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# Tribological Performance of Medical Grade UHMWPE Polymer at Egg Albumen Lubricated Condition

**H. Unal[1,*], A. Mimaroglu[2]**

[1]Faculty of Technology, University of Sakarya, Esentepe Campus, Turkey
[2]Faculty of Engineering, University of Sakarya, Esentepe Campus, Turkey



**Abstract** In this experimental study, the friction and wear performance of medical grade UHMWPE polymer under egg albumen lubrication condition are evaluated. The sliding experiments were carried out on a pin-on-disc wear tester. The contact configuration used was a polymer pin on a rotating stainless steel disc. Tests conditions were 2000m travelling distance, room temperature, 40 to 120N load and 0.5 m/s sliding speed. The results show that the coefficient of friction and specific wear rate increase with the increase in load and speed values. The coefficient of friction of UHMWPE under egg albumen 20g/l lubricant conditions is lower than that of under egg albumen 10g/l lubricant conditions. Moreover, for the range of load and speed values of this study the specific wear rate using egg albumen lubricant registered lower values than that of the dry conditions. Finally the specific wear rate values for medical grade UHMWPE polymer at egg albumen lubricant conditions are at the order levels of $0.5x10^{-14}m^2/N$ respectively.

**Keywords** UHMWPE, Tribology, Egg Albumen

## 1. Introduction

In prosthesis technology, knee replacements are usually the only solution for patients whose joints are totally worn out. In knees the loads on the prosthesis can reach peak values of three times the body weight during normal walking conditions [1] and can peak between four to five times the body weights during more stressful surface activities, such as walking upstairs. This is of concern as contact stresses can exceed the compressive yield stress of the prosthesis material [2-4]. The geometry of the prosthesis and the type of loading determine the contact area and size of the contact stresses in the prosthesis component [5–7]. On the other hand the tribological behavior of prostheses material is important such as wear. In such cases wear should be low and the debris produced must not be toxic. Excessive wear can cause the prostheses to work loose within the bone, resulting in pain, reduce life and instability. Ultra-high molecular weight polyethylene (UHMWPE) is a useful thermoplastic polymer for biomaterials applications. This is due to its excellent properties, such as bio- compatibility, chemical stability, high impact strength, high wear resistance, and low friction [8, 9]. On the other hand, that, UHMWPE has low hardness and creep resistance, which may lead to excessive permanent deformation of the bearing surface, and ultimately affect the surface geometry. Understanding, enhancing tribological and mechanical properties of UHMWPE will be important to prolong the longevity of joint replacement components and alleviate pain of the patients. In past, studies have been carried out on wear characteristics of UHMWPE and point out the recognition of multidirectional motion in wear mechanisms and the development on an orientation-softening wear concept [10,11]. Furthermore, extensive studies were conducted to improve UHMWPE wear resistance, such as ion implantation, fiber reinforcement, cross-linking [12-15] and grafting [16]. Apart from molecular weight role of UHMWPE, factors affecting the wear characteristics of UHMWPE include prostheses geometry [3], presence of third party, topography, speed, loading and lubrication [17-21].

The aims of this study are to clarify the friction and wear performance of GUR 1020 medical grade UHMWPE polymer sliding against AISI 316L stainless steel under egg albumen lubricated conditions and to evaluate the level of influence of applied load and sliding speed values. Friction and wear tests against stainless steel disc were carried out on a pin–on–disc arrangement. These tests were at room temperature under 40, 80 and 120 N applied load values and at 0.5, 1.0 and 2.0 m/s sliding speeds.

## 2. Experimental

Materials

Pin samples were machined from a non-sterilized Chirulen®1020 UHMWPE medical grade rod with 6mm

diameter and 50mm length for tribological tests, respectively. AISI 304L stainless steel discs were machined to 10 mm thickness and 100 mm diameter, and was grind to 0.09 μm Ra surface roughness and with a hardness value of 297 HV. Material properties and the specific wear test conditions (that is, materials, ambient temperature, speed and humidity) are summarized in Table 1.

