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The Analysis of Wear on Artificial Hip Joint with Dimple on Femoral Surface

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Abstract. This paper proposes the replacement of artificial hip joints which is one of the successful methods used to restore the movement of damaged hip bones. The main contribution of this work is to reduce wear caused by contact pressure between the femoral head and acetabular cup surfaces, where the average wear rate is very high. This can be achieved through the use of dimple on the femoral head surface from the artificial hip joint and subsequently computed by using the *Archard equation*. To validate the contact pressure accuracy of the proposed model, mesh sensitivity that used with 3 levels of mesh size are 1.2, 1.1 and 1.0. In this study for more accurate result, the mesh sensitivity used is with the mesh size of 1.0. The performance calculation results from wear are shown that in a hip joint using dimple the maximum contact pressure and the wear depth are decreased compared to the hip joint without dimple which are 67.25 MPa and 1.064×10^{-10} mm from the previous value of 77.44 MPa and 1.185×10^{-10} mm. Therefore, based on differences in the distribution of contact pressure that occurs shows volumetric wear on the hip joints using a dimple lower than without a dimple.

Keywords: artificial hip joint, dimple, contact pressure, wear volume, wear depth

1. Introduction

The replacement of artificial hip joints is a successful bone replacement surgery in the world of health, hip joint replacement is a method used to restore the movement of the hip joint. Although it has been said to be successful, the results after replacement of these bone connections will depend on several factors such as the patient's condition, implant, and surgeon. Based on the database of The Nordic Arthroplasty Register Association shows that there is an increase in revision surgery every 2, 5, 10 to 15 years after primary surgery [1]. Therefore, a factor that can be improved in engineering science is the implant factor either from the design part or from the material part as an example the addition of dimple on the femoral head surface without lubrication can reduce contact pressure and wear with an elliptical dimple can increase lubrication performance [2]. Materials commonly used for hip bone implants are metal femoral heads against polyethylene acetabular cup, but there is a lack of wear and tear which is



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caused by wear debris polyethylene which can develop on the articulation surface resulting in osteolysis [3]. So to avoid the occurrence of wear debris, the use of new material that is metal-on-metal at the turn of the hip joint. Metal-on-metal materials in the 1970s suffered a lot of failures due to high friction and wear, but for the next generation it has been shown that the development of designs such as surface texturing can reduce wear and improve the life of hip joints [4]. As an alternative, a new generation of metal-on-metal (MOM) bearing material has a lower volumetric wear [5]. However, with the use of new alternative materials will produce new problems due to small metal wear particles that affect the body condition. The metal wear particles on the MOM pads are cobalt ions, and the nanometer-sized chromium [5], is very easily absorbed by body tissue, so that it can spread to other organs [6]. Particles and metal ions can spread to the organs through blood, potentially harmful effects on the human immune, reproduction, nervous system and the kidney organs [7]. Reducing wear and friction is important in the application of artificial hip joints. With the addition of textures to the surface of the bearings such as a micro-dimple, this can increase the loading capacity of the material, and wear resistance [8]. The dimple-bearing surface produces a lower wear rate than the non-creaked surface, due to the reduced surface contact area, reduce the coefficient of friction and decrease the contact pressure between the surfaces.

2. Materials and Method

The artificial hip joint 3D models were made using *Solidworks 2014* and consist of two components, the femoral head and the acetabular cup. The bearing dimension of artificial hip joint obtained from a previous study. The diameter of the femoral head, clearance, and cup thickness is 28 mm, 50 μm and 5 mm respectively [6]. The radius of dimple is 1 mm and the depth of dimple is 0,5 mm. The position of the dimple is located at the center point of the surface of the femoral head. The materials used in this simulation are metal-on-metal that made from composite material cobalt (Co), chromium (Cr) and molybdenum (Mo) which is assumed to be linear elastic and homogeneous. The properties of the material obtained from the book study of handbook material [9], with 210 GPa elasticity modulus, poisson ratio 0.3, and material density of 8300 kg/m^3 .

The limits and problems of this research are taken with normal movement patterns, then used as a reference for the imposition on the normal movement patterns as daily activities conducted after total hip replacement surgery. In general, simulations in normal conditions with vertical load, horizontal load and diagonal load. The loading cycle when normal conditions are seen in figure 1 [10].

