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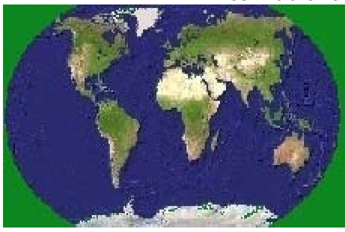

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Wear-contact analysis of hip implant coated with functionally graded material

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Abstract
In this paper the wear of acetabular cup in Metal-on-Metal implant is estimated and a means of reducing the wear by using functionally graded materials is addressed. The contact pressure is obtained through finite element tool (Ansys) and the wear is obtained by Archard equation from the contact pressures obtained by Ansys. The contact pressures and wear is estimated for both Metal-on-Metal hip implant as well as implant coated with functionally graded material and the results are compared. The contact pressures are obtained for various loads and orientation of femoral head and acetabular cup according to a 3 dimensional gait cycle. The gait pattern associated with normal walking of human at 4 km/hr is considered for analysis. It was found that the maximum hip load in the gait cycle was about 230% of the body weight of the patient. This gait cycle is divided into 8 instances .It is shown in this work that the linear wear for functionally graded implants are far lesser than Metal-on-Metal implants commercially used today.

Keywords: Functionally graded materials, Acetabular cup, Femoral head, Wear effects, Gait cycle.

1. Introduction
Hip replacement surgery is considered as an effective solution for patients with osteoarthritis. This has been in practice from late 1960's and since then there has been a continuous search in finding the optimum material for the implants. Initially the implants were made of steel and chrome, which faced a number of drawbacks such as wear, failure and infection in some patients. Since then there has been various advances in the use of material. Modern day hip-implants use metals like (titanium alloys and chromium alloys) and ceramic materials .Metallic implants have a lower wear rate but these metallic implants releases metal ion in the blood stream and there by leads swelling of tissues around the implant and this in turn causes the implant to loosen and causes failure of hip prosthesis .Use of ceramic implants usually leads to failure as ceramic materials are very brittle materials and thereby leads to fracture upon impact loading .Though ceramic materials are very hard and lead to less wear and are biologically inert, these materials can lead to sudden fracture due to impact load . Thus these ceramic implants is not suitable for people who are very active and young .Metallic implants wear out faster than the ceramic implants but are not as brittle as the ceramic materials . Metal debris is very reactive to some humans. This arises the need for usage of material that are hard on the outer, that is wear resistant and are stronger in the inner core of the implant, that is, that can withstand impact loads. This need requires a material with different properties within the same geometry. One such material is functionally graded material.

Fig 1: Human hip joint and hip prosthesis

M. M. Mak and Z. M. Jim (2002) analyzed the contact pressure distribution for various clearances of acetabular cup and femoral head ranging from 0.02 mm to 0.08 mm. They had evaluated the contact pressures using a finite element technique for a 2 dimensional model and compared the results with hertzian technique, which saw a close similarity between them. They had used ceramic on ceramic (alumina) implant model with a minimum 5 mm thick ceramic insert and UHMWPE (ultra high molecular weight poly ethylene) inlay. The variation of contact pressures for various thickness of ceramic insert was also studied in this paper.

Functionally graded material is a material whose property is a function of space and varies gradually from point to point within the geometry. Many human organs like the bones and teeth are naturally occurring functionally graded material. Artificially such a material can be manufactured by various methods like powder metallurgy, rapid prototyping, centrifugal casting, etc. This variation of properties of a functionally graded material is used in application where different functions are required at different location of the same material. This allows the material to have the best of various material properties like the wear resistant, high strength, corrosion resistant, etc. Various applications of functionally graded materials are heat shield in re-entry vehicles in space application, Dental implants, ball bearings gears, turbine blades etc. Artificially manufactured functionally graded materials came to be used in late 1980's for a space application in Japan. Since then functionally graded materials has found its applications in various fields and the applications are ever increasing.

