Evaluation of Contact Stress Distribution of Hip Joint Model using Finite Element Method

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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 contact pressure distribution in acetabulum region using finite element analysis software Ansys. The stress distribution obtained from static analysis was found to be within the acceptable range. A symmetric distribution of pressure was observed and magnitude of contact pressure decreases as the angular distance increases from the centre of contact. The maximum contact pressure predicted as 4.847 MPa at contact surface of head and ace tabular cup.**

KEYWORDS: Hip joint, Hybrid Polymer Matrix composite, Static Analysis, contact stress analysis

I. INTRODUCTION

Total hip replacement (THR), is a surgical procedure in which the diseased parts of the joint are replaced and removed with new artificial material, which is known as prosthesis. Now a day's stainless steel, Titanium alloy, cobalt chromium alloy and other biocompatible alloys and composite materials are used for preparing the prosthesis. The function of hip joint is to with stand loads during various activities of human being and to provide stability rather than mobility. (Scott J. Hazelwood et al**,** 2007). Also Stiffness of prosthesis material is an important parameter in stress shielding process and relative micro motion between interface of bone and implant as described by (Simoes J.A, et al, 2001). Both metal matrix and fibre reinforced composite materials have been in use these days due to their more durability, less weight and better biocompatibility. Loads acts on Hip joint due to different activities of human being like Fast Walking, Standing Up and down, Stair Climbing, Jumping etc, results in aseptic loosening of Hip joint due to cyclic variation of loads, which leads to damage of hip joint and Finally the Fracture as stated by (S. H. Toeh et al, 2000). Also Fracture of the Hip joint will occur due to the process of wear, corrosion and environmental stress cracking, which occurs as a result of shear stress distribution at the ball and socket interface at the proximal or distal end of the prosthesis as reported by (M. Sivasankar et al). Since detoriation of metal alloys with surrounding bone leads to stress shielding and loosening of implant in patients and hence results in Osteoporosis disease, which in turn reduces the life of the metallic implant material (Xi SHi Wan G et al, 2005). **(**Mark. P. Stagier et al**,** 2006) stated that metallic materials undergo the process of degradation through corrosion, due to the electrolytic reaction with human blood and its elements, which in turn leads to wear and friction of hip joint implant material. (Toeh. S.H, 2000) gave the overview of fatigue fracture problem associated with metallic, polymer and ceramics. (Ramakrishna. S, et al**,** 2001) reported the applications of various polymer matrix composites materials to replace different implants of human body like bone plates, joints, heart valves, lenses and teeth. Also Identification of fatigue resistance to crack initiation and propagation of Ultra High molecular weight polyethylene is important to be used as one of the prosthesis material for load bearing applications as suggested by (Ravikumar Varadarajan et al, 2006). (A Zafer Senalp et al 2007) evaluate fatigue behavior of newly designed stem shape using Good man, Soderberg and Gerber criteria of stress life approach based on von misses stress distributions obtained from static analysis results. (Joy H Jones et al, 2007) used the stress life approach to performed fatigue analysis of endoskeleton prosthesis using the results of finite element analysis. (Oguz Kayabasi et al, 2006) have also used the stress life approach to calculate fatigue life of three dimensional hip prosthesis model based on static and dynamic von misses stress distribution for different loading conditions. (S. H. Toeh et al, 2000) Stated that major problem associated with failure of medical devices are fatigue fracture and wear. In the research work carried, gave the overview of fatigue fracture problem associated with metallic, polymer and ceramics. Fatigue of biomaterials arises due to adverse effect of host tissue response to wear debris particles. (Bergmann et al, 2001) studied the fatigue life of hip prosthesis due to contact forces for different activities of the human being. For five different patients they took the data which contains complete gait and hip contact data as well as calculated muscle activities during different activities of human being. Two kinds of the materials Viz, Ti-6Al-4v alloy and Co-Cr alloy are considered as the material of the choice for Hip joint. Fatigue life is calculated using residual strength degradation model and concluded that prosthesis of Ti-6Al-4v alloy has the maximum fatigue life compare Co-Cr alloy material. (Sandra A begg et al) They carried their research on numerical analysis of hip prosthesis by considering Charnley prosthesis model made of stainless steel 316L as the material of choice for hip joint prosthesis.