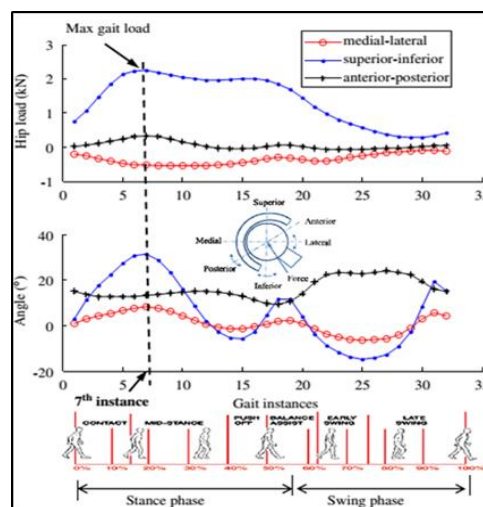


Figure 1. Gait load of a normal walking cycle

Along with the development of science and technology, the use of software in computers to simulate wear began to be developed, especially on the model [11]. Archard put forward a phenomenal model to explain about sliding wear. In the model, it is assumed that the critical parameters in the sliding wear are the contact pressure and the sliding distance between the contact surfaces. By equation [11]:

$$V_w = K \cdot \frac{F_N}{H} \cdot S \quad (1)$$

The wear coefficient K is a constant provided to match the calculation between theory and test. Often, from formula (1) it is easier to write by dividing both sides by contact area A and by substituting K/H with K_w , then:

$$V_w = K \cdot F \cdot S \quad (2)$$

Sometimes the value of F in the above equation is modified to the value of P , aims to find W_l that is the depth of linear wear. The wear coefficient of Cobalt Chromium Molybdenum (Co-Cr-Mo) material is based on laboratory test of metal (Co-Cr-Mo)-on-metal (Co-Cr-Mo) of $0.5 \times 10^{-8} \text{ mm}^3/\text{Nm}$ (running-in) and $0.15 \times 10^{-8} \text{ mm}^3/\text{Nm}$ (steady state) [12].

Three-dimensional models of an artificial hip joint were made using *Solidworks 2014* software. The models consist of the acetabular cup and the femoral head with dimple and without dimple. The design are created based on the data obtained from the references. The modeling design that were created in dry or no lubrication condition to be simulated using *Abaqus / CAE 6.14-1*. Then, from both of these models, the samples of the femoral head without dimple and using dimple will be simulated to know the contact pressure that occurs on the acetabular cup.

The 3D model of femoral head made in the form of semi-circular 3D because the model is assumed based on the literature shown in Figure 2.

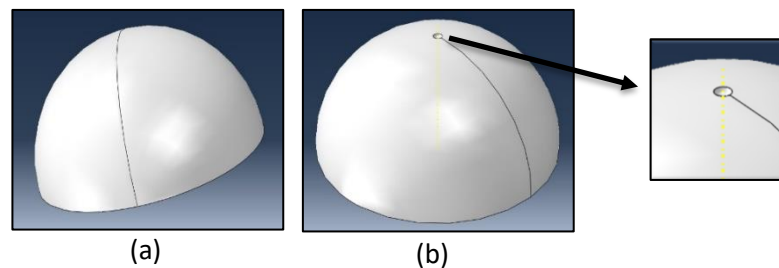


Figure 2. A model of the femoral head (a) without dimple and (b) with dimple.

The 3D modeling of the acetabular cup is a geometry that represents the sample form of the hip joint based on the dimensions already obtained from the literature. There is only one model because the acetabular cup used at each hip joint without dimple or using dimple are same as in Figure 3.

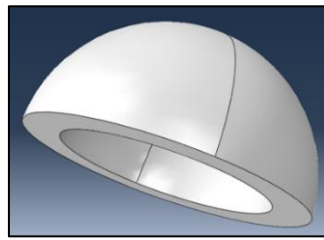


Figure 3. A 3D model of the acetabular cup.

