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The Investigation of Micro-Dimpled Metal on Plastic Interface for Artificial Hip Replacement

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ABSTRACT

Surface texturing by fabricating micro dimple on a surface have been proven to be very effective to improve tribological performances of sliding surfaces. Studies and research shown that micro-dimple reduced friction coefficient significantly and increase the service life of artificial hip replacement. This study aim to investigate and to compare the wear factor between four different micro-dimpled dimensions which comprise diameter, depth and pitch. The main objectives are firstly to determine parameter to fabricate micro-dimple surface, secondly to optimise surface micro-dimple pattern and finally to determine surface characterisation. Four samples have been chosen with different dimple parameter. In this experiment, pin-on-plate wear test machine was used. The result shown that wear factor at the pin for pattern 1 (1.53905×10^{-6} mm^3/Nm), pattern 2 (1.50764×10^{-6} mm^3/Nm) and pattern 3 (1.61234×10^{-6} mm^3/Nm) were compatible with result done at the same test rig at Newcastle University, where else result for pattern 4 (3.66440×10^{-6} mm^3/Nm) slightly off for varies reasons. On the other hand, there are no significant mass loss at the plates although the surface roughness of the plates have record changes. Conclusion from the experiment is wear factor from less dense micro-dimple is lower than wear factor in denser micro-dimple.

1.0Introduction

Surface texturing by fabricating micro dimple on a surface have been proven very effective to improve tribological performances of sliding surfaces (Ito *et al.*, 2000; Borghi *et al.*, 2008; Amanov *et al.*, 2012; Fan *et al.*, 2014; Choudhury *et al.*, 2015a). Several studies have documented the benefit of micro-dimpled on a sliding surfaces (Chyr *et al.*, 2014; Roy *et al.*, 2015). These benefit can be implemented in improving tribological properties in mechanical seals, load carrying capacity in journal of bearings, surgical blades and most importantly in artificial hip replacement in orthopaedic surgery (Ito *et al.*, 2000; Young *et al.*, 2011; Gupta *et al.*, 2013; Velasquez *et al.*, 2013).One of the most important benefit in applying micro-dimple on a surface is in artificial hip replacement. Studies and research shown that micro-dimple reduced friction coefficient significantly and increase the service life of artificial hip replacement (Borghi *et al.*, 2008; Sawano *et al.*, 2009).

The main aim of this study is to investigate and to compare the wear factor between four different micro-dimpled dimensions which comprise diameter, depth and pitch.

The main objectives of this study are:

i. To determine parameter to fabricate micro-dimple surface

ii. To optimise surface micro-dimple pattern such as diameter, pitch and depth

iii. To determine surface characterisation.

2.0 Methods

2.2.1 Pin-on-plate wear test machine

There are a lot different test exist to measure friction and wear that replicate the contact between artificial hip joint.

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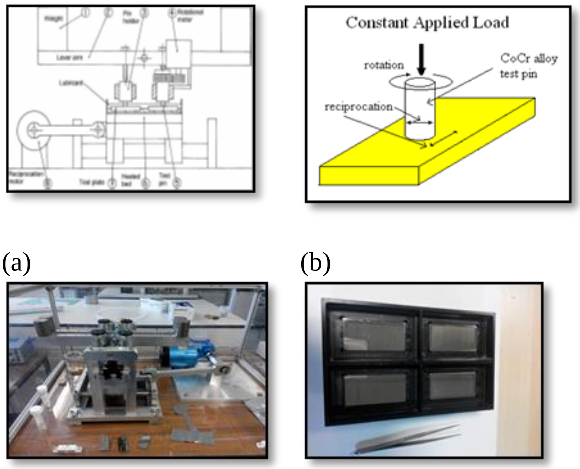
The pin-on-plate wear test machine were employed for this experiment at School of Mechanical Engineering, Newcastle University. Throughout the experiment, a constant load of 40 N applied to each pins with a 28 mm total travel. This load equal to 1.4 MPa contact stress which replicate the contact stress in artificial hip joint (Joyce, 2009). The frequency of the linear and angular movement was set to 1 Hz.

