Advances in Materials and Processing Technologies 2003

TOTAL HIP PERFORMANCE UNDER MAGNETIC FIELD

M. Zaki[1] A. Aljinaidi[2] and M. Hamed[3]

1. Professor, Dept. of Production Engineering, Mansoura University, Egypt; email: mostafazaki8@hotmail.com
2. Assoc. Professor, Dept. of Production Engineering, King Abdulaziz University, Saudi Arabia; email: aljinaidi@hotmail.com
3. Assoc. Professor, Dept. of Production Engineering, Alexandria University, Egypt; email: mhmamed@hotmail.com

ABSTRACT

Recently, there is an increasing utilization of magnetic fields in bioengineering applications. However, no attention has been given to the artificial implant joint materials. Therefore, this work aims to elucidate the tribological behaviour of artificial joint materials under the effect of a medium strength magnetic field. Investigation was carried out on a designed hip simulator, which duplicates the physiological loading and motion cycles during normal human walking. The variations in friction and wear were evaluated under the influence of magnetic field. A "JRI Modular Muller Standard-Total Hip" was used with an inserted head of high alumina ceramic and UHMWPE socket. The tests were conducted under both dry and lubricated sliding using saline solution. The results have indicated that the presence of magnetic field of 270 Gauss strength resulted in high beneficial reductions in friction and wear, which can lead to prolong the implant life.

Keywords: Magnetic Field, Friction, Wear, Hip Joint

1. INTRODUCTION

Recently, there has been an increasing demand for the utilization of magnetic fields in medical applications. Among these applications are: excitation of neural tissues [1], hyperthermia therapy of cancer [2], use of magnetic pellets implanted in the head to deliver drugs and therapies into deep brain tissues [3], retention of dental prosthetic appliances [4], recovery of sick injured cells and fractured bones [5], detection of inflammations and necroses [6], treatment of delayed union bone fractures and back-pain [7] and magnetic resonance imaging. Still efforts have been continued to design optimized electro-magnetic coils and magnets of better shielding for biomagnetic applications [8-11]. Kumagai [12] found that under the effect of weak magnetic field, a conducting fluid is capable to generate a pressure exceeding the ordinary hydrodynamic pressure, thus wear was reduced for ferromagnetic material surfaces. Kumagai et al. [13] found that the transition from mild wear to severe wear was retarded with increasing magnetic flux density. Hiratsuka et al. [14] found considerable decrease in wear owing to strong magnetic field while Muju et al. [15] concluded that wear rate of materials are reduced on application of external magnetic field [16]. Hiratsuka [17] reported reductions in wear of metals under boundary lubrication when applying a magnetic field. Although the effect of magnetization has been used in many biomedical applications and few in tribological ones but no attention has been paid to its effect on the function of artificial joints. Therefore, this work aims to investigate the effects of magnetic field upon the artificial joint performance in terms of friction and wear.

2. SIMULATOR DESIGN

A dynamic hip simulator has been designed and constructed to allow in-vitro investigation of the tribological response of hip joint under dynamic functional activities, e.g., walking, in the presence of magnetic field. The controlled inputs are the time-histories of three parameters of a given dynamic activity: flexion angle, flexion-extension moment and the femoral-pelvis force components. The designed simulator shown in Figure 1 has the capability of: single test position, capability of application of physiological loads with fixed profile and changeable amplitudes, sinusoidal motion in one plane with changeable amplitudes but fixed profile and friction readout in one plane.