2. Modeling Functionally Graded Material

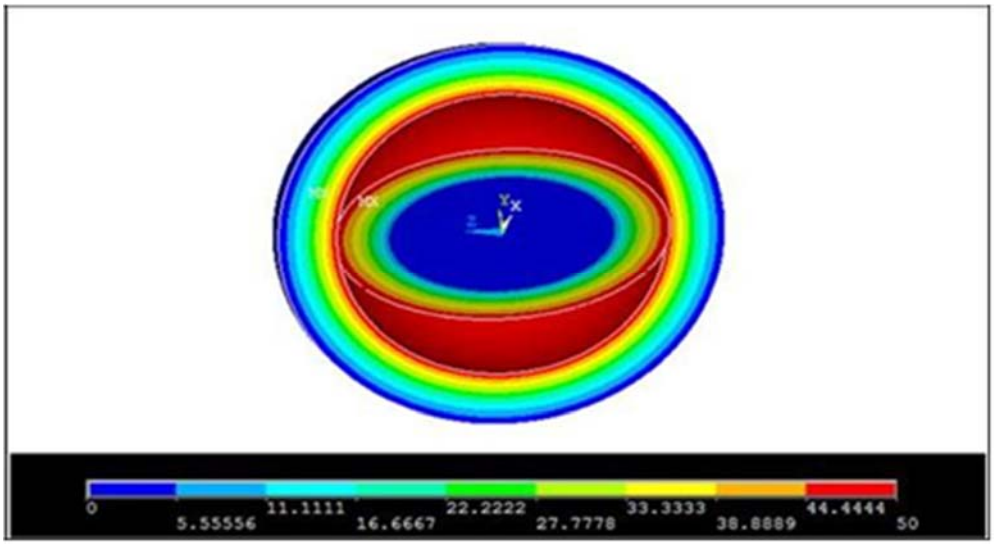
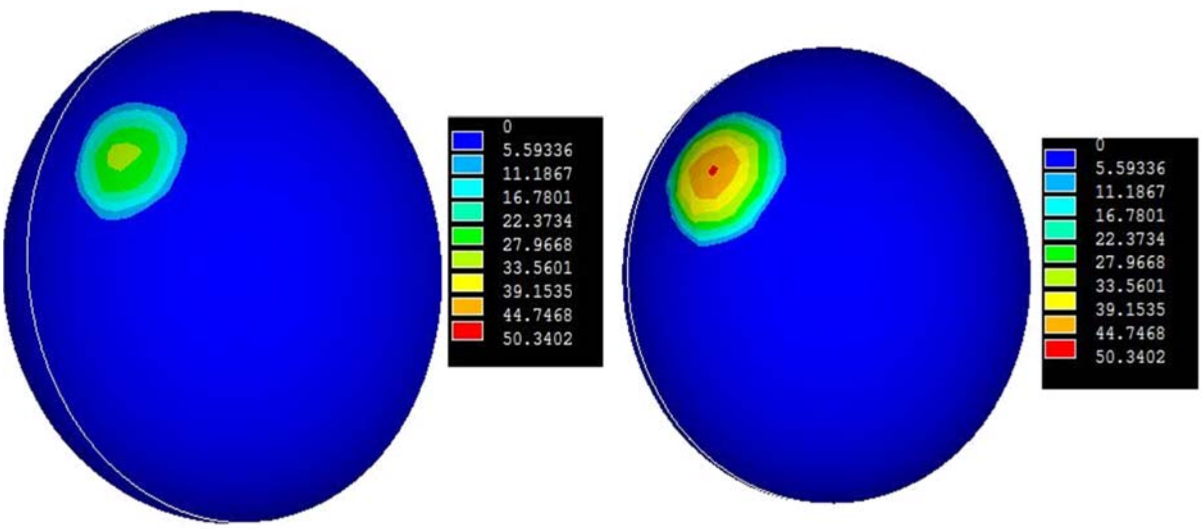


Fig 2: Temperature profile obtained from thermal analysis

3. Result and Discussion

3.1 Contact pressure plots for Metal-on-Metal implant

The Metal implant used in this case is a titanium alloy (Ti6 Al4V). The young's modulus and the Poisson ratio are taken as 100 GPa and 0.3 respectively. The contact pressure plots are obtained for all the 9 gait instances. The loads and the head orientations are obtained from the gait pattern discussed before. The maximum contact stresses are obtained at the instance 3 where the hip loads resultant are maximum in the gait cycle, which is about 238% of the body weight. The minimum peak contact stress is obtained at instance 8 where the hip loads resultant is minimum.