Table 1. Test parameters of GUR 1020 UHMWPE polymer material

| | |
|---|---|
| Ambient temperature, ( ℃ ) | 21±2 |
| Applied Load, (N) | 40, 80, 120 |
| Sliding speed, m/s | 0.5 |
| Humidity, RH, (%) | 56±2 |
| Dropping velocity of egg albumen, (drops/min) | 10, 20 |

The tribometer and tests

A pin-on-disc apparatus connected to a computer was used to evaluate the friction coefficient of the GUR 1020 medical grade UHMWPE polymer against steel under egg albumen lubricated conditions. Before each tests the flat-ended polymer pins and AISI 304L stainless steel discs were cleaned with alcohol and acetone and then installed in the pin-on-disc apparatus. The friction and wear tests were performed at room temperature, sliding speeds of 0.5 m/s and applied load values from 40 to 120 N. These wide ranges of test condition were decided to cover severe working condition of knee joint such as jogging. These tests were carried out under egg albumen lubricated conditions. The lubricants were added to the rubbing surfaces at a rate of 10 and 20 drops per minute to ensure the presence of lubricant media during the test period.

**Figure 1.** Schematic diagram of wear test machine

Figure 1 shows a schematic diagram of the pin-on-disc wear test machine that was designed and used for this work. As shown in this figure, the rig consists of a stainless steel table which is mounted on a turntable, a variable speed motor which provides the rotational motion to the turntable, hence to the disk sample and a pin sample holder which is rigidly attached to a pivoted loading arm.

This loading arm is supported in bearing arrangements to allow loads to be applied to the specimen. During the test, friction force was measured by a transducer mounted on the loading arm. The friction force readings were taken as the average of 35 readings every one sec for a period of a 66 min test time which ensures the sufficient sliding distance within the steady state wear region. For this purpose a microprocessor controlled data acquisition system was used. Finally, the specific wear rates were calculated from mass loss and the represented. Sliding wear data is the average of at least three runs.

# 3. Results and Discussion

Figures 2a,b,c presents the variation of under lubricated coefficients of friction of UHMWPE polymer with sliding distance, tested at 0.5m/s sliding speed and 40, 80, 120N applied load. It is clear from these figures that there is a running-in stage for about 600 m sliding distance followed by a steady state condition. The lowest friction coefficient is for egg albumen 2 condition followed by egg albumen 1 condition.

Figure 3 presents the variation of under lubricant friction coefficients of UHMWPE polymer with applied load tested at 0.5 m/s condition. It is clear from figure 3 that the coefficient of friction value for UHMWPE polymer decreases linearly with the increase in load value. There is an average decrease of 40% in friction coefficient for 200% increase in load value. As it is known that UHMWPE polymer is a visco-elastic material which it's deformation under load is visco-elastic. Therefore, the variation of friction coefficient with the load follows the equation $\mu = KxN^{(n-1)}$ where $\mu$ is friction coefficient, N is the applied load, K and n are constants, n constant value is between 0.66 and 1 **[22]**. According to this equation, the friction coefficient decreases with the load increase. It is also clear from figure 3 that the friction coefficient for UHMWPE polymer is the lowest under egg albumen 2 lubrication conditions. This could be explained that the egg albumen as a lubricant might function to significantly hinder the friction induced thermal effect.

Figures 4 shows the variation of specific wear rate of UHMWPE polymer with applied load, tested at 0.5m/s and under lubricant condition. This figure shows that, the average specific wear rates for UHMWPE polymer is in the order of $7.5x10^{-15}$ $m^2/N$ to $5.0x10^{-15}$. The highest wear rate is for UHMWPE polymer under egg albumen 1 followed by egg albumen 2 lubricant. The lowest wear rate is $5.0x10^{-15}$ $m^2/N$ using egg albumen 2 lubricant. In all cases the specific wear for GUR 1020 medical grade UHMWPE is linearly decreasing with the increase in applied load values. This is a decrease of 33% in specific wear rate for 200% increase in

applied load values. In lubrication process, egg albumen lubricant enhances boundary lubrication. The minimum wear rate is obtained with the increment of egg albumen amount in the lubricants.