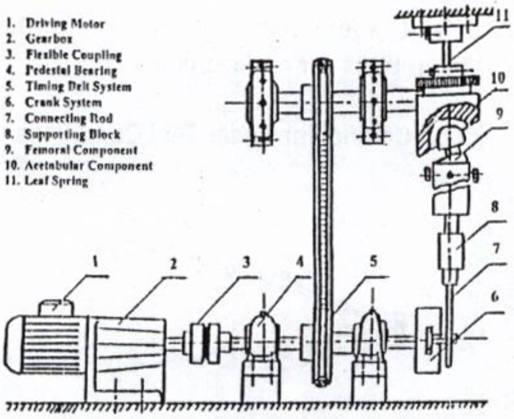

Figure.1. Layout of the Hip Simulator

3. TESTED JOINT MATERIALS

The materials favored internationally for use in orthopaedic prostheses are ultra high molecular weight polyethylene in combination with high alumina, high-density ceramic, as it has a high tolerance to the biological environment in which the joint had to function under severe loading conditions. A Modular Muller Standard Design made of Titanium (Ti-6Al-4V) was used. The head was made of Alumina Ceramic ($Al_2 O_3$) while the cup was made of ultra-high molecular weight polyethylene (UHMWPE). The materials comply with the specifications and correct composition. Annular disc magnet made of earth-cobalt of medium strength of 270 Gauss (0.027 Tesla), was used due to its high attractive and repulsive forces with minimum magnet dimensions. This magnetic field strength is safe for use in biological applications [18-19]. The magnet was located at the base of the femoral neck at a distance 30 mm from the top of the ball head and was well shielded. For maximum repelling magnetic force for a magnet in small separation, Ksienski [20] found that a disc magnet should has a size ratio of about 0.4, which is the ratio of thickness to outer diameter of the magnet.

4. TEST PROCEDURE

Tests were carried out with and without the presence of magnetic field and under dry and lubricated conditions. Each test was carried out for duration representing a total sliding distance of about 83 Km equivalent to 4.2×10^6 walking cycles. The friction forces were picked up by load cells and recorded. Weighing of the liner was performed at intervals of sliding distance using a sensitive digital electronic balance of accuracy 10^{-3} gr. The wear rate was calculated from the equation:

$$\text{Wear Rate} = V / (W \times L)$$

Where, V is the polymeric volume loss in mm^3, W is the applied load in N. and L is the cumulative sliding distance in m.

Flexion and extension movements were examined in the simulator. The angles of movement varied between $\pm 20^\circ$. For normal walking, the speed varies from zero at the turning points to a maximum of about 75 mm/s. A crank mechanism was designed to give exact motion to that described. The frequency of operation was 80 steps/min, which reflects the motion frequency at implanted hip. As hip forces vary from zero to three times body weight, a cam system was designed to give the exact load variations with time of cycle. Tests were performed under dry and lubricated conditions using physiological saline solution. An effective magnet design, of concentric circles of alternating polarities, was used. The reproducibility of the friction and wear test values was within 20%, which was considered acceptable

4. TEST RESULTS

4.1 Wear Rate Under Test Conditions

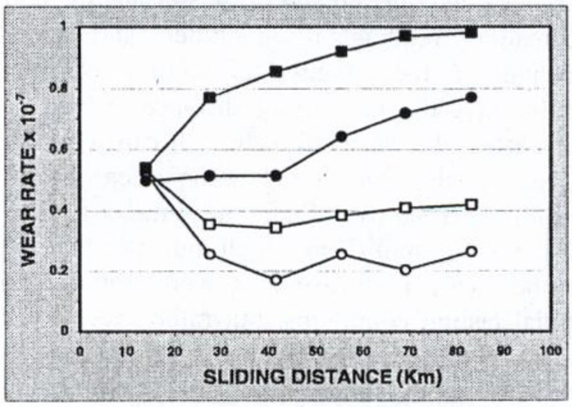

Figure 2. Wear Rate under Test Conditions (■ Dry, • Lubricated, □ Dry + Mag., ○ Lub+Mag)

Figure 2 gives comparative results for the wear rate of UHMWPE against alumina ceramic, for the tests conducted on the hip simulator, under varied testing conditions. There are clear indications of an interesting and important influence of magnetic field upon the wear rates of UHMWPE when paired with ceramic, either under dry or saline lubricated conditions. In general, the wear rate value of relatively soft materials sliding against hard counterfaces varied according to the surface quality variation of the counterface due to the nature of transfer. Artificial joint components are not exceptional as they are produced with a high-quality finish. The figure indicates that the wear rates, in dry and lubricated tests, increased with increasing sliding distance. The saline lubricated wear rate values were relatively lower in values (about 50% less) compared to those obtained in dry sliding. In dry and lubricated sliding the wear rate has an order of magnitude of 10^{-7} $mm^3/N.m$.

The results indicate that the presence of magnetic field between the present materials totally alters the wear rate behavior. In the presence of magnetic field, the wear rates behave differently as their values decrease with increasing sliding distance. The wear rate values under dry conditions, with magnetic field application, were relatively higher compared to those obtained with similar testing conditions but lubricated with saline. The results exhibit continuous decreases in the wear rates with progressive sliding. It was suggested that the presence of magnetic field affects to a large extend the polymer transfer nature and formation rending it smoother and more oriented in the direction of sliding over the entire investigated sliding distance, which in turn affect the wear rate values. It can see from Figure 2 that the initial wear rates for all performed tests was almost the same at a value of 0.5×10^{-7} $mm^3/N.m$ which indicates that the further wear rate variations were not due to initial testing conditions, but rather due to the later formation of polymer transfer and its variation with sliding and test environment. Therefore, for total hip replacement, using ceramic ball paired with polyethylene socket, the investigated specific magnetic field strength would have a high beneficial effect upon the prosthesis life and would lead to longer life for the prosthesis. Therefore, although UHMWPE paired with ceramic counterface is superior in terms of wear to UHMWPE/Stainless Steel, the existence of magnetic field would improve further its tribological performance and hence its life. Longer life prosthesis means a reduced probability of failure and less chance for further clinical operations for replacement.

