The Effect of The Machining Process UHMWPE on The Wear Behaviour of Acetabular Cups for Hip Implants

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ABSTRACT

Ultra High Molecular Weight Polyethylene (UHMWPE) has been consumed in human hip implants for the last decades. Improving the reliability of hip joint implants can reach by the understanding of wear behavior and morphology of the polyethylene. The purpose of this investigation was to determine the effect of the manufacturing process UHMWPE on the wear behavior of acetabular cups for hip implants. Tribological tests of UHMWPE acetabular liner on AISI 316L stainless steel femoral head were carried out with a tribometer test configuration in a dry condition. In this study, wear testing was examined with constant applied load of 800 N. The superficial injures that occured during the test were assessed by coordinate measuring machine (CMM) and roughness measurements. A correlation between the surface roughness from machining process and wear mass loss was assessed

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and discussed. Based on the results of the test data and observations on the specimens it can be concluded that the machining UHMWPE acetabular cups using milling CNC significantly affected the UHMWPE surface roughness developing its wear act, in terms of, the rate of wear depth and wear coefficient produced. The results show high linearity.

Keywords: *Acetabular Liner; Milling; UHMWPE; Wear; Surface Roughness*

Introduction

Total Hip Replacement (THR) has greatly upgraded the condition of life of patients influenced by hip osteoarthritis or rheumatoid arthritis. The replacement of the natural yet injured hip joint by an artificial appliance, common as the hip joint prosthesis is a clinical way extensively implemented in orthopedics with a outstanding success in the last decades [1]. The most commonly used prosthesis in hip implant design is a combination of metal femoral head articulates against a UHMWPE acetabular cup [2]. Implant malfunctions are often induced by wear and tear that affects permanent orthopedic implants [3] requiring revision surgery [4].

The wear behavior of hip implants rely on their surface condition, which is mostly created through the machining process chain. The scientifict works exhibits numerous reports attending either the impact of the manufacturing condition on the gained surface characteritics, or the perform of the surface characteristics on the existence of implant. Bruschi et al. [5] investigated the machining conditioning of Ti6Al4V acetabular cups for human hip implants and tested the wear in vitro using a commercial tribometer. The result shown that the implementation of multiple passes and the consumption of cryogenic cooling for reaching the ultimate contour of Ti6Al4V acetabular cups signify an raised strategy to acquire advanced wear performances. The effect of the surface quality of the implant pair on several types of materials such as MoM bearings [6] was also observed on the wear [7] and fatigue [8] resistance through in vitro tests.

The major challenge connected to wear is the production of debris, which can stimulate an extremely inflammatory biological response that can conduct to following contained periprostetic bone loss, and finally make a revision operation necessary [9]. For this reason, wear testing and wear analyses are thus still acting critical parts in development and research of hip joint designs for enhanced functioning and endurance before implantation. Hip simulator experiments have become an effective tool for fundamental investigation and for preclinical testing to minimize patient’s danger when accepting new implant types. A hip joint simulator is a device, which is employed to measure wear or tribological properties [10] of the biological prosthesis under simulating the biomechanics of hip human joints remarked in vivo, based on the gait of a typical patient.

Numerous reports have been achieved by researchers, engineers, and scientists to assess the involve the wear behavior of UHMWPE acetabular cups involving design, material, amount and type of protein lubricant, suitable implant positioning applying simulators, the applied force and the direction of motion. Niemczewska-wojcik [11] analyze the pattern of surface topography and wear mechanism at the following phases of operation activity. Trommer et al. [12] assessed the wear performance of non crosslinked UHMWPE articulating versus two metallic counterfaces, specifically stainless steel (SS) and cobalt chromium alloy (CoCr) by completing tests in a hip joint simulator. Several other researchers also use the hip joint simulator to analyze wear with various research parameters such as the type of simulator [13]-[14],daily life motions [15], implant material pairs [16]. The results showed that the wear behavior of the artificial hip joint was influenced by motion [17], loading [18], sterilization approach[19], and hip simulation test approach [20].