From the literature survey, it is concluded that most of the research are carried with respect to biocompatible materials using Stainless Steel 316L, Ti-6Al-4v alloy and Co-Cr alloy as the material of choice for Hip joint prosthesis. Different failure theories are predicted to estimate the failure mechanism of the hip joint implant materials and to increase the life of the implant materials by considering different aspects of design and reaction of biomaterials in the aggressive body environment. Hence in this study fatigue analysis of Hip joint is carried out by considering properties of fabricated biocompatible polymer matrix composite specimens as per ASTM standards as the material of choice for hip joint prosthesis.

II. MATERIALS AND METHODS

A. Finite element modelling of Hip Joint

The Figure 1 represent Hip joint model developed using CATIA modelling package. Both the stem, cap and femur bone are separately built and assembled using Catia assembly options. Standardized Human femur anthropometry data based on experimental results as suggested Taner Ziylan [11] is considered to developed Hip joint model. Also optimised design variables parameters were considered to build the model as reported by M Sivasankar [3]. The model is exported to hyper mesh for meshing in 'step' file format and meshed using solid meshing options. The meshed view of the modelled is shown in Fig 2. The structure is Tetra meshed due to complicated geometry with internal Cancellous and cortical bones. Solid 45 is a 4 nodded element with three degree of freedom at each node. Contact Elements TARGE169 is used to represent various 2-D "target" surfaces for the associated contact elements. Conta171, Conta172 and conta175 are used to represent various 3-D solid elements. Contact of elements takes place when surface element penetrates the target segment element. Contact condition of completely bonded type is selected for contact surfaces.

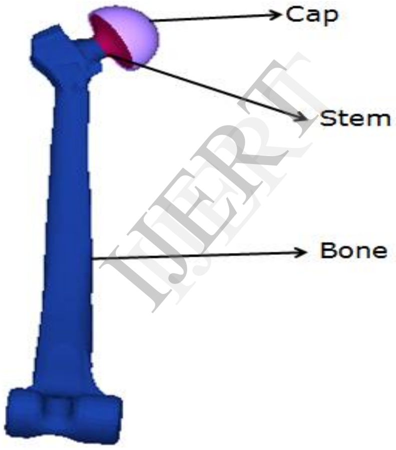
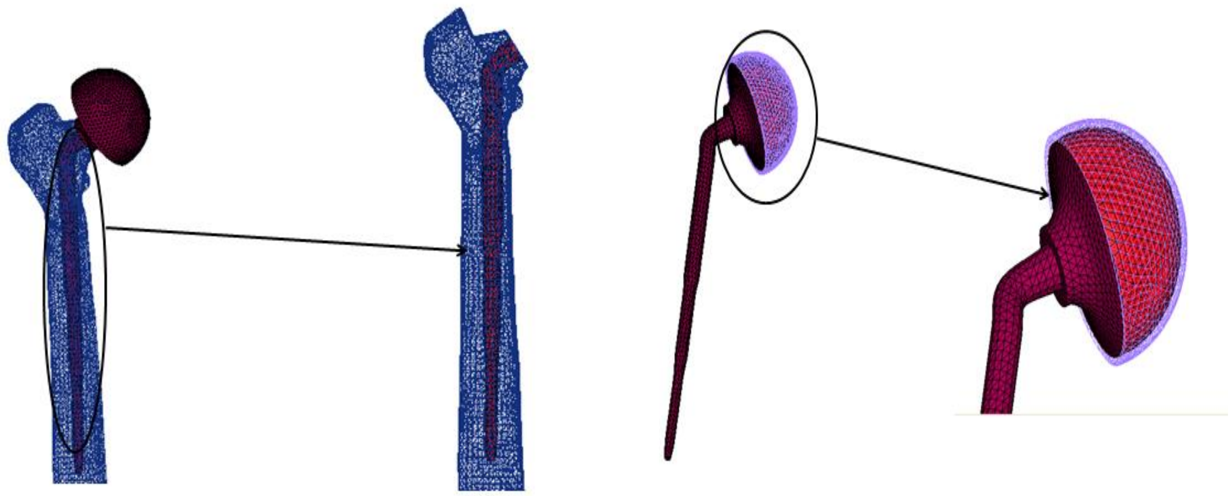


Fig 1 Components of Hip joint system



a. Contact definition at stem and bone interface **b.** Contact Definition at stem and cap interface

Fig 2 Contact definition at stem and bone interface and stem and cap interface

B. Material model

In this research study, property of newly developed polymer matrix composite material is used for hip joint stem component. To study the behaviour of the Hip joint model Cancellous bone and cortical bone are assigned with different material properties.

