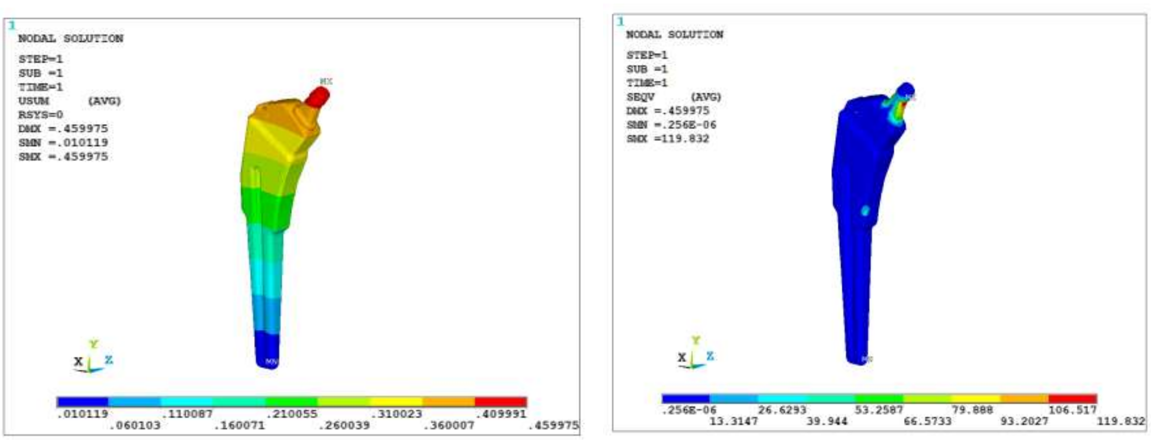
(e) Deformation & stress plot of Acetabular component

Figure (e) shows the deformation and stress acting on component of acetabular component. The maximum deformation acting on this is -5.2×10^{-6}mm and stress is 1.87Mpa



(f) Deformation & stress plot of femoral head

Figure (f) shows the deformation and stress acting on component of femoral head. The maximum deformation obtained is -5.47×10-6mm and stress is 1.29Mpa



(g) Deformation & stress plot of femoral stem

Figure (g) shows the deformation and stress acting on component of femoral stem. The maximum deformation obtained is -4.57×10^{-6}mm and stress is 119Mpa

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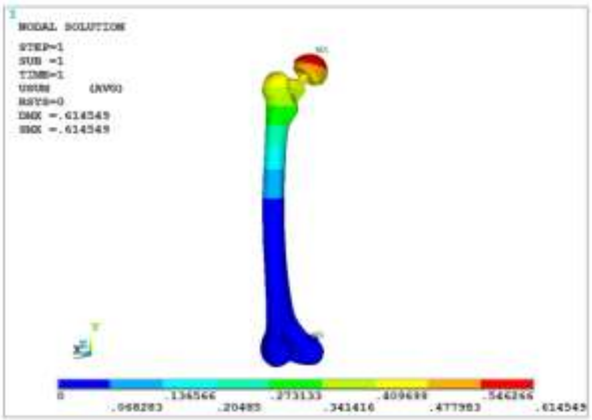
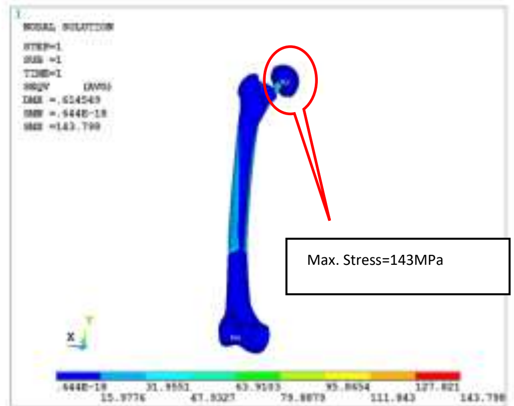
Contour plots for Material with Cobalt Chromium Alloy during running