However, none of the aforementioned studies be found in the literature presented a clear specific machining UHMWPE for acetabular cup requirements to get good surface quality that of great importance in the wear behavior of the hip joint components. Therefore, the objective of the present research is aimed at investigating the influence of the machining process of UHMWPE on the wear bahavior of UHMWPE of biomedical interest for acetabular cup of artificial hip joint. To this aim, UHMWPE acetabular cups were machined under dry condition using CNC milling machine to obtain great surface roughness; afterwards, their wear actions under specifications imitating the ones feature of the human body was evaluated using an in vitro wear test. In this study, a hip joint simulator was used to test the wear on the acetabular liner. The wear of the UHMWPE acetabular liner was tested for 30,000 cycles with a constant loading of 800 N.

Material and Method

Specimens preparation steps using CNC milling

The acetabular liner specimens made from UHMWPE in this study were manufactured using a 3 axis CNC Milling machine type YCM 1020 EV 20 in dry conditions (without lubrication). The steps of the UHMWPE acetabular liner manufacturing process with a CNC Milling machine are shown through the flow chart in Figure 1. Based on the ASTM F2033-12 standard [21], acetabular cup products produced from the manufacturing process must have a roughness value below 2 micrometers, and dimensional accuracy in the range of +0.3 and -0.0. To achieve this standard, manufacturing optimization is carried out with cutting parameters in the form of toolpath strategy, spindle speed, feed rate, and step over [22]-[23]. Based on the optimization results obtained 3 samples that have the best level of surface roughness (Table 1). The 3 samples were then tested for wear to see the effect of the surface roughness level on wear behavior.

Table 1: Three samples of acetabular liner from machining process

Acetabular Liner	Surface Roughness (µm)	Accuracy Dimensions (mm)
Specimen 1	0.926	14.439
Specimen 2	1.161	14.470
Specimen 3	0.848	14.354

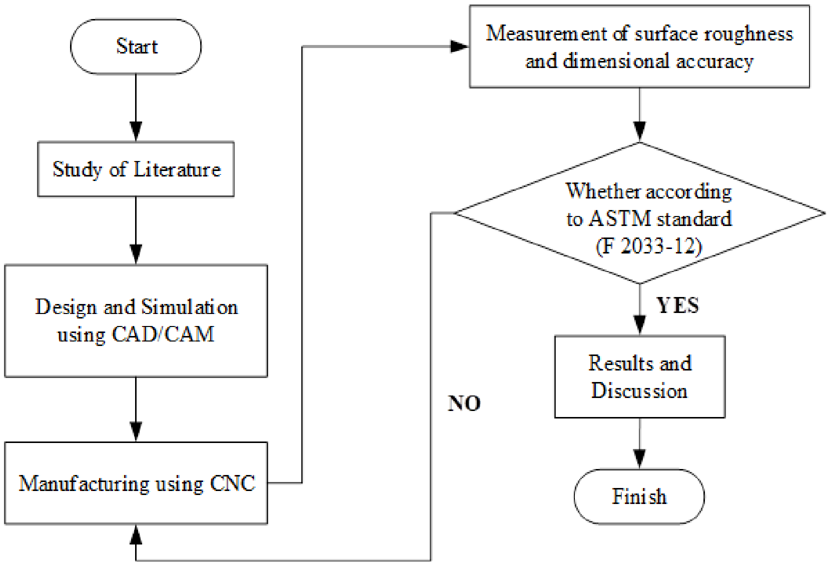

Figure 1: Acetabular liner manufacturing process using a CNC Milling machine

Sample measurement

UHMWPE acetabular liner products produced by the CNC Milling process are then measured for surface roughness and dimensional accuracy. Dimensional accuracy measurement is done using a coordinate measurement machine (CMM). Some researchers also use CMMs to measure wear on biomedical components such as hip and knee implants [24]-[25]. The surface roughness measurement was carried out using the Mark Surf PS1 surface roughness measuring instrument. Roughness measurement with this tool is carried out using a stylus with 3 repetitions of measurements for each point. From the measurement results, the average value is then taken. The results of measuring surface roughness and dimensional accuracy before and after the wear test are shown in a Table 2.