Table 1 Material properties assigned for various components of hip joint system

Material	Modulus o f Elasticity (Mpa)	Poison's ratio	Yield stress(Mpa)
Cancellous Bone	600	0.2	15
Cortical Bone	15000	0.3	210
UHMWPE/ 40 wt% TiO_2 Polymer composite	6500	0.4	35.6
Cap	6500	0.3	35.6

C. Loading Conditions

Static analysis is carried out using finite element software Ansys version 11. The boundary conditions applied in this work are, a normal right hip in one leg standing position, supporting the whole body weight was considered. All the nodes located at the bottom were fixed as shown in Fig 3. The hip is subjected to a vertical load of 250, 500, 750 and 1000N through pelvis on the surface of the implant during average walking, Upstairs, Sitting and knee Bending. These loads represent a person of average weight of 70 kg [2]. An abductor muscle force of 1937 N at an angle of 20^0 to the proximal area of greater trochanter is considered. These loads act on hip joint in terms of percentage of body weights.

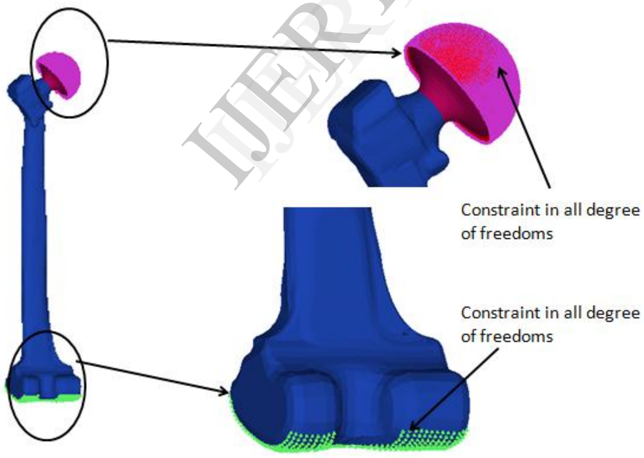


Fig 3: Boundary Conditions applied to the model

III. STATIC ANALYSIS AND RESULTS

Loads acting on the Hip joints due to daily activities were used to carry out the static analysis [2]. Static analysis is done in order to understand the fatigue locations in the hip joint. For optimised safety design of the Hip joint it is necessary that von misses stress distribution obtained from static analysis must be lower than the endurance limit of stem material to avoid fracture due to fatigue. The von misses stresses obtained from analysis are lower than the yield stress of prosthesis material. The results of static analysis shows maximum stresses are concentrated on the Neck portion of hip joint compared to the bottom of Femur. Fig 4, Fig 5& Fig 6 represent overall von misses stress distribution for the load case of 250N, 750N and 1000 N respectively. Maximum stress of 59.265 Mpa was obtained for the load case of 1000N. The different contours represent variation of stress in the structure. Stress distributions obtained from static analysis are below the ultimate tensile strength of prosthesis material.