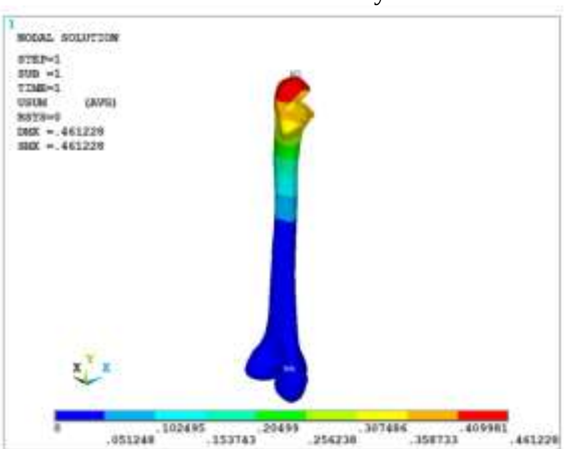
Figure: 7(a) , 7(b), 7(c) ,7(d) ,7(e),7(f) &7(g)

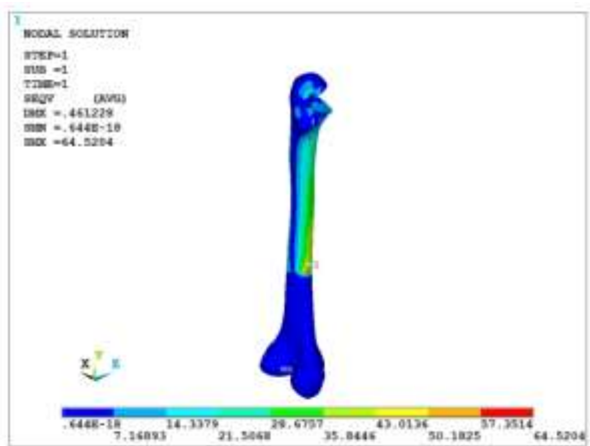




(a) Deformation Plot during Running ***(b) Stress Plot during Running***

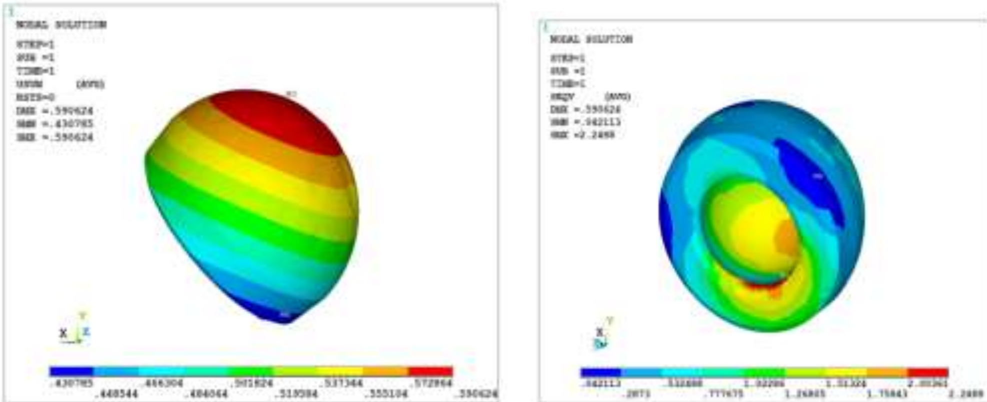
Figure 7(a) and 7(b) shows the deformation and stress plot of stainless steel during running. Initially 29.9kg of load is applied on Acetabular component and femoral head. And 69.9kg of load is applied on femoral stem. For that condition maximum stress obtained during deformation is -6.14×10^{-6}mm and maximum stress is 143Mpa.In this condition there is not much stress observed in bone component and other components. All components are safe under this loading condition. But however these stresses observed with stainless steel are higher than the stress observed with cobalt chromium alloy.





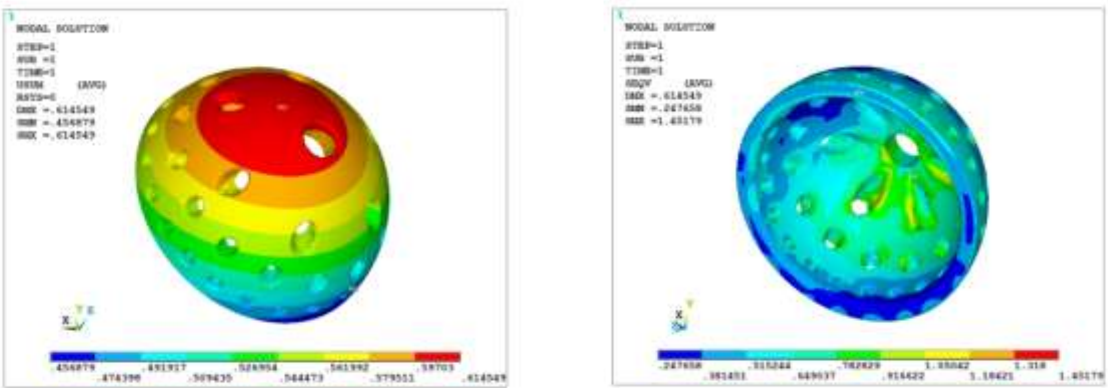
(c) Deformation Plot for Bone during Running ***(d) Stress Plot for Bone during Running***