Pin-on-plate wear test machine replicate a hip joint, in term of contact pressure, speed and lubrication. **Figure 1 (a)** shows the schematic diagram of the wear test machine, **Figure 1 (b)** shows the samples movement at wear test machine, **Figure 1 (c)** Illustrating the machine at Newcastle University Laboratory and **Figure 1 (d)** shows how the samples is placed at the wear test machine.

Before the test was carried out, the samples and its holder was cleaned properly to make sure that no foreign object which will affect the experiment. After that, the specimen is weighted to take the initial mass. The specimens were weighted again after the experiment to determine mass loss of the pins and plates.

The test was carried out for 120 hours and every 60 hours the test was broken down and pins and plates was taken out from the machine to measure the weight to monitor the progress of the experiment. This procedure was done in order to determine the rate of wear of the pins and the plates. **Table 1** shows the experiment parameters.



(c) (d)

Figure 1.(a) Pin-on-plate wear test machine schematic diagram (Joyce, 2009) (b) Pin and plate moving sequence (Charlton, 2011) (c) Pin-on-plate wear machine (d) Samples orientation in a machine.

2.2.2 Lubrication

A Bovine serum was used in this experiment because in most artificial hip replacement experiment, bovine serum is used as a lubrication medium because it is internationally recommended (Harsha and Joyce, 2011; Zhou *et al.*, 2011; Roy *et al.*, 2013; Choudhury *et al.*, 2015a). This lubrication is similar to natural lubrication inside the hip (Bell *et al.*, 2000; Harsha and Joyce, 2011). One hundred percent bovine serum was used in this experiment. This is equivalent to 52 g/l of protein (Joyce *et al.*, 2003).

2.2.3 Experiment parameter

The experiment parameters were chosen according to a simulated hip joint, defined in relations of contact pressure and lubrication. **Table 1** illustrated the experiment parameters that were chosen and used in this study.

Table 1. Experiment parameters.

Parameters	Value
Test machine setup	Pin-on-plate
Pin-on-disk stroke length	28 mm
Pins diameter	6.3 mm
Plate dimensions	25 x 50 x 2 mm^3
Pin diameter	6.3 mm
Rotational frequency	1 Hz
Linear frequency	1 Hz
Load	40 N
Experiment length	120 Hours (432000 strokes)
Type of lubrication	Bovine serum

3.0 Result

3.1 Result of parameter to fabricate micro-dimple surface

The wear test run for 120 hours which is equivalent to 24192 meter. Every 60 hours the test was broken down and pins and plates was taken out from the machine to measure the progress.

The result of the experiment is recorded by measuring the mass loss of the pin. After the mass loss was obtained, equation (1) was used to calculate the volume loss. The value of UHMWPE density = 953 kg/m^3 (Joyce, 2009). After the volume loss was calculated, equation (2) was used to calculated wear factor. In equation (2), sliding distance = 60 x 3600 x .056 = 24192 m and load = 40 N.

For the first 60 hours (12096 m) the mass loss for pattern 1 is 1.01 mg and the wear factor is 2.11488 x10^{-6} mm^3/Nm, the mass loss for pattern 2 is 0.74 mg and the wear factor is 1.54952 x 10^{-6} mm^3/Nm, the mass loss for pattern 3 is .72 mg and wear factor is 1.50764 x 10^{-6} mm^3/Nm and the mass loss for pattern 4 is 2.4 mg and the wear factor is 5.02547 x 10^{-6} mm^3/Nm.