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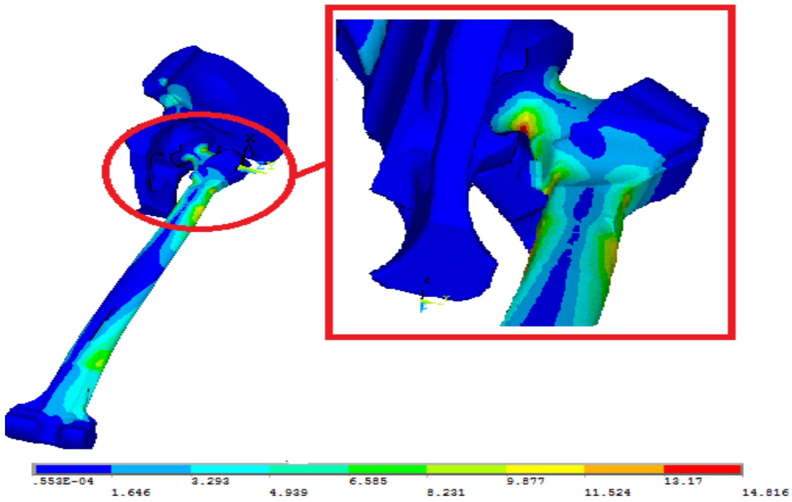


Fig 4: Von misses Stress Distribution for load case of 250 N

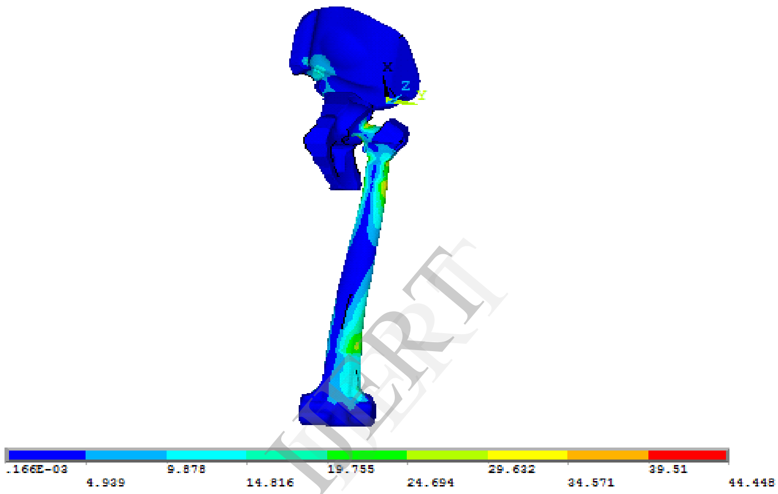


Fig 5: Von misses Stress Distribution for load case of 750 N

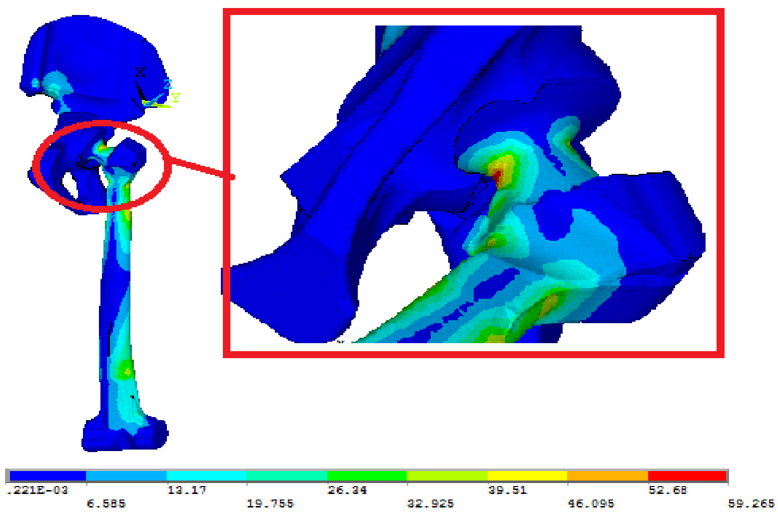


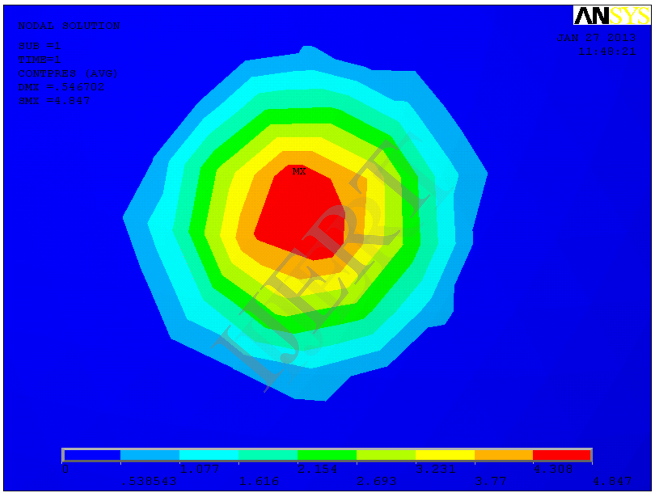
Fig 6: Von misses Stress Distribution for load case of 1000 N