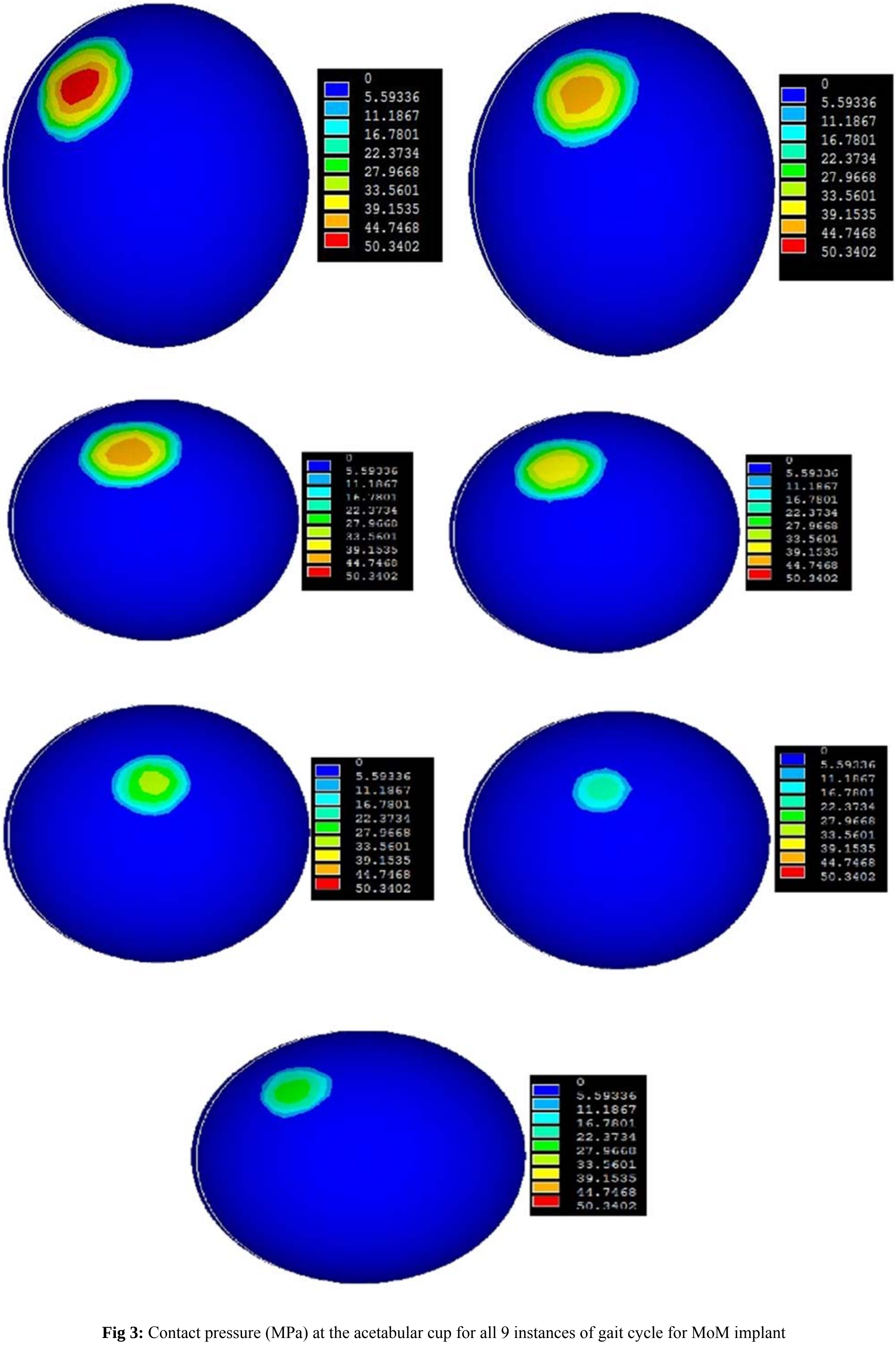


Fig 3: Contact pressure (MPa) at the acetabular cup for all 9 instances of gait cycle for MoM implant