In the second 60 hours the mass loss for pattern 1 is 0.46 mg and the wear factor is 0.963215 x10^{-6} mm^3/Nm, the mass loss for pattern 2 is 0.70 mg and the wear factor is 1.46576 x 10^{-6} mm^3/Nm, the mass loss for pattern 3 is .82 mg and wear factor is 1.71704 x 10^{-6} mm^3/Nm and the mass loss for pattern 4 is 1.1 mg and the wear factor is 2.30334 x 10^{-6} mm^3/Nm.

Overall result shown that pattern 4 has the highest wear factor (3.66440 x 10^{-6} mm^3/Nm), followed by pattern 3 (1.61234 x 10^{-6} mm^3/Nm), pattern 1 (1.53905 x 10^{-6} mm^3/Nm) and finally pattern 2 (1.50764 x 10^{-6} mm^3/Nm). The value were obtain after an average from two experiment (60 hours each) were taken. The complete value of mass loss, volume loss, wear factor and average wear factor is illustrated in **Table 2**.

$$\text{Volume loss, } v = \frac{mass\ loss\ (g)}{density\ (g/mm^3)} \quad (1)$$

$$\text{Wear factor, } k = \frac{volume\ loss\ (mm^3)}{Load\ (N)\ x\ sliding\ distance\ (m)} \quad \text{(Joyce, 2009)} \quad (2)$$

3.2 Result for surface micro-dimple pattern such as diameter, pitch and depth

3.2.1 Wear testing

The procedure conducted to pins, was also done to the plates. Every 60 hours (24192 meter) the plates was measured to determine the differences of mass. For the first 60 hours of experiment every plates recorded a mass gain. The pattern 1 was gaining 0.7 mg, pattern 2 gaining 0.2 mg, pattern 3 gaining 0.2 mg and pattern 4 gaining 0.05 mg. For the second 60 hour, Pattern 1 loss 0.2 mg, pattern 2 loss 0.17 mg, pattern 3 loss 0.5 mg and pattern 4 loss 0.25 mg.

Overall result pattern 1 gaining 0.25 mg, pattern 2 gaining .015 mg, pattern 2 losing 0.15 mg and pattern 3 losing 0.01mg.Mass loss or mass gain of the stainless steel plates are represented in **Table 3**. Mass gain is marked with positive (+) and mass loss is marked with negative (-) sign.

Table 2. UHMWPE mass loss, volume loss and wear factor.

Pattern	1st 60 hour			2nd 60 hour			Average wear factor (mm^3/Nm) (x 10^{-6})
	Mass loss (g)	Volume loss (mm^3)	Wear factor (mm^3/Nm) (x 10^{-6})	Mass loss (g)	Volume loss (mm^3)	Wear factor (mm^3/Nm) (x 10^{-6})	
1	0.00101	1068.783	2.11488	0.00046	486.7725	0.963215	1.53905
2	0.00074	783.0688	1.54952	0.00070	740.7407	1.46576	1.50764
3	0.00072	761.9048	1.50764	0.00082	867.7249	1.71704	1.61234
4	0.00240	2539.683	5.02547	0.00110	1164.021	2.30334	3.66440

The reason for some of the plates was gaining mass will be discussed in the next chapter.

Table 3: Stainless steel wear test result

Pattern	1st 60 hour Mass (-) loss/ (+) gain (g)	2nd 60 hour Mass (-) loss/ (+) gain (g)	Average
1	+ 0.00070	- 0.00020	+ 0.000250
2	+ 0.00020	- 0.00017	+ 0.000015
3	+ 0.00020	- 0.00050	- 0.000150
4	+ 0.00005	- 0.00025	- 0.000100