Table 2: The results of measuring surface roughness and dimensional accuracy before and after wear testing

Acetabular Liner	Surface Roughness (μm)			Accuracy Dimensions (mm)		
	Before	After	% different	Before	After	% different
Specimen 1	0.926	0.7756	16.24	14.439	14.331	0.75
Specimen 2	1.161	0.7182	38.14	14.470	14.134	2.32
Specimen 3	0.848	0.6786	19.98	14.354	14.228	0.88

Hip joint simulator test

The tribometer machine used to test the acetabular liner wear in this study is shown in Figure 2. The working principle of this machine is like the human hip joint, there is the femoral head which is an analogy of the human thigh bone and the cup which is the human pelvis. This test machine is made with a maximum load of 3000 N. According to Hua et al. [26] the resultant constant hip joint contact force is 2500 N which corresponds to about 70 kg for 3-4 times body weight.

The acetabular liner test parameters refer to the ISO 14242 standard, as well as previous studies [19][20][22][27] as shown in Table 3. The parameters tested are the number of cycles and loading. The ISO 14242 standard states that wear tests can be performed on cycles of up to 5 million cycles. Previous studies run between 1 to 5 million cycles [24]. In this study, the number of cycles given was different from previous studies. This study focuses on the influence of the UHMWPE machining process on acetabular liner wear. The amount of force on the acetabular liner is determined by the weight of the human body. In this study, an artificial hip joint was tested under a constant vertical load of 800 N on the counterbody which is considered to be an artificial hip joint receiving the burden of the entire human body. An average patient can be assumed to weigh 800 N [28].

Table 3: The acetabular liner test parameters

Specimens	Parameters	
	Load	Cycles
Specimen 1 Specimen 2 Specimen 3	800 N	30.000

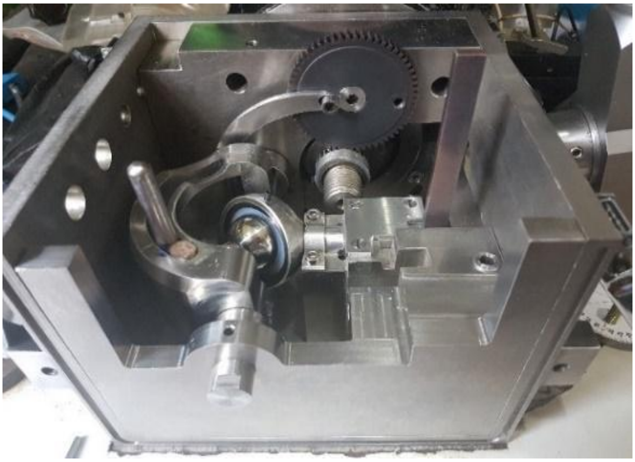

Figure 2: Tribometer machine

The specimens were tested up to 30000 cycles. All acetabular liners or cup samples were matched with AISI 316L stainless steel femoral head (28 mm) and encapsulated in specimen chambers. Prior to gravimetric measurement of wear, the acetabular liner and femoral head specimens were brushed with 70% alcohol using cotton to remain sterile. After wear examination, these activities were iterated under equal terms, and gravimetric wear was computed by the transform in mass. This test is carried out in dry conditions without using a lubricant, and the temperature chamber is not controlled but is measured periodically. The temperature of the room at this test is 20 °C. The experimental set-up for testing the acetabular liner made from UHMWPE is shown in the flowchart in Figure 3.