4.2 Friction Coefficient Under Test Conditions

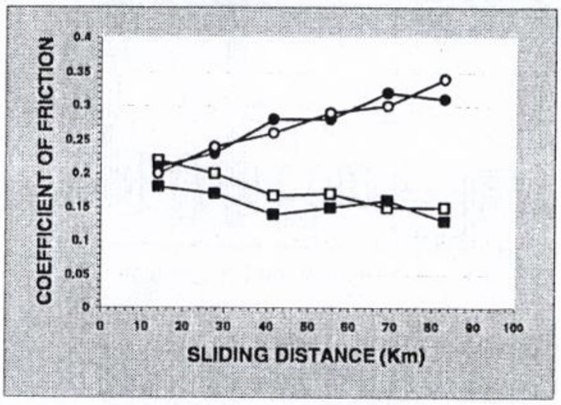

Figure 3 Friction under Test Conditions (■ Dry, • Lubricated, □ Dry + Mag., ○ Lub+Mag)

It is known that polymer surfaces are subjected to high strains in the sliding process and the orientation of the long molecules of the polymer on the sliding surface can influence friction. The friction tends to fall as the molecules align themselves with the direction of sliding. Figure 3 illustrates the frictional behavior of UHMWPE paired with alumina ceramic. The coefficients of friction under dry sliding and dry sliding with the presence of tested magnetic field experienced gradual reductions, from 0.2 to 0.15, with increasing sliding distances. On the other hand, the coefficients of friction resulted in lubricated sliding and lubricated sliding with magnetic field show general trend of increasing friction with increasing sliding distance. For the smooth ceramic surface, adhesive processes govern the initiation of sliding and a polymer transfer occurs under the dry sliding conditions. The highly oriented chain, of the polymer transfer, in the direction of sliding tends to reduce friction. With the presence of lubricant, the beneficial transfer formation is retarded leading to higher friction. The presence of magnetic field, between rubbing surfaces, has little effect about the coefficient of friction variation under the tested conditions.

CONCLUSIONS

From the results, the following conclusions can be drawn out:

1) The wear rate values, for the investigated materials on the simulator, were relatively lower than the values noted in the literature for the same materials tested on pin-on-disc machines. This was due to the difference in contacting surface configurations between the pin-on-disc and the ball-on-socket. The Hertzian contact zone moves in a circular path over the cup surface and changes in size with the variations in load. The friction values were in agreement with those in the literature.

2) The presence of lubricant resulted in lower wear rates compared with the conditions of dry sliding, either in the presence or absence of magnetic field. The coefficient of friction is highly affected by the saline lubricant, resulting in higher friction values.

3) The magnetic field of 270 Gauss strength has amazing beneficial effects on wear. Reductions in wear rates were pronounced under lubricated sliding. It is suggested that in the presence of magnetic field, induced double-layer forces may be the cause of wear reductions.

4) The polymer transfer to the hard counterface plays a dominant role in dictating the wear of UHMWPE/Ceramic materials under lubricated sliding conditions. The formation of protective layer of hydroxides on the ceramic surface and the possibility of hydrodynamic action result in friction and wear reductions.

REFERENCES

[1] Chunye, R., Peter, P. and Dejan, B. "A Novel Electric Design for Electromagnetic Stimulation-the Slinky Coil". *Trans. of Biomedical Eng.*, Vol. 42, pp. 918-925, 1995.

[2] Stauffer, P.R., Sneed, P.K., Hashemi, H. and Phillips, T.L. "Practical Induction Heating Coil Designs for Clinical Hyperthermia with Ferromagnetic Implants". *Trans. of Biomedical Eng.*, Vol. 41, pp. 17-21, 1994.

[3] Robert, G.M., Rogers, C.R., Bert, W., Michael, A.L., George, T.G., Kevin, G.W., Elizabeth, G.Q., Matthew, A.H. and Sean, M.G