Figure 7(c) & 7(d) shows stress and deformation obtained on the bone during running. The force acting on bone is less than the force acting on the femoral head and femoral stem so the design is safe under loading condition.



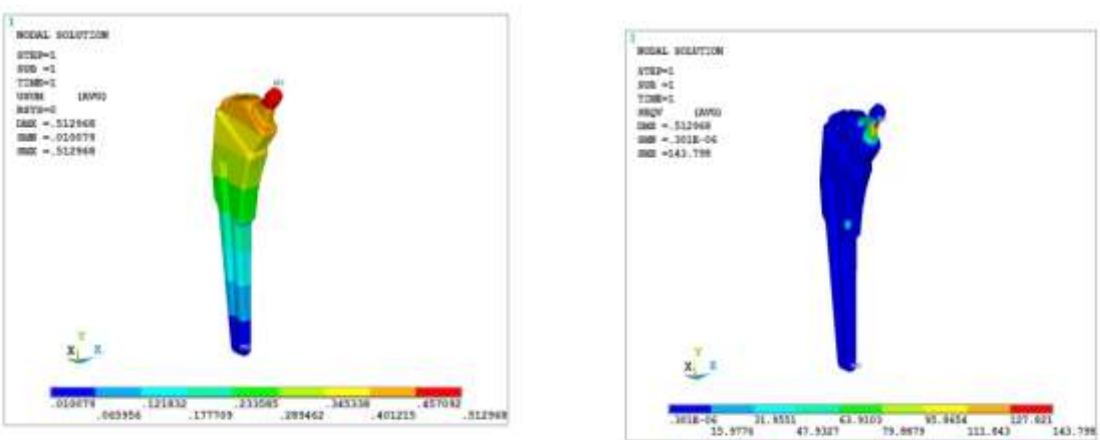
(e) Deformation & stress plot of Acetabular component

Figure (e) shows the deformation and stress acting on component of acetabular component. The maximum deformation acting on this is -5.90×10^{-6}mm and stress is 2.26Mpa



f) Deformation & stress plot of femoral head

Figure (f) shows the deformation and stress acting on component of femoral head. The maximum deformation obtained is -6.14×10-6mm and stress is 2.45Mpa



(g) Deformation & stress plot of femoral stem

Figure (g) shows the deformation and stress acting on component of femoral stem. The maximum deformation obtained is -5.12×10^{-6}mm and stress is 143.7Mpa

Comparison of Simulation Results

Below tables helps us to compare the results of stress, deformation and the heat flux obtained for the individual materials.

Table: 4 Walking Condition

Material	Load case (kg)		Von- mises stress (MPa)	Total Deformation (mm)	Yied Stress (MPa)	Factor of Safety
	bone	alloy				
Stainless Steel	69.6	29.9	167	7.6	250	1.49
Cobalt Chromium Alloy	69.9	29.9	119	0.54	300	2.5

Table:5 Running Condition

Material	Load case (kg)		Von- mises stress (MPa)	Total Deformation (mm)	Yied Stress (MPa)	Factor of Safety
	bone	alloy				
Stainless Steel	53.6	48.7	191	0.74	250	1.3
Cobalt Chromium Alloy	53.6	48.7	143	0.61	300	2.09

IV. CONCLUSION

From the FE Analysis performed with two different material it was observed that Stainless Steel Material yields less Factor of Safety in Comparison with Cobalt Chromium Alloy for all the load cases and Hence, it is suggested to go with Cobalt Chromium Alloy so that for long run it can withstand the loads which arises during Walking & Running