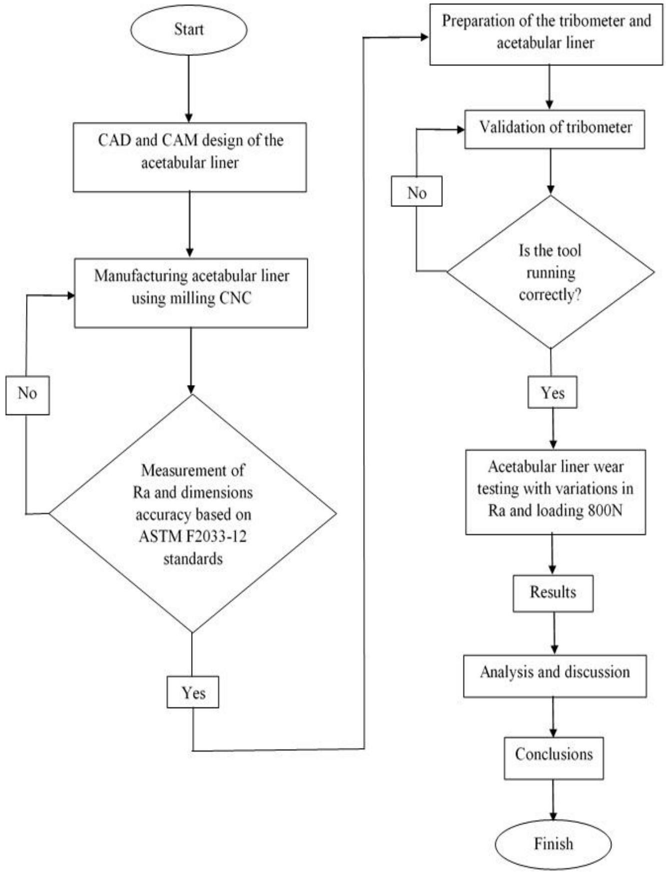

Figure 3: Flowchart of the testing procedure of the UHMWPE acetabular liner using tribometer

Results and Discussion

The outcomes of the existing studies will be exploited to improve the prototypes of a hip implant. The research that has been done produces data in the form of number of cycles and wear depth. The data is then processed and graphed the relationship between the number of cycles and the depth of wear that occurs in three specimens. The test results also get the value of changes in acetabular liner volume by weighing. The weight changes in these three specimens prove that wear occurs during the test which is simulated for the walking cycle. Based on the results obtained in this study, it showed that specimen 2 had the highest difference in weight, which was 0.0296 grams. The specimen 1 and specimen 3 have the same difference in weight, which is 0.0014 grams.

The wear rate was determined by linear regression of wear (mm) vs number of cycles. The wear depth (mm) of the UHMWPE cups are recorded as a function of the test length in cycles with 800 N force (Figure 4). Based on the Figure 4 it can be seen that the trend resulting from the three specimen tests shows almost the same trend. The specimen 3 shows the lowest result of wear depth compared to other specimens, and specimen 1 displays the results of the greatest wear depth. In the trend of the results of specimen testing 1 there was a difference in the wear depth value from cycle 0 to cycle 3000 compared to specimen 2 and specimen 3. Then the trend of three test specimens after cycle 3000 to cycle 30000 showed a similar trend.

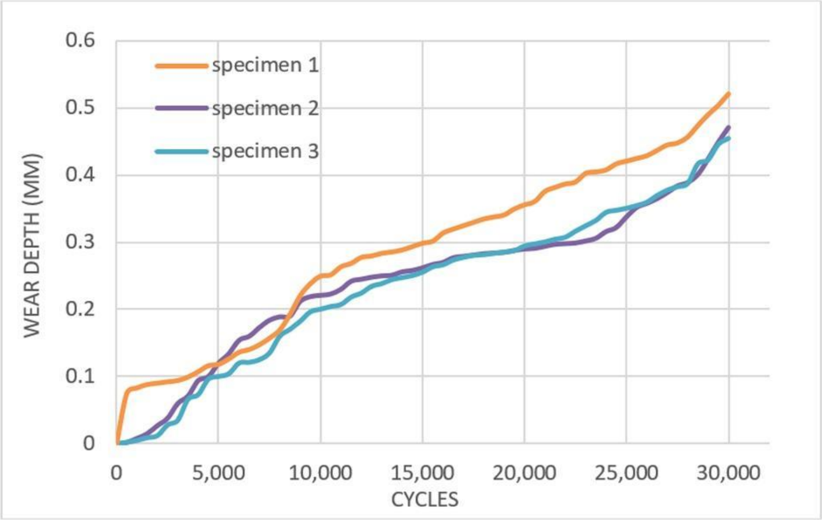

Figure 4: Comparison of test results of 1, 2, 3 specimens with 800 N force

The test results obtained, it can be concluded that the testing of acetabular liner wear with variations in surface roughness shows different wear depth values for each specimen. From the graph it can be seen that the wear depth value on specimen 1 reaches 0.52 mm for 30000 test cycles. Specimen 2 shows that the wear depth reaches 0.471 mm and specimen 3 reaches 0.454 mm. Then from the graph, the linear line equation is y = 1E-05x + 0.0645 for specimen 1, y = 1E-05x + 0.0548 for specimen 2, and y = 1E-05x + 0.0307 for specimen 3. Where y is the mass reduction after x test time.