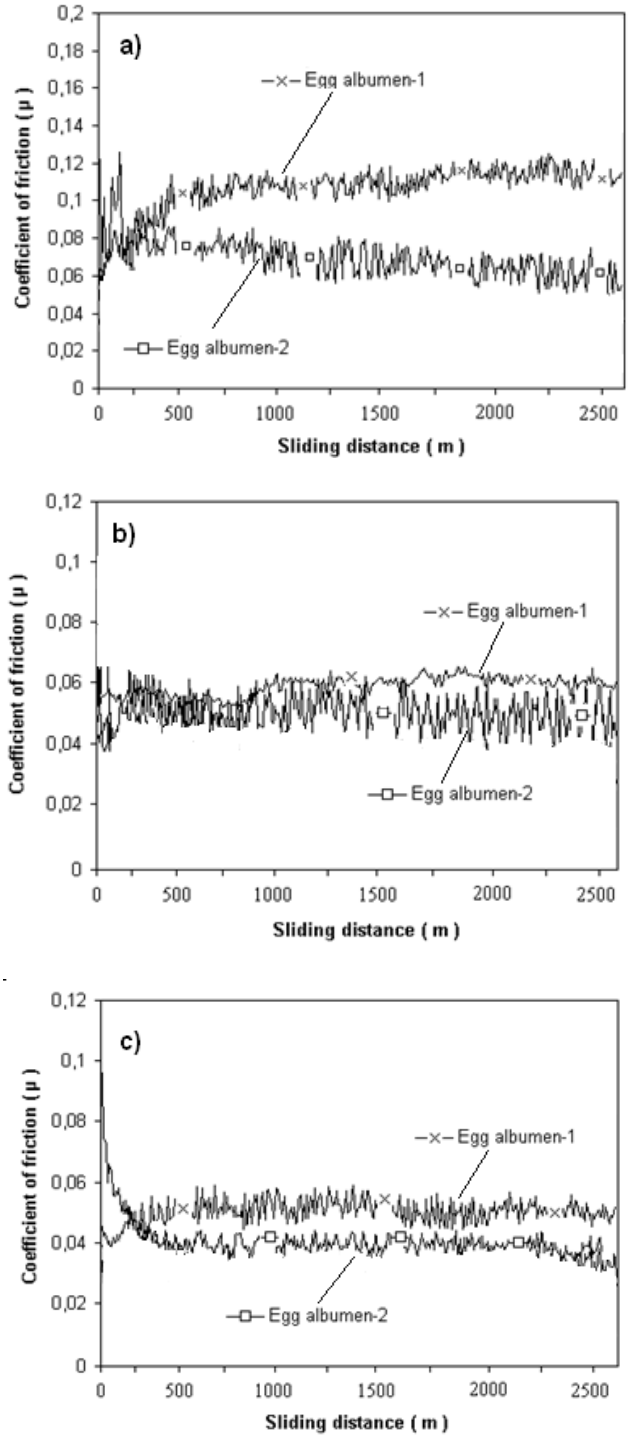



**Figure 2**. The relationship between coefficient of friction and sliding distance of medical grade UHMWPE polymer against AISI 304L stainless steel disc under different sliding conditions a) applied load:50N b) applied load:100N c) applied load:150N (sliding speed:0.5m/s)