2.1. Meshing the model

The meshing model applied for the completion of the model, should first be done in convergent studies (mesh sensitivity). This convergent study is very important in order to minimize the time to complete the finite element model because it will get an effective mesh for the model. Usually the greater the meshing element used, the results obtained will be more accurate and stable.

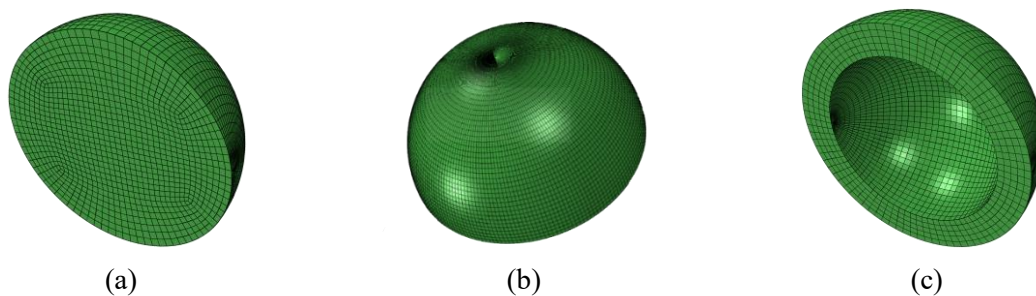


Figure 4. Meshing model of the hip joint (a) femoral head without dimple (b) femoral head with dimple (c) acetabular cup

3. Result and Discussion

The results of the simulation process when the femoral head and acetabular cup are frictioning together will be divided into two parts, the first is the model simulation results of the hip joint 3D without dimple and the second is the simulation results of hip joint 3D modeling with the addition dimple on the femoral head surface.

The result of the simulation model by using the comparison of mesh sensitivity test can be seen that the more elements used, the simulation result will also be more accurate and stable. Noticeable in this graph of Figure 5.

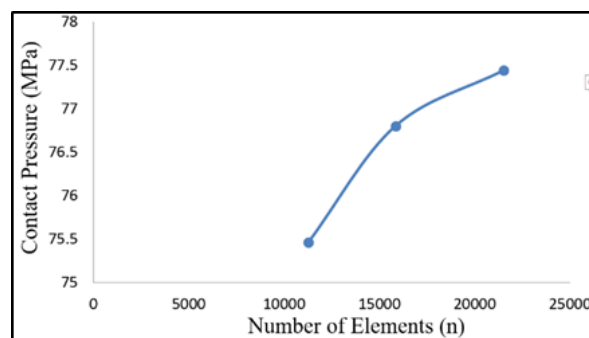


Figure 5. Comparison of maximum contact pressure to mesh sensitivity difference without dimple.

It can be seen that the value of contact pressure to the difference of the number of elements, where the maximum contact pressure in a mesh size 1.2 with the number of elements 11288 is 75.46 MPa, then the maximum contact pressure in a mesh size 1.1 with the number of elements 15860 is 76.8 MPa, while the maximum contact pressure in a mesh size 1.0 with the number of elements 21536 is 77.44 MPa. Then by using a mesh size 1.0 with the number of elements 21536 then obtained the result of the overall contact pressure from phase 1 to phase 32. Noticeable in Figure 6.