Validation is needed before testing using a tribometer machine to determine whether the tool used is good enough. The validation method is to calculate the wear coefficient value generated from the test using the Archad equation with the femoral head radius of 14 mm and the acetabular liner radius of 14.1 mm. The load used is equal to 800 N with 30000 cycles. In this test the wear coefficient value is 1.945 x 10^{-4} mm^3/Nm. This value is then compared with the research from Dowson et al. [29] by entering parameters in the formula produced from the study. The results of the validation can be seen in the Figure 5. The results of the validation show that the two charts have almost the same trend. However, there are differences in the test results where the wear value obtained is higher than the results of the equation Dowson et al. [29] when the cycle runs more than 4500 cycles. It can be concluded that the tools used to carry out testing are good enough to produce the same wear trends as the research.

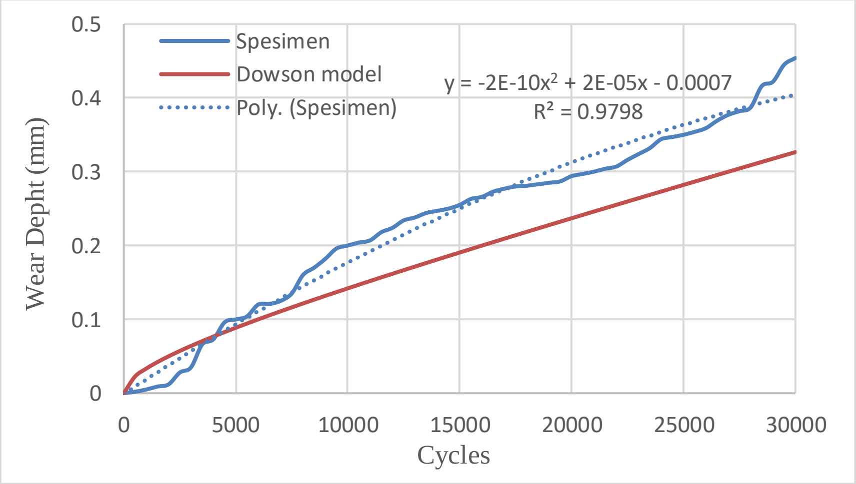

Figure 5: Validation of test with Dowson model

Different wear rates can be predictable through in vitro test for bearings with diverse bearing specifications or with diverse materials. Various wear rates can also be projected in vivo for patients with dissimilar implant orientation or with dissimilar activities. Conversely, enormous variances in wear rate for the equal category of device with same bearing specifications through hip simulator test are more likely qualified to the diversities in simulator testing conditions and testing techniques rather than wear properties of the bearing. In the present study, the tribological behavior of UHMWPE acetabular cups surface was investigated articulating against femoral heads using a hip joint simulator based on walking cycle. The difference in specimen values on wear test is because the surface roughness of each specimen. The value of surface roughness is obtained from machining process with CNC milling machines [22]. Then for this test three acetabular liners were taken which had the best surface roughness value from nine specimens that was made.

The wear of UHMWPE acetabular cup is obviously revealed in this work. Based on the results shows that specimen 1 has a greater wear coefficient value than the 2 and 3 specimens, they are 2.78 x 10^{-4} mm^3/Nm, 2.2 x 10^{-4} mm^3/Nm, and 1.95 x 10^{-4} mm^3/Nm, respectively. This is related to the surface roughness. As the results of the study [30] tested UHMWPE with a range of initial surface roughness values of 1-2 µm contacted with high density alumina ceramic the value of surface roughness was 0.02 µm in conditions of wet test (distilled water) and dry test produced a wear value different coefficient. The value of surface roughness on the UHMWPE acetabular liner specimens for this test will decrease after the test has become smoother than the initial surface roughness value (Table 2). The surface roughness reduced after wear examination as a effect of the *fl*attening of the contacting surface. As the results of previous studies by tested the UHMWPE acetabular liner which has a maximum initial surface roughness of 2µm contacted with femoral heads made of stainless steel (SS, ASTM F138) and CoCr alloy (ASTM F75) having a maximum initial surface value 0.005 µm roughness [11]. After testing with hip joint wear simulator for 5 million cycles, the surface roughness value was reduced from the initial value, in the worn area of 0.65 µm, the pristine area was 0.80 µm and the average surface roughness of SS and CoCr alloy femoral heads (0.012 ± 0.005) µm and (0.008 ± 0.002) µm. Roussignol et al. [31] tester four UHMWPE cups which has the initial average surface roughness 0.95 µm. After 1 million cycles, the average roughness reduced ranging from 0.053 µm and 0.25 µm. The average roughness after 5 million cycles was similar to that of the XLPE bearings. The results of the wear depth and wear coefficient are produced in addition to testing affected by surface roughness can also be affected by the wear mechanism that occurs when testing, such as debris produced and the presence of third body abrasion.