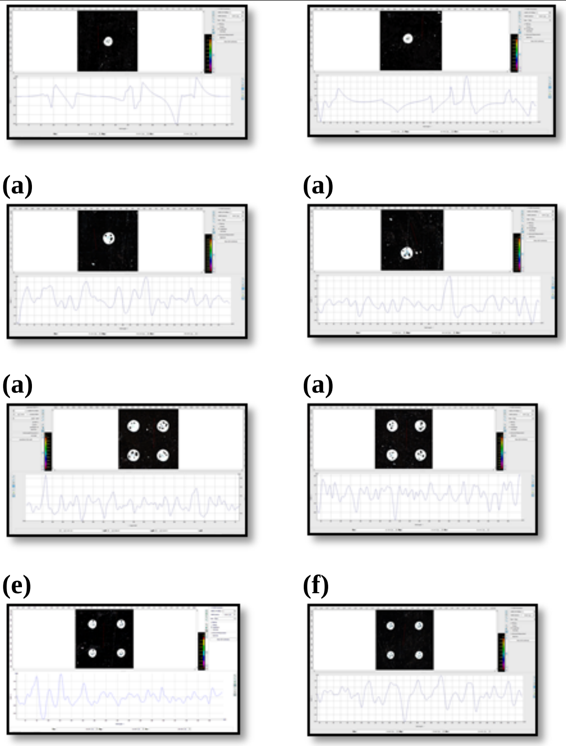
3.2.2 Dimple profile

Dimple profile was measured using 3D optical profiler (Zygo NewView™ 7300 non-contacting profilometer). The dimple profile before the experiment showing uniform and stable dimensions. After the experiment, the dimple profile are measured using Alicona non-contacting profilemeter.

The overall result shown that the dimple profile are between 7.61005 µm and 11.1569 µm. Pattern 3 recorded the highest dimple depth with the of 11.1569 µm. This was followed by pattern 4 (8.61495 µm), and then pattern 1 (8.46595 µm) and finally pattern 2 (7.61005 µm). The complete picture of surface roughness measurement in each location are illustrated in **Table 4.**

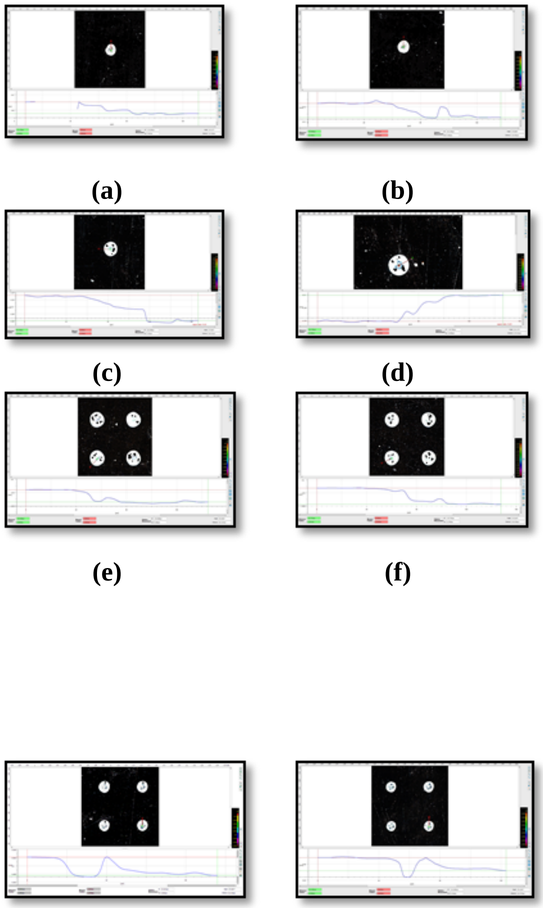
Table 4. Dimple profile.

Pattern	location	Dimple depth (µm)	Average depth (µm)
1	1st	7.5037	8.46595
	2nd	9.4282	
2	1st	7.1232	7.61005
	2nd	8.0969	
3	1st	9.9160	11.1569
	2nd	12.3978	
4	1st	9.0883	8.61495
	2nd	8.1416	



(a) (a) (a) (a) (e) (f) (g) (h)

Figure 2. Surface roughness analysis using Alicona non-contacting profilemeter after the experiment for pattern 1 (a) and (b), pattern 2 (c) and (d), pattern 3 (e) and (f), and pattern 4 (g) and (h).