V. REFERENCES

[1] Mattei L, Di Puccio F, Ciulli E. A comparative study of wear laws for soft-on-hard hip implants using a mathematical 173
wear model. Tribology International.2013; 63: 66-77.
[2] Udofia I.J, Yew A, Jin ZM. Contact mechanics analysis of metal-on-metal hip resurfacing prostheses. Proceedings of 179
the Institution of Mechanical Engineers Part H, Journal of engineering in medicine. 2004; 218: 293-305.
[3] S. Kaptoge, et al., "Prediction of incident hip fracture risk by femur geometry variables measured by hip structural analysis in the study of osteoporotic fractures," Journal of Bone and Mineral Research, 2008, vol. 23.12, pp. 1892-1904.
[4] Cheng XG, Lowet G, Boonen S, Nicholson PH, Brys P, Nijs J, Dequeker J. Assessment of the strength of proximal femur in vitro: Relationship to femoral bone mineral density and femoral geometry. Bone.1997;20:213–218.
[5] G. Bergmann, F. Graichen, A. RohlmannHip Joint Loading During Walking and Running, Measured in Two Patients
[6] E. Schileo, et al., "To what extent can linear finite element models of human femora predict failure under stance and fall loading configurations?," Journal of biomechanics, 2014, vol. 47.14, pp. 3531-3538.

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

[7] N.A. Ramaniraka, L.R. Rakotomanana, and P.F. Leyvraz, "The Fixation of The Cemented Femoral Component: Effects of Stem Stiffness, Cement Thickness and Roughness of the Cement-Bone Surface," The Journal of Bone and Joint Surgery, vol. 82-b, no. 2, 2000.
[8] E.L. Masterson, C.A. Busch, C.P. Duncan and K. Drabu, "Impaction allografting of the proximal femur using a Charnley-type stem: A cement mantle analysis," The Journal of Arthroplasty, vol 14, no. 1, 1999, pp. 59-63.
[9] H. Malchau, P. Herberts and L. Ahnieit, "Prognosis of total hip replacement in Sweden: Follow-up of 9267.5 operations performed 1978-1990," ActaOrthopScand, vol. 64, 1993, pp. 497-506.
[10] Z. Lu, Finite Element Analysis of the Effects of Stem Geometry, Surface Finish and Cement Viscoelasticity on Debonding and Subsidence of Total Hip Prosthesis, PhD thesis, Faculty of the Graduate School, University of Southern California, 2001.
[11] A.I. Spitzer, "The Triple-Tapered Stem: The Evolution of The Next Generation of Cemented Total Hip Arthroplasty," Orthopaedic Technology Review, vol. 3, no. 4, 2001.
[12] Abdul Halim Abdullah, MohdAsriMohd Nor and Alias MohdSaman, "Stress and Strain Distribution in Cemented Total Hip Arthroplasty for Walking Load Case," Proc. Int. Conference on Computer Technology and Development (ICCTD 09), Nov. 2009.
[13] D.T. Reilly, A.H. Burrstein, and V.H. Frankel, "The Elastic Modulus for Bone," Journal of Biomechanics, vol. 7, 1974.
[14] P. Kowlczyk, "Design optimization of cementless femoral hip prostheses using finite element analysis," Journal of Biomechanical Engineering, vol. 123, 2001, pp. 396-402.
[15] B. Mahaisavariya, K. Sitthiseripratip, and J. Suwanprateeb, "Finite Element Study of the Proximal Femur with Retained Trochanteric Gamma Nail and After Removal of Nail," Int. J. Care Injured, vol. 37, 2006.
[16] M. Morlock, E. Schneider, A. Bluhm, M. Vollmer, G. Bergmann, V. Muller and M. Honl, "Duration and frequency of everyday activities in total hip patients," Journal of Biomechanics, vol. 34, 2001, pp. 873-881.
[17] N. Goetzen, "Loadshift-Numerical Evaluation of a New Design Philosophy for Uncemented Hip Prosthesis," Proc. 10th Annual Symposium on Computational Methods in Orthopaedic Biomechanics, 2002.
[18] C.J. Sychterz and C.A. Engh, "The Influence of Clinical Factors on Periprosthetic Bone Remodeling," Clinical Orthopaedics and Related Research, 1996, pp. 285-292.
[19] R.D. Jamison, "Fabrication and Characterization of a Composite Material Human Hip Prosthesis," Proc. The Third Joint ASCE/ASME Mechanics Conference, 1989

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