The amount of wear in vivo is commonly in the variety of 50-100 mg per year [32]. The value of polyethylene wear in the range of 20-35 mg per 1 million cycles was found in numerous primary simulator experiments [33]. Furthermore, the total wear of the UHMWPE acetabular cups was 6378 mg (gamma-irradiated cups) and 7672 mg (EtO-sterilised cups) after tested five million cycles [34]. Trommer et al. [12] obtain about 48 mg/10^6 cycles of the UHMWPE wear rate, corresponding to a linear wear rate of 0.16 mm/year, externally of the femoral head material. Shibo et al. [18] results mass wear rates of UHMWPE in distilled water lubrication of 31.73 mg/million cycles and 15.20/million cycles relating to practical loads of 784 N and 392 N, respectively. In addition, the wear rate of 13.06 mg/million cycles and 6.15 mg/million cycles for employed load 784 N and 392 N, respectively, was obtained UHMWPE with uni-directional in distilled water lubrication. Bragdon et al. [35] obtained the average yearly wear rates of 25 mg per million cycles from simulator test that similar to the average annual wear rates gained from assessment of popular MoP total hip reconstruction at autopsy. All polyethylene components were create of ram extruded UHMWPE and gamma sterilized, after being machined.

In this study, a weight decrease was found after wear testing with the lowest weight change was 0.0014 g (1.4 mg/30000 cycles). As this research uses simplified wear mechanism, the data cannot be immediately compared with wear experiment outcomes from literature that uses the a total hip endoprosthesis simulator [18]. The light in this study is investigated the influence of manufacturing process using CNC milling on surface roughness of UHMWPE acetabular cup. Then surface roughness influence the wear behavior of acetabular cup for artificial hip joint. Nevertheless, the results if plotted into a graph and calculated based on the line linear equation of 1 million cycles, the UHMWPE wear rate of manufacturing results using CNC milling machines is in accordance with the in vivo wear rate provisions in the literature [32].

The wear instruments initiate in the current research connecting to surface roughness largely approve with the literature, but are the fundamental to describe wear of components formed from this generally applied implant material under surface environments and loading related to that of a hip joint replacement. Based on the results of the test data and observations on the specimens it can be concluded that the acetabular liner milling process results with variations in surface roughness affect the rate of wear depth and wear coefficient produced. Then in addition to the roughness variation factor on acetabular liner, wear mechanism such as third body abrasion, adhesive/ fatigue wear that occurs during wear testing can also affect the test results.

Conclusion

The works displayed the outcomes of an experimental operation intended at exploring the influence of the manufacturing process of UHMWPE by milling CNC on the wear of acetabular liner by means of in vitro wear testing. Based on the results of the acetabular liner wear test on the artificial hip joint made from UHMWPE resulting from the machining process with CNC milling machines is as follows:

1. Wear depth in specimen 3 has the lowest wear depth of 0.454 mm compared to specimens 1 and 2 which have an 800 N loading value of 30000 cycles.
2. The specimen 1 has a greater wear coefficient value than the 2 and 3 specimens. The results of the wear coefficient are produced in addition to testing affected by surface roughness can also be affected by the wear mechanism that occurs when testing, such as debris produced and the presence of third body abrasion.

3. Acetabular liner from the milling process with variations in surface roughness affect the rate of wear depth and the wear coefficient value produced.
4. Upcoming exploration will concentration on the authentication of the wear results. Our supreme goal is to production and assessment an UHMWPE acetabular cup on the total hip endoprosthesis simulator.

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