(a) (b) (c) (d) (e) (f) (g) (h)

Figure 3. Dimple depth analysis using Alicona non-contacting profilemeter after the experiment for pattern 1 (a) and (b), pattern 2 (c) and (d), pattern 3 (e) and (f), and pattern 4 (g) and (h).

3.3 Result for surface characterisation.

3.3.1 Surface roughness

Before the experiment was conducted, Ra was measured using 3D optical profiler (Zygo NewView™ 7300 non-contacting profilometer). The surface roughness (Ra) of the samples was 0.007 µm, showing that the prepared samples have a very smooth surface. The surface roughness re-measured after the experiment. Two different location was measured in each sample. Surface roughness was analysed using Alicona non-contacting profilemeter.

The overall result shown that the surface plates roughness are between 50 nm and 70 nm. Pattern 2 recorded the highest roughness with the roughness is 69.00145 nm. This was followed by pattern 2 (60.1626 nm), and then pattern 1 (56.5962 nm) and finally pattern 4 (51.33475 nm). The complete picture of surface roughness measurement in each location are illustrated in **Table 5**. The surface roughness recorded by Alicona non-contacting profilemeter is presented in **Figure 2**.

Table 5. Surface roughness.

Pattern	Location	Surface Roughness, Ra (nm)	Average, Ra (nm)
1	1st	48.6188	56.5962
	2nd	64.5736	
2	1st	72.1231	69.00145
	2nd	65.8798	
3	1st	57.5923	60.1626
	2nd	62.7329	
4	1st	58.2871	51.33475
	2nd	44.3824	

4.0 Discussion

4.1 Wear factor

To investigate the average life of an artificial hip joint in wear testing machine, it is importance to determine the relationship between the life of the artificial hip joint and the wear amount of UHMWPE (Sawano *et al.*, 2009).

4.1.1 Pins

It was clear that from wear testing machine, samples with less dense micro-dimple produced lower volume loss as a result lowered the wear factor compared with more dense micro-dimpled.

This result is contradict with result published by (Fan *et al.*, 2014) which stated that tribological properties was improved in more dense micro-dimpled. Previous measurements from wear test machine at Newcastle University using the same test rig the wear factor were 1.6 x 10^{-6} mm^3/Nm (Joyce, 2009). The result shows that this work produces the same trend as that experiment except for pattern 4, where the wear factor more than double from other 3 patterns. This result mostly contributed because of the smaller dimple pitch and the depth of the dimples. For pattern 3 which has same pitch but shallower dimple pitch produced smaller wear factor. For pattern 1, pattern 2 and pattern 3 wear factor produced were constant result which are similar to standard result at Newcastle University test rig.

There are many factors that contributed to the difference for pattern 3. Human error, sample fabrication or machine error are can caused of such result. More test have to be done to identify the main and exact cause of the illustrated result.

4.1.2 Plates

There are no significant mass loss in plates after 120 hour of experiment. Even pattern 1 and pattern 2 are gaining some mass. This is because the UMHWPE wear debris trapped inside the micro-dimpled and it were contributing to the mass gained. The wear debris trapped inside micro-dimpled in pattern 1 and pattern 2 because dimple diameter, dimple depth and dimple pitch at those pattern were bigger than at pattern 3 and pattern 4. So, the probability of wear debris to trapped inside the micro-dimple were slightly higher.

This trend is parallel with statement made by Sawano *et al.* (2009) and Ito *et al.* (2000) where micro-dimpled provide an escape route for wear debris and at the same time prevent further damage to the surface of the plates. Although pattern 3 and pattern 4 has loss some mass, the different is too small (less than 0.2 mg). This trend can be concluded as no weight loss during the experiment pin-on-plate wear test machine.