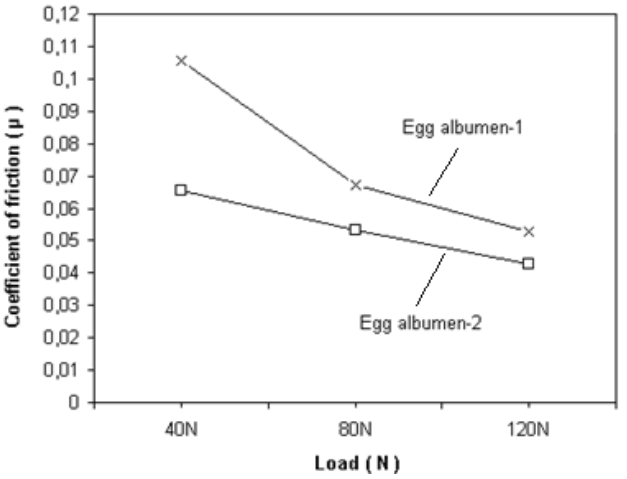



**Figure 3**. The relationship between coefficient of friction and applied load values of medical grade UHMWPE polymer against 304L stainless steel disc under sliding speed of 0.5m/s

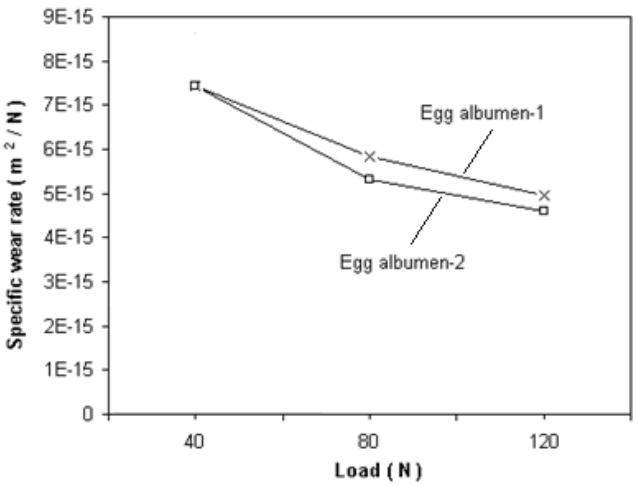
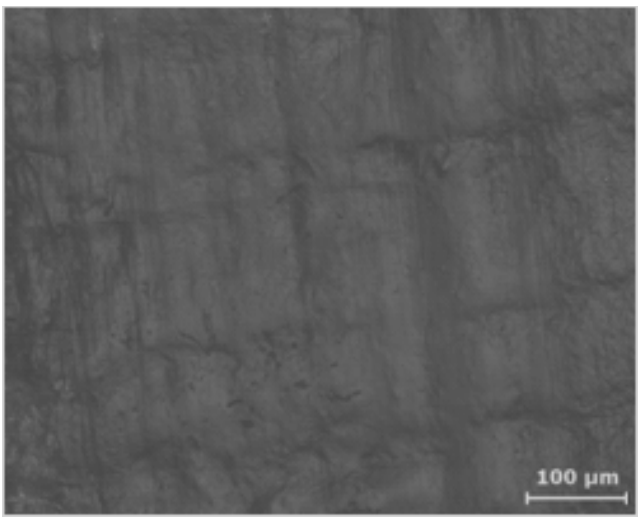
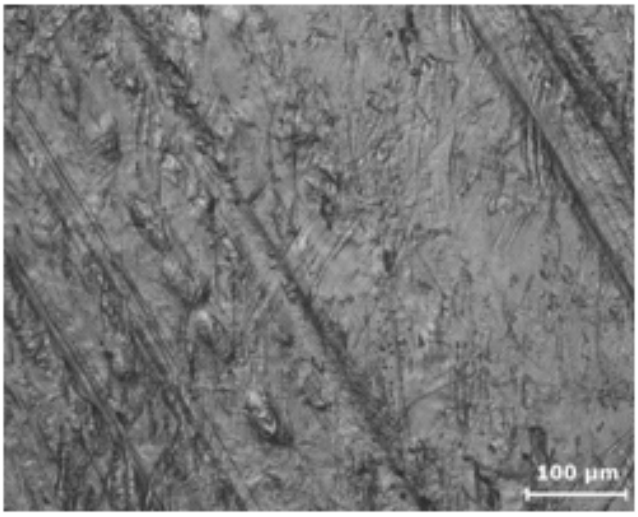