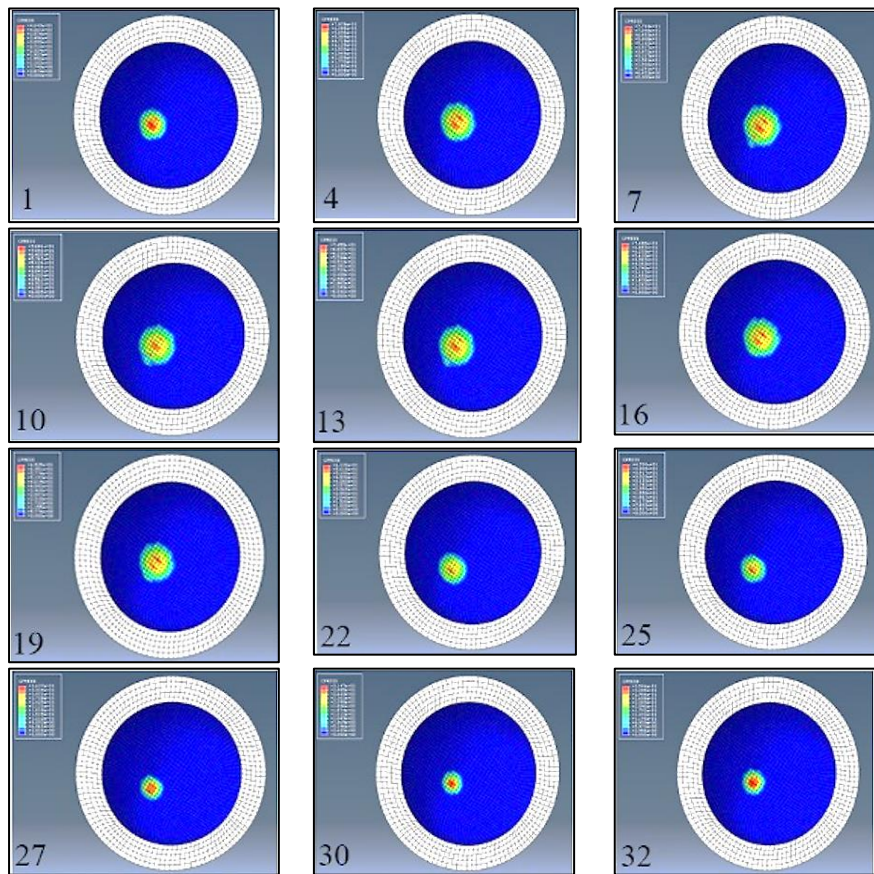


Figure 6. Distribution of contact pressure without dimple on the acetabular cup from phase 1 to phase 32.

Then, on the hip joint geometry using dimple also performed comparative sensitivity testing mesh, can be considered in Figure 7. The result above is the amount of contact pressure value from difference number of elements, where the maximum contact pressure in a mesh size 1.2 with the number of elements 8346 is 66.98 MPa, then the maximum contact pressure in a mesh size 1.1 with the number of elements 12494 is 67.18 MPa, while the maximum contact pressure in a mesh size 1.0 with the number of elements 15846 is 67.25 MPa. By using a mesh size of 1.0 with the number of elements 15846 then the result of the overall contact pressure from phase 1 to 32 are shownn in Figure 8.

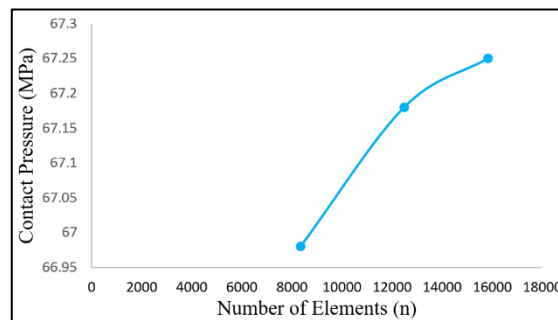


Figure 7. Comparison of maximum contact pressure to mesh sensitivity difference without dimple