4.2 Surface Roughness

Although UMHWPE is the softer material compared to stainless steel, the surface roughness of the plate were affected by sliding of the pins. Even though it was concluded that there was no change in mass of the plates, the surface roughness clearly becomes less smooth compared to the surface roughness before the experiment begins. Initially the surface roughness, Ra is just around 10nm. At the end of the experiment, the surface roughness become less smooth.

4.3 Dimple profile

The study has shown that the dimple depth has changed dramatically when it is compared to the depth before the experiment. This change is due to sliding effect caused by the pin effect during the wear test experiment. This makes the micro-dimpled become shallower and at the same time making the micro-dimple diameter smaller.

4.4 Study limitation

Every research has its own limitation and this study is not excluded. The limitations of this study are:

i. Pin-on-plate wear test machine replicates the movement of the prosthetic hip joint and there are no actual means to exactly replicate the real movement of the prosthetic hip joint. Although the data of pin-on-plate wear test machine can be used to determine the surface characteristic when designing artificial hip replacement, the machine cannot replicate the movement and dynamic loading of hip joint (Choudhury *et al.*, 2014). The actual way to know how this artificial hip joint work is by building the artificial hip replacement and perform the replacement surgery to the patient. Unfortunately, this method is time consuming and is potential in causing hazard to the patient.

ii. The experiment itself considers 4 different types of dimensions exclusively. Wider dimensions variable are needed before the conclusion can be made to determine the optimized dimension should be used as the surface characteristic of an artificial hip replacement.

iii. The length of experiment are only 120 hours which equal to 24192 meter. The length of the experiment should take longer hour to reduce the risk of bias and the possibility of debris obscuring the final result.

5.0 Conclusions

This study comprises of three major elements:

1. Determining the parameter of the micro-dimpled surface by reviewing the previous studies,
2. Fabricating the micro-dimpled surface using CNC micro machining, and
3. Conducting the pin-on-plate wear test to replicate prosthetic hip joint movement.

The wear factor of four samples with different pitch, diameter and depth were investigated using pin-on-plate wear test machine under 100% of bovine serum lubrication. The comparison between these four samples was made and from the experiment result, it can be established that:

i. Wear factor will increase in denser dimple. For example, in this experiment the wear factor is higher in samples with 0.5 mm pitch compare with samples with 1 mm pitch.

ii. Surface roughness of the samples is affected by the pins although the pins are softer material than stainless steel.

iii. It was difficult to control the micro-dimpled dimensions because of the difficulty to keep the samples 100% vertical during the machining process.

iv. Generally, the micro-dimpled dimensions used have produced stable results and does not differ much from the intended dimensions. The produced dimensions confirm that the CNC micro machining may use as a tool to produce micro-dimpled with reasonable accuracy.

6.0 Suggestions

To determine the optimized dimple dimensions and parameters further work are suggested to be tested in these areas:

i. Different dimple pitch, diameter and depth need to be tested in order to define the optimized parameter.

ii. The micro-dimpled specimen needs to be tested with longer cycle in a different frequency and stroke length.

iii. The lubrication also plays a significant role which affect the tribology performance, it is suggested that different lubrication or different lubrication viscosity can be used in future work.

7.0 Bibliography

Amanov, A., Cho, I.S., Pyoun, Y.S., Lee, C.S. and Park, I.G. (2012) 'Micro-dimpled surface by ultrasonic nanocrystal surface modification and its tribological effects', Wear, 286-287, pp. 136-144.

Bell, J., Besong, A.A., Tipper, J.L., Ingham, E., Wroblewski, B.M., Stone, M.H. and Fisher, J. (2000) 'Influence of gelatin and bovine serum lubricants on ultra-high molecular weight polyethylene wear debris generated in in vitro simulations', Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, 214(5), pp. 513-518.

Borghi, A., Gualtieri, E., Marchetto, D., Moretti, L. and Valeri, S. (2008) 'Tribological effects of surface texturing on nitriding steel for high-performance engine applications', Wear, 265(7-8), pp. 1046-1051.

