Advanced Materials Research
ISSN: 1662-8985, Vol. 1123, pp 196-200
doi:10.4028/www.scientific.net/AMR.1123.196
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Submitted: 2014-08-24
Revised: 2015-04-04
Accepted: 2015-04-06
Online: 2015-08-26

The Effect of the Wall Thickness on Wear of an UHMWPE Acetabular Liner

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Keywords: artificial hip joint, acetabular liner, thickness, wear, contact stress

Abstract. A larger diameter of femoral head of artificial hip joint (AHJ) is commonly recommended for increasing range of motion (RoM) and for avoiding dislocation. Unfortunately, increasing that diameter will reduce the material liner thickness of the acetabular component. The behaviour of the AHJ contact system with thickness variation of the Ultra High Molecular Weight Polyethylene (UHMWPE) acetabular liner was studied numerically and experimentally. Finite element analysis was employed for calculating contact stresses and the wear volume was measured experimentally. Numerical results show higher contact stresses with decreasing liner wall thickness. Yet, the experimental results suggest that wear decreases as well with decreasing wall thickness. These findings are important in designing an optimised acetabular liner for larger RoM.

Introduction

Wear of total hip arthroplasty remains one of the most challenging and unsolved problems in tribology. The ideal bearing surface for total hip arthroplasty has therefore received much attention. Research on polyethylene bearing surface has been initiated by Sir John Charnley [1]. Since his introduction, the development of new highly wear resistant materials for the artificial hip joint (AHJ) is progressing, see e.g. the work of [2] on polymer surfaces or the work of [3] on ceramics. The effect of the range of motion on wear however, has received limited attention. An important example of human activity, where the range of motion causes wear related problems is Shalat, a religious activity for Moslems. Some activity in Shalat contains an extreme movement which could only be limitedly practiced by total hip arthroplasty (THA) patients.

Research on the development of artificial hip joint for Shalat has been initiated. The research was started by studying the movement of Western style and Japanese style activities on the AHJ [4], by a numerical study on the effect of Shalat movement on wear of the AHJ [5] and by studying the effect of impingement on plastic deformation of Ultra High Molecular Weight Polyethylene (UHMWPE) components due to repetitive movement in Shalat [6]. Evaluation of the design and prototype of the AHJ is performed in order to allow for Shalat releated movement of AHJ patients. In the previous research [5, 6] it was shown that the range of motion (ROM) can be increased and the risk on dislocation during Shalat movement can be reduced by enlarging the diameter of the femoral head component. This implies a decrease in the thickness of the acetabular liner as the diameter of the entire system of the AHJ cannot be changed easily. Reduction in the thickness of the acetabular liner could possibly affect the load bearing capacity, wear behaviour and contact stresses of the AHJ. This paper studies the effect of wall thickness on the overall wear of UHMWPE acetabular liner of the AHJ system. The contact stress distribution is also part of the evaluation.

Method

Wear behavior as a function of the thickness of the UHMWPE acetabular liner was measured experimentally while the stress and the contact pressure that occur at the contact between the metal femoral head and the UHMWPE acetabular liner was calculated using a commercial finite element based software. The wear testing was conducted using a hip joint simulator with single axis motion. A load of 245 N was applied for the test. The UHMWPE acetabular liner specimen has the size of the inner diameter of 28 mm with the thickness variation of 10 mm and 14 mm, see Fig. 1(a). This geometry is often used for the AHJ patients in Indonesia. Fig. 1(b) shows the position of the UHMWPE acetabular liner specimen positioned at the holder of the hip joint simulator equipment. The wear experiments were performed for 50 thousand cycles (one cycle is one movement of the hip joint simulator so that the position is back to the initial one). The wear data was taken for every 10 thousand cycles. Due to the very small amount of wear, the wear was measured by its weight loss. Using the density of the UHMWPE, the wear is then represented in volume.

(a) (b)

Fig. 1. (a) The two thickness variation of the UHMWPE acetabular liner specimens and (b) the specimens of (a) when it is installed in the holder.