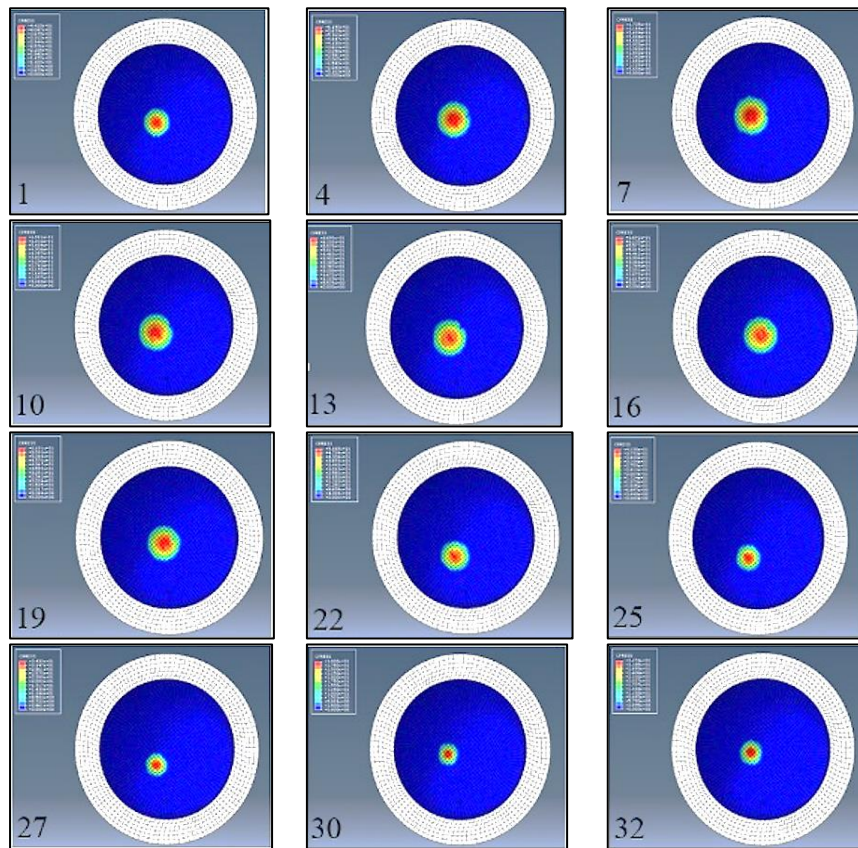


Figure 8. Distribution of contact pressure using dimple on the acetabular cup from phase 1 to 32.

The results of the simulation mainly of contact pressure is reduced and decreased as a result of the addition dimple geometry on the femoral surface. This is because, with dimple, the area of surface contact will also decrease. This is evidenced by the maximum surface contact pressure dimple of 67.25 MPa, then compared with the surface without dimple is 77.44 MPa.

The results of the simulation mainly of contact pressure is reduced and decreased as a result of the addition dimple geometry on the femoral surface. This is because with dimple, the area of surface contact will also decrease. This is evidenced by presence of dimple, the maximum surface contact pressure is 67.25 MPa, then compared with the surface without dimple is 77.44 MPa. Noticeable in Figure 9.

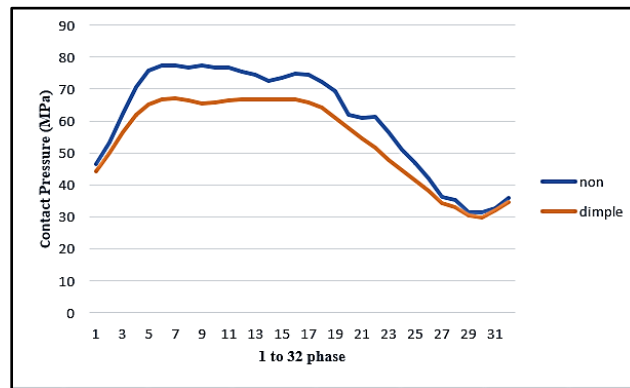


Figure 9. The comparison of contact pressure using dimple and without dimple on the acetabular cup from phase 1 to 32

The wear depth occurring between the hip joint without dimple and hip joint using dimple has different values from each other, this is due to the difference in the value of the contact pressure (P). The equations used are derived from the *Archard equation* [11]. With the addition dimple on the surface of the femoral head then the area of contact occurs will decrease, hence the result of the contact pressure value that occurs between two surfaces will also decrease from before. The percentages comparison of hip joint wear depth without dimple and using dimple can be seen in figure 10.

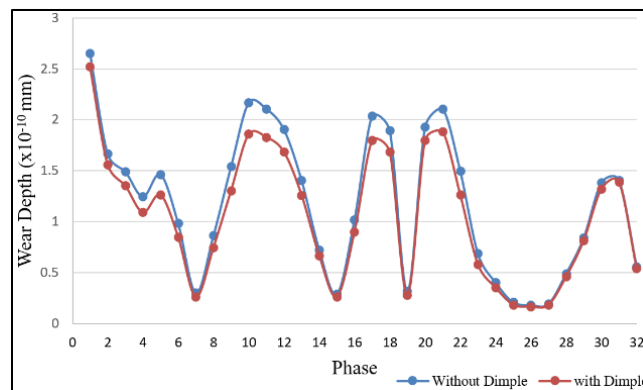


Figure 10. The comparison of wear depth between hip joint without dimple and hip joint using dimple

In the hip joint without dimple, the average value of the average wear depth of all phases is 1.18499×10^{-10} mm. While on the hip joint using dimple, the value of the average wear depth of the whole phase is 1.06401×10^{-10} mm. Therefore, the percentage comparison of the average wear depth is 10.21%. This is due to the different values in the contact pressure of each phase, either hip joint without dimple or hip joint that uses dimple.