**Figure 4.** The relationship between specific wear rate and applied load values of medical grade UHMWPE polymer against AISI 304L stainless steel disc under sliding speed of 0.5m/s.




a)




b)

**Figure 5**. The worn surfaces of UHMWPE polymers under different sliding conditions a) Egg albumen 1 lubricant b) Egg albumen 2 lubricant (applied load: 120N, sliding speed:0.5m/s)

The optical microscopy examination of GUR 1020 UHMWPE polymer pin worn surface under egg albumen 1 and egg albumen 2 lubricated conditions reveal different type of surfaces, see figure 5 (a-b) respectively. For egg albumen 10g/l lubricant, figure 5(a) show the formation of adhered layer on the surface of the pin and in case of egg albumen 20g/l lubricant more protein lead to agglomerated which is due to plastic strain accumulation process caused by continuous sliding process

# 4. Conclusions

The following conclusions can be drawn from the present study.

The friction coefficient of GUR 1020 UHMWPE polymer under egg albumen 20g/l lubricant conditions is lower than that of under egg albumen 10g/l lubricant conditions. The highest wear rate is for UHMWPE at 0.5m/s sliding speed and under 40N applied load under both under egg albumen 20g/l lubricant conditions and egg albumen 10g/l lubricant conditions with a value of $7.5x10^{-15}$ $m^2/N$ The lowest wear rate is $4.5x10^{-15}$ $m^2/N$ for UHMWPE under egg albumen 20g/l lubricant conditions at 0.5 m/s sliding speed and under 120N applied load value. For the range of lubricants used in this investigation, the specific wear rate is highly influenced by the change in applied load and the egg albumen lubrication media. For the range of lubricants used in this investigation, egg albumen 20g/l lubricant condition is the most effective lubricant.

# REFERENCES

[1] J.B. Morrison, The mechanics of muscle function in locomotion, J. Biomechanics, 3 (4), 431-451, 1970.

[2] D.L. Bartel, A.H. Burstein, M.D Toda, and D.L. Edwards, The effect of conformity and plastic thickness on contact stresses in metal-backed plastic implants, J. Biomedical. Engineering, 107, 193-199, 1985.

[3] T.Stewart, , Z. M Jin, D.Shaw, D.D.Auger, M.Stone and J.Fisher, Experimental and Theoretical Study of the Contact Mechanics of Five Total Knee Joint replacements, Proc. Instn Mech. Engrs, Part H, Journal of Eng. in Medicine, 209, 225-231, 1995.

[4] T.M. McGloughlin, Contact stress analysis of tibial components of prosthetic knee implants. PhD thesis, Department of Mech. and Manufac. Eng., Trinity College Dublin, 1995.

[5] M.J., Pappas, G.Mahis, and F.F. Buechel, In Biomaterials and Clinical Applications (Eds A. Pizzogerrato, P. G. Marchetti, A. Ravagholi and A.J.C. Lee), pp. 259-264, Elsevier, Amsterdam, 1987.

[6] D.L Bartel, V.L., Bicknell, M.S. Ithaca and T.M. Wright, The effect of conformity thickness and material on stresses in ultra-high molecular weight components for total joint replacement , J. Bone Jt. Surg., 68(7), 1041-1051, 1986.

[7] P.S. Walker, M.BenDov, M.J. Askew, and J.Pugh, The deformation and wear of plastic components in artificial knee joints-An experimental study, Engng Medicine, 10(1), 33-38, 1981.