The finite element analysis software ABAQUS was employed for calculating the contact stresses and the von Mises stress of the contact between the femoral head and the acetabular liner. In this model the geometries of the contact system use the same geometries as of the experimental testing. Material property of the femoral head was assumed to be a rigid. The UHMWPE acetabular liner was a deformable material with the yield stress of 25.2 MPa, the elastic modulus of 893 MPa and the Poisson's ratio of 0.44. A static load of 245 N, the same load for the experiment, was applied to the femoral head. Fig. 2 shows the finite element contact model of the femoral head and the acetabular liner.

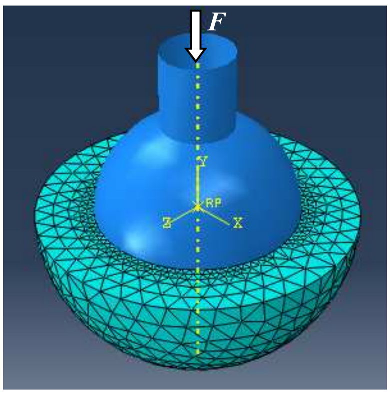

Fig. 2. The finite element contact model between the femoral head and the acetabular liner.

Results and Discussion

Fig. 3 depicts the results of the wear of the UHMWPE acetabular liner as a function of the cycle test for the two variation of the acetabular liner thickness. The wear volume measured experimentally for system with the thicker acetabular liner (14 mm) was greater than the wear volume measured for the system with the thinner one (10 mm). The femoral head is kept constant of 28 mm diameter. Results of finite element analysis of the contact system are presented in Fig. 4 and 5. Fig. 4 shows the distribution of the von Mises stress (top view) of the two different acetabular liner thicknesses. The maximum value for the contact stress and the von Mises stress is depicted in Fig. 5.

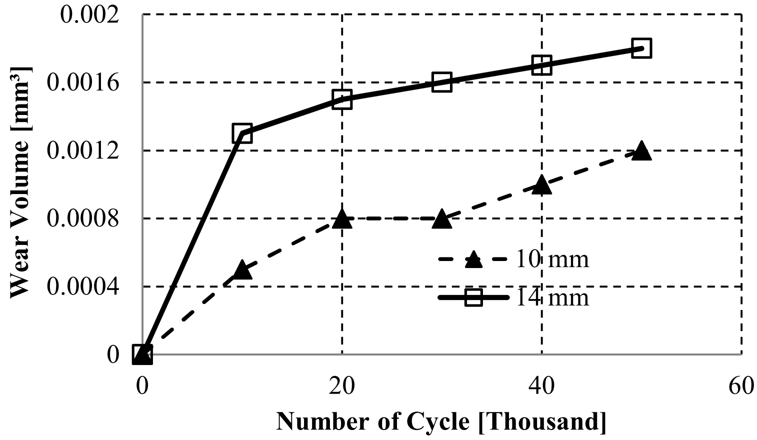

Fig. 3. The volumetric wear of the UHMWPE acetabular liner with varying wall thickness (▲ for 10 mm and □ for 14 mm).