4. Conclusions

This paper presents a study the effects of dimple on wear volume and the depth of wear on artificial hip joints has been successfully investigated. The following are the key conclusions drawn from the study:

1. The maximum contact pressure on the hip joint using dimple is 67.25 MPa, while the maximum contact pressure on the hip joint without dimple that is 77.44 MPa. Using dimples produce lower maximum contact pressure.
2. The volumetric wear on hip joint using dimple is lower than without dimple that indicate the distribution of contact pressure significantly different.
3. The wear depth that occurs between the hip joint without dimple and hip joint using dimple has different value results of 1.18499×10^{-10} mm and 1.06401×10^{-10} mm with the percentage comparison of the average of depth wear is 10.21%.

References

- [1] E. N. Glassou *et al.*, “Association between hospital procedure volume and risk of revision after total hip arthroplasty: A population-based study within the Nordic Arthroplasty Register Association database,” *Osteoarthr. Cartil.*, vol. 24, no. 3, pp. 419–426, 2016.
- [2] H. Basri *et al.*, “The Analysis of Dimple Geometry on Artificial Hip Joint to the Performance of Lubrication,” *J. Phys. Conf. Ser.*, vol. 1198, p. 042012, 2019.
- [3] E. Ingham and J. Fisher, “The role of macrophages in osteolysis of total joint replacement,” *Biomaterials*, vol. 26, no. 11, pp. 1271–1286, 2005.
- [4] D. Dowson and Z. M. Jin, “Metal-on-metal hip joint tribology,” *Proc. Inst. Mech. Eng. Part H J. Eng. Med.*, vol. 220, no. 2, pp. 107–118, 2006.
- [5] M. Topolovec, A. Cör, and I. Milošev, “Metal-on-metal vs. metal-on-polyethylene total hip arthroplasty tribological evaluation of retrieved components and periprosthetic tissue,” *J. Mech. Behav. Biomed. Mater.*, vol. 34, pp. 243–252, 2014.
- [6] L. Gao, P. Yang, I. Dymond, J. Fisher, and Z. Jin, “Effect of surface texturing on the elastohydrodynamic lubrication analysis of metal-on-metal hip implants,” *Tribol. Int.*, vol. 43, no. 10, pp. 1851–1860, 2010.
- [7] G. M. Keegan, I. D. Learmonth, and C. P. Case, “Orthopaedic metals and their potential toxicity in the arthroplasty patient: A review of current knowledge and future strategies,” *J. Bone Joint Surg. Br.*, vol. 89, no. 5, pp. 567–573, 2007.
- [8] Q. Meng, L. Gao, F. Liu, P. Yang, J. Fisher, and Z. Jin, “Contact mechanics and elastohydrodynamic lubrication in a novel metal-on-metal hip implant with an aspherical bearing surface,” *J. Biomech.*, vol. 43, no. 5, pp. 849–857, 2010.
- [9] N. A. Peppas, *Handbook of Biomaterial Properties*, vol. 65, no. 3, 2002.
- [10] M. S. Uddin and L. C. Zhang, “Predicting the wear of hard-on-hard hip joint prostheses,” *Wear*, vol. 301, no. 1–2, pp. 192–200, 2013.
- [11] J. F. Archard, “Contact and rubbing of flat surfaces,” *J. Appl. Phys.*, vol. 24, no. 8, pp. 981–988, 1953.
- [12] F. W. Chan, J. D. Bobyn, J. B. Medley, J. J. Krygier, and M. Tanzer, “Wear and lubrication of metal-on-metal hip implants,” *Clin. Orthop. Relat. Res.*, no. 369, pp. 10–24, 1999.