Charlton, P. (2011) The application of ZEEKO polishing technology to freeform femoral knee replacement component manufacture. University of Huddersfield [Online]. Available at: http://eprints.hud.ac.uk/14062/1/Mr_Phillip_Charlton_PhD_Thesis_June_2011.pdf.

Choudhury, D., Ay Ching, H., Mamat, A.B., Cizek, J., Abu Osman, N.A., Vrbka, M., Hartl, M. and Krupka, I. (2015a) 'Fabrication and characterization of DLC coated microdimples on hip prosthesis heads', J Biomed Mater Res B Appl Biomater, 103(5), pp. 1002-12.

Chyr, A. (2014) Experimental study of using a patterned microtexture to reduce friction in prosthetic hip joints. University of Utah.

Fan, H., Hu, T., Zhang, Y., Fang, Y., Song, J. and Hu, L. (2014) 'Tribological properties of micro-textured surfaces of ZTA ceramic nanocomposites under the combined effect of test conditions and environments', Tribology International, 78, pp. 134-141.

Gupta, K.K., Kumar, R., Kumar, H. and Sharma, M. (2013) 'Study on Effect of Surface Texture on the Performance of Hydrodynamic Journal Bearing', International Journal of Engineering and Advanced Technology (IJEAT), 3(1).

Harsha, A.P. and Joyce, T.J. (2011) 'Challenges associated with using bovine serum in wear testing orthopaedic biopolymers', Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, 225(10), pp. 948-958.

Ito, H., Kaneda, K., Yuhta, T., Nishimura, I., Yasuda, K. and Matsuno, T. (2000) 'Reduction of Polyethylene wear by concave dimples on the frictional surface in artificial hip joints', The Journal of Arthroplasty 15(3).

Joyce, T.J. (2009) 'Wear tests of orthopaedic biopolymers with the biolubricant augmented by a visco-supplement', Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 223(3), pp. 297-302.

Malchau, H., Herberts, P. and Ahnfelt, L. (1993) 'Prognosis of total hip replacement in Sweden: follow-up of 92,675 operations performed 1978-1990', Acta Orthopaedica, 64(5), pp. 497-506.NHS (2015) Hip replacement. Available at:http://www.nhs.uk/conditions/Hip-replacement/Pages/Introduction.aspx (Accessed: 6/08/2015).

Patel, A., Pavlou, G., Mújica-Mota, R.E. and Toms, A.D. (2015) 'The epidemiology of revision total knee and hip arthroplasty in England and Wales', The Bone & Joint Journal, 97-B, pp. 1076–1081

Roy, T., Choudhury, D., Ghosh, S., Mamat, A.B. and Pingguan-Murphy, B. (2015) 'Improved friction and wear performance of micro dimpled ceramic-on-ceramic interface for hip joint arthroplasty', Ceramics International, 41(1), pp. 681-690.

Roy, T., Choudhury, D. and Pingguan-Murphy, B. (2013) 'The Effect of Micro Tools Fabricated Dent on Alumina/Alumina Oxide Interface', Pharmaceutical and Biomedical Engineering, 7(11).

Sawano, H., Warisawa, S.i. and Ishihara, S. (2009) 'Study on long life of artificial joints by investigating optimal sliding surface geometry for improvement in wear resistance', Precision Engineering, 33(4), pp. 492-498

Velasquez, T., Han, P., Cao, J. and Ehmann, K.F. (2013) ASME 2013 International Manufacturing Science and Engineering Conference collocated with the 41st North American Manufacturing Research Conference. American Society of Mechanical Engineers.

Young, L., Benedict, J. and Davis, J. (2011) ASME/STLE 2011 International Joint Tribology Conference. American Society of Mechanical Engineers.

Zhou, X., Galvin, A.L., Jin, Z., Yan, X. and Fisher, J. (2011) 'The influence of concave dimples on the metallic counterface on the wear of ultra-high molecular weight polyethylene', Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 226(6), pp. 455-462.