IV. CONTACT STRESS ANALYSIS

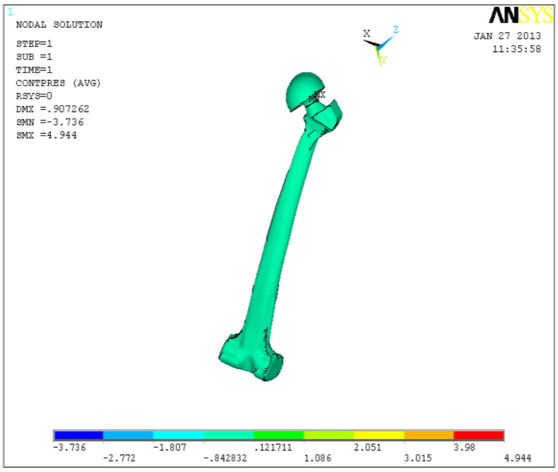
Fig 7 represents contact pressure distribution of three dimensional finite element model for the given loads and boundary conditions. The maximum contact pressure predicted as 4.847 MPa. This indicates distribution of pressure from centre of the contact point to edge of the acetabulum cup. Fig 7c represents contact status of hip bearing components under normal loading conditions.

Fig 8 represents variation of von misses stress distribution for the applied boundary conditions and loads along the medial and lateral side of hip joint model. Fig 9 represents contact deformation along stem surface, cup and Hip joint model. The different contours represents variation of contact pressure, von misses stresses and deformations. For spherical bodies, contact of hip joint head and acetabuler cup during normal loading condition, a circular type of contact patterns were observed, which was also reported in the literature. Due to contact of head of femur and acetabuler cup at one point, results in formation of Hertzian contact pressure. By considering the contact simulation of the hip joint model, it is understood that micro separation of bearing components will takes place, due to normal loading condition. Also a symmetric distribution of pressure was obtained and magnitude of contact pressure decreases as the angular distance increases from the centre of contact. Also the maximum von stress distribution value of 60.604 Mpa was obtained. It was observed that, the maximum contact pressure and maximum von misses stress distribution will occur at the anterior end of the head and acetabuler cup of the femur. A plastic deformation of the cup was observed above the rim radius of the cup.

For a 3D anatomic and axi symmetric model, Ahmet C clinger et al [13] measured the peak contact pressure of 2.5 Mpa.

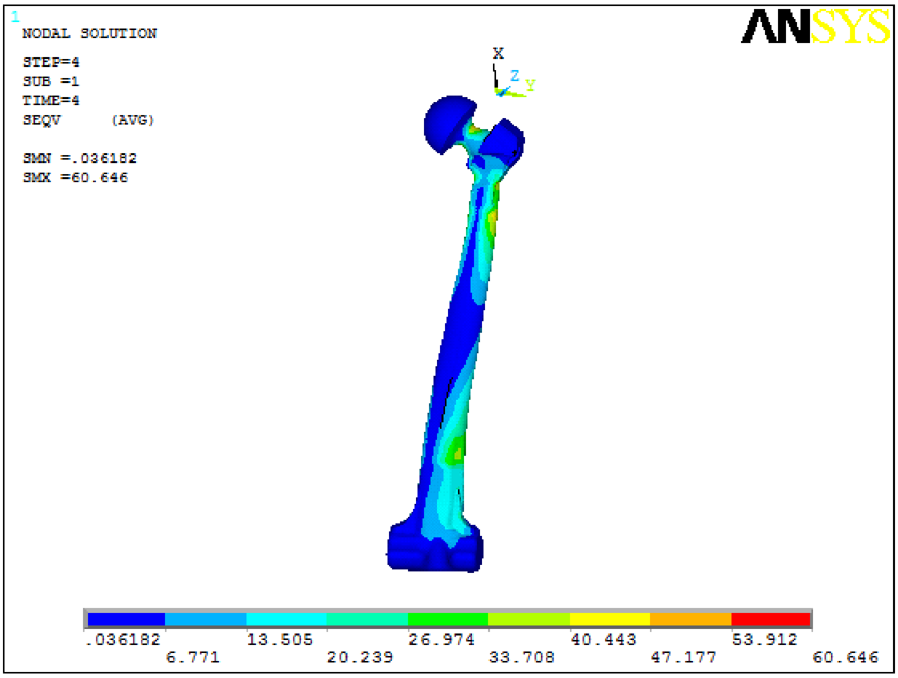


a. Contact pressure distribution along head of femur and acetabuler cap surface

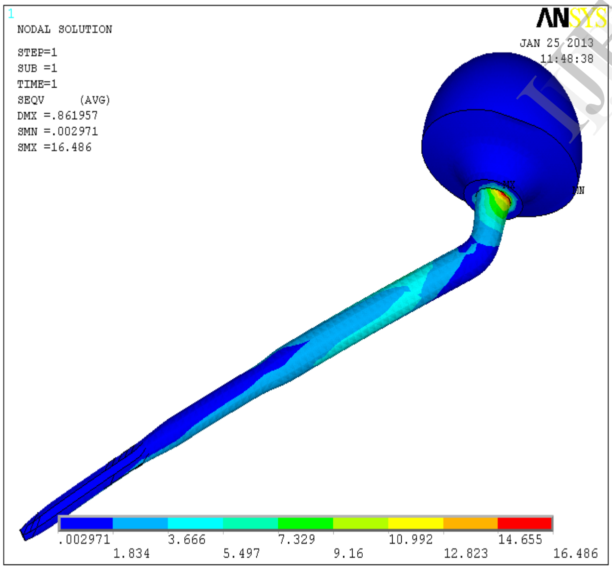


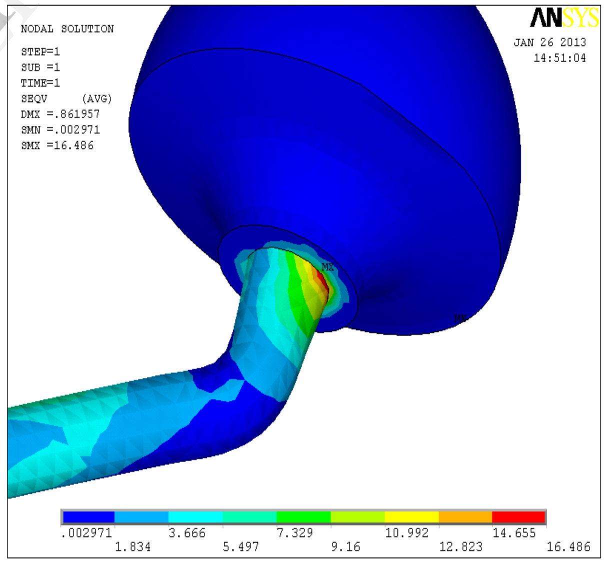
b. Contact pressure along hip joint | c. Contact status along head of femur and cap surface

Fig 7 Contact pressure distribution along head of hip joint model and acetabulum cap



a. Von misses stress distribution for the load case of 1473 N

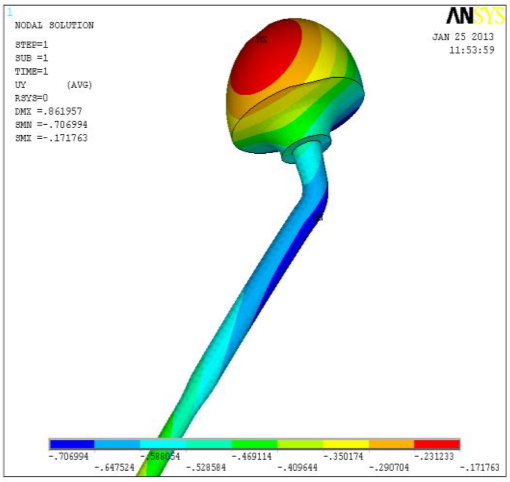




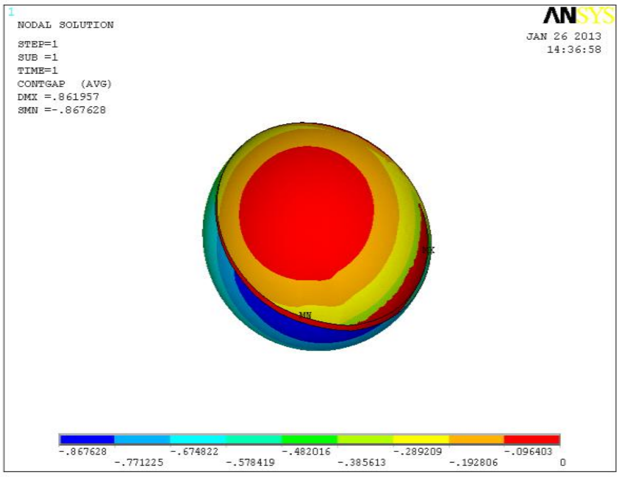
b. Von misses stress along the stem surface

c. Enlarged view of stress distribution along the stem

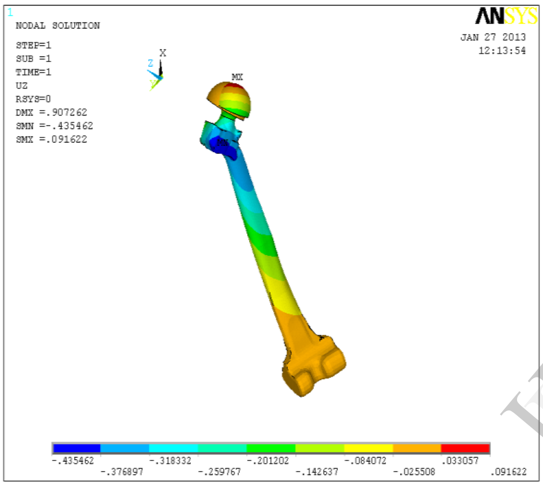
Fig 8 Von misses stress distribution along the stem surface



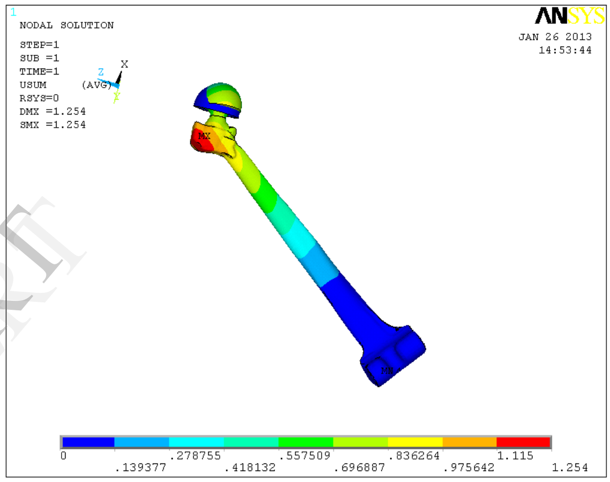
a. Contact displacement along stem



b. Contact displacement in the acetabuler cap



c. Contact displacement along hip joint in z-direction



d. Contact displacement along hip joint in y-direction

Fig 9 Contact displacement in the hip joint and stem surface

V. CONCLUSION

Material properties of fabricated composites specimen were used to carry out static and contact analysis of Hip joint model using finite element method. The von misses stresses obtained from analysis are lower than the yield stress of prosthesis material. Stress distribution obtained from static analysis results are within the acceptable range. The maximum contact pressure predicted as 4.847 MPa and distribution of pressure takes place from centre of the contact point to edge of the acetabulum cup. Contact of head of femur and acetabulum cup at one point, results in formation of Hertzian contact pressure. A symmetric distribution of pressure was observed and magnitude of contact pressure decreases as the angular distance increases from the centre of contact. Also the maximum von stress distribution value of 60.604 Mpa was obtained.

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