Wear plots for Metal-on-Metal implant

The wear, linear wear is estimated at every node of the acetabular cup by the Archard equation as discussed before. The plots below show the cumulative linear wear at every instant of the gait cycle. The cumulative linear wear are obtained by a computer written program for which the contact pressures are the input at every node and cumulative wear is obtained by Archard equation at every node .

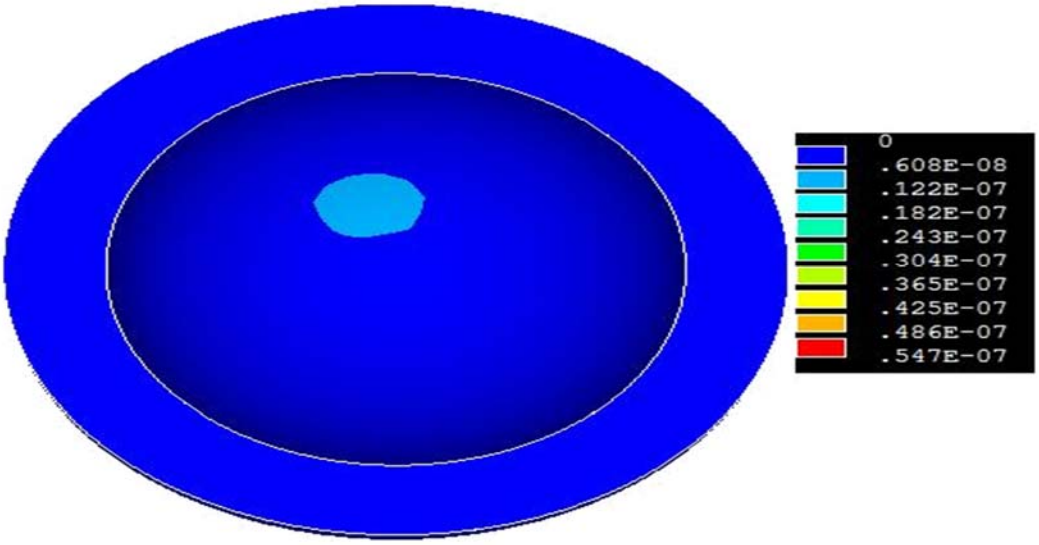


Fig 4: Cumulative linear wear in acetabular cup (μm) for instance 1 of the gait cycle for MoM implant