[8] J.I. Onate, M. Comin, I. Braceras, A. Garcia, J.L. Viviente, M. Brizuela, N. Garagorri, J.L. Peris and J.I. Alava, Wear reduction effect on ultra-high-molecular-weight polyethylene by application of hard coatings and ion implantation on cobalt chromium alloy, as measured in a knee wear simulation machine, Surface and Coating. Technology, 142-144, 1056-1062, 2001.

[9] BJ Briscoe and SK Sinha, Wear of Polymers, J Eng.Tribology, Proc.Instn Mech.Engrs part J, 216, 401-413, 2002.

[10] T M McGloughlin and AG Kavanagh, Wear of ultra-high molecular weight polyethylene (UHMWPE) in total knee prostheses: a review of key influences, Proc Instn Mechanical Engineers, Part H: J. of Engineering in Medicine (214), 349-359, 2000.

[11] A El-Domiaty, M El-Fadaly and A Es Nassef, Wear characteristics of Ultrahigh Molecular Weight polyethylene, J Mat Engng and Performance JMEPEG-ASM, 11(5), 577-583, 2002.

[12] G.Lewis, Properties of crosslinked ultra-high molecular-weight polyethylene, Biomaterials, 22, 371-401, 2001.

[13] S.M Kurtz, M.L. Villarraga, M.P Herr, J.S Bergstrom, C.M. Rimnac, and A.A.Edidin, Thermomechanical behaviour of virgin and highly crosslinked ultra-high molecular weight polyethylene used in total joint replacements, Biomaterials, 23, 3681-3697, 2002.

[14] O.K. Muratoglu, E.S. Greenbaum, C.R.Bradgon, M. Jasty, A.A. Freiberg, and W.H. Harris, Surface analysis of early retrieved acetabular polyethylene liners, J. Arthroplasty, 19(1), 68-77, 2004.

[15] F.W. Shen, and H. McKellop, Surface-gradient cross-linked

polyethylene acetabular cups: oxidation resistance and wear against smooth and rough femoral balls. Clin. Orthop. Relat. Res.,1(430), 80-88, 2005.

[16] T Moro, Y.Takatori, K. Ishihara, T. Konno, Y.Takigawa, T. Matsushita, U.I. Chung, K. Nakamura and H. Kawaguchi, Surface grafting of artificial joints with a biocompatible polymer for preventing periprosthetic osteolysis, Nature Mater., 3(1), 829-837, 2004.

[17] JL Hailey, E Ingham, M Stone, BM Wroblewski and J Fisher, Ultra-high molecular weight polyethylene wear debris generated in vivo and in laboratory tests; the influence of counterface roughness, Proc.Instn. Mech. .Engrs, Part H, J.Engineering in Medicine, 210(H1), 3-10, 1996.

[18] L Caravia, D Dowson, J Fisher and B Jobbins, The influence of bone and bone cement debris on counterface roughness in sliding wear tests of ultra-high molecular weight polyethylene on stainless steel, Proc. Instn. Mech. Engrs, Part H, J.Eng.in Medicine, 1990, 204, 65-70, 1990.

[19] PSM Barbour, DC. Barton and J Fisher, The Influence of Contact Stress on the Wear of UHMWPE for Total Replacement Hip Prostheses, Wear, 181-183, 250-257, 1995.

[20] A Wang, C Stark and JH. Dumbleton, Mechanistic and morphological origins of ultra-high molecular weight polyethylene wear debris in total joint replacement prosthesis, Proc. Instn. Mechanical Engineers, Part H3, J.Eng.in Medicine, 210, 141-155, 1996.

[21] M Kernick and C. Allen, The sliding wear of UHMWPE against zirconia in saline containing proteins, Wear, (203-204), 537-543, 1997.

[22] H., Uetz, J. Wien, Tribologie der Polymere, Carl Hanser Verlag, München-Vienna, 1985.