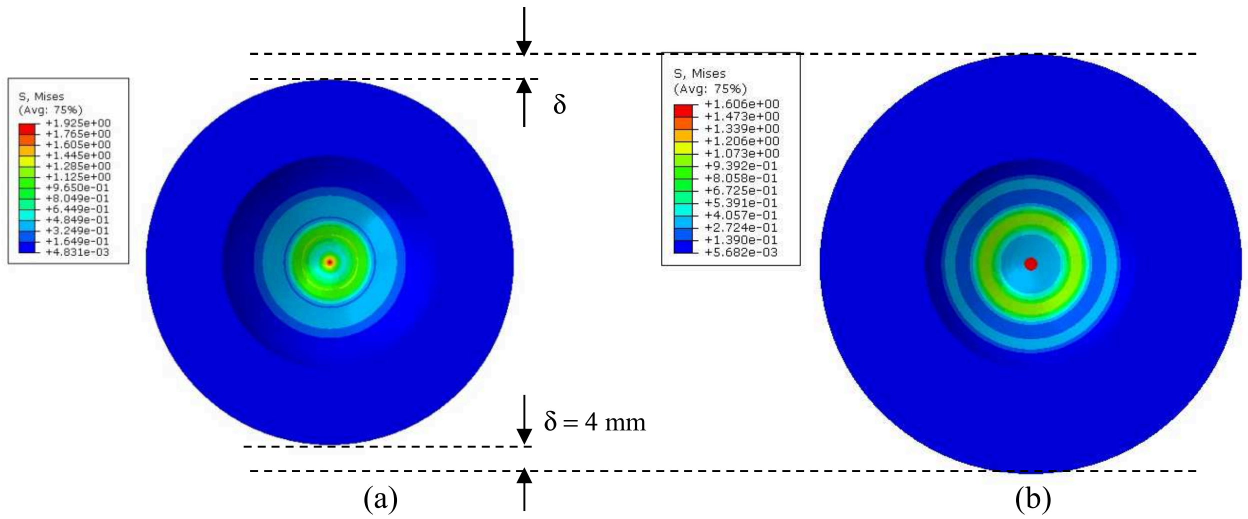

Fig. 4. The von Mises stress distribution of the UHMWPE acetabular liner (top view) for the thickness of: (a) 10 mm and (b) 14 mm.

The experimental investigation reported that the wear volume measured for the test piece of the thinner liner was lower than the thicker one. This finding is consistent with result of the previous researchers [7-9]. When the specific wear rate is assumed to be constant, according to the Archard wear equation the wear volume is directly proportional to the sliding distance and the mean contact pressure. Here, from the finite element analysis the maximum contact stress value for the thinner acetabular liner is higher than the thicker one but the wear volume for the thinner acetabular liner is lower than the thicker one. These phenomena may be caused by the contact area of the tribological system. The smaller contact area will lead to a small area of sliding, and as a result the wear volume will be smaller for the same specific wear rate. The smaller contact area for the thinner acetabular liner was also reported by [9].

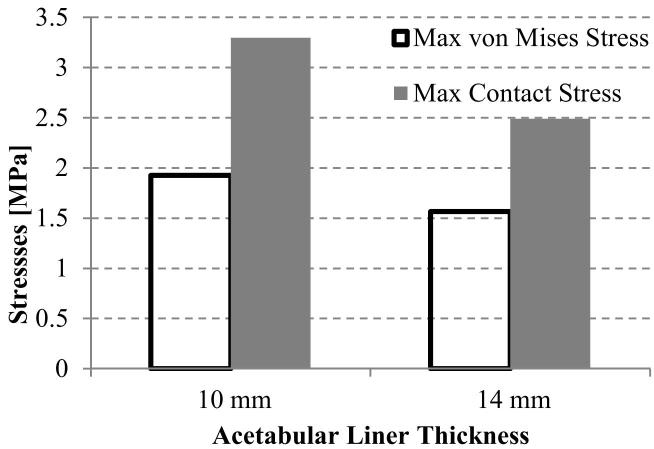

Fig. 5. The maximum of von Mises and contact stresses distribution of the acetabular liner.

Conclusion

The behaviour of the AHJ contact system with the thickness variation of the UHMWPE acetabular liner was studied numerically and experimentally. The finite element analysis was employed for calculating contact stresses and the experiment was performed for measuring wear volume. Results show that the higher contact stresses were for the lower liner thickness. However, the experimental investigation reported that the volumetric wear of the thinner liner is lower than the thicker one. The contact area seems to be the dominant factor in determining the volumetric wear. The smaller contact area will lead to a small sliding area so that the wear will be smaller for keeping other factors constant. This phenomenon is interesting to be explored since by reducing the contact area will increase the mean contact pressure, and the mean contact pressure is proportional to the wear.

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Advanced Materials Science and Technology II
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