Wear plots for 3D FGM on FGM implant

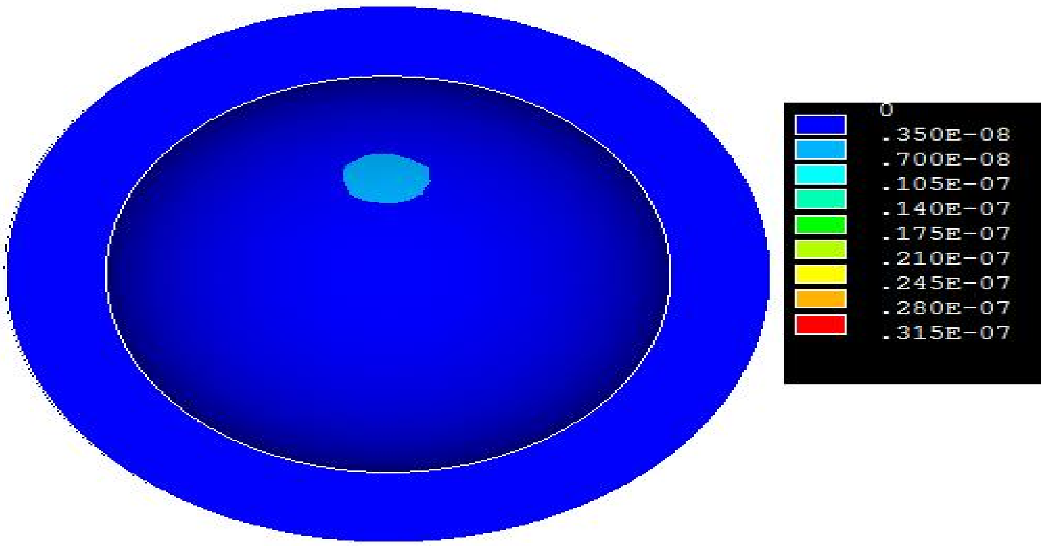


Fig 5: Cumulative linear wear in acetabular cup (μm) for instance 1 of the gait cycle for FGM implant

Total cumulative linear wear at every instan

Total wear is estimated as the sum of cumulative linear wear estimated at all nodes. This depicts the overall picture of wear in the acetabular cup. The figure depicts the wear progress with the gait cycle .It can be seen that the wear for FGM coated implants are far leaser than the metallic implants .Though FGM coated implants are harder and have a higher contact stresses the wear coefficient value is lesser than that of the metallic implants thus the wear calculated by archard equation turns out to be lesser than the metallic implants.

Thus the total wear can be estimated for every instance of the gait cycle. It has been estimated that an average human uses around 10^6gait cycles every year. Thus the total wear can be estimated for an year and is found to be 0.92201 μm for FGM coated implants and 2.3215 for the metallic implant. This wear rate is in good agreement with the measurement by clinical laboratory studies which is 1.27-15.7 μm for metallic implants.

The wear rate per year of FGM coated implants are 39% lesser than the metallic implants.

Thus an FGM coated implant has far lesser wear than the metallic implants and are less harmful to humans than the metallic implants as the ceramic are biologically inert and do not react with blood stream.

Table 1: Total cumulative linear wear (µm) in the acetabular cup after 1 year or 10^6 gait cycles for both MoM and FGM coated implant

Implant Type	Total Cumulative Wear
	(µm)
MoM	2.32150
FGM on FGM	0.92201

4. Conclusion

The wear-contact in the hip prosthesis using functionally graded material was studied. The wear was estimated by contact stresses which were obtained using finite element software ansys. The methodology followed and the results obtained were discussed in the previous chapters. The summary of the work is presented below:

1. A simple 2d implant was modeled and the results of peak contact pressure validated using literature for ceramic implant, where the peak gait load of 2500N approx was considered.
2. The 2d implant was modeled with FGM coating using an indirect method (thermal analysis followed by structural analysis) and the variation of peak contact pressures for varying radial clearances of acetabular cup and femoral head was studied.
3. The 2d implant model was then studied for variation of peak contact pressures with the variation of acetabular insert thickness .The model was also studied for variation of peak contact stresses for a ceramic and a metallic implant.
4. A 3D model of the acetabular cup and the femoral head was modeled and the loads were applied using gait pattern. The peak contact stress for an instance is verified for PCD on PCD implant and a good agreement was obtained.
5. The 3D model was then modeled with Metal-Ceramic FGM and the contact stresses were obtained for all gait instances. The variation of peak contact stresses with gait cycle for metallic and FGM coated implant was then studied.
6. The cumulative linear wear was estimated for both metallic and FGM coated implants using Archard equation discretized within nodal points. The wear plot is generated using cumulative linear wear at each node and at each instant of the gait cycle and the wear progression is visualized for both metallic and FGM coated implants.
7. The total wear which is the sum of all nodal cumulative linear wear is obtained at each instance and studied for both metallic and FGM coated implant.
8. The total wear is obtained after 1 year or 10^6cycles for both the implants and was found that FGM implants wear 61% less than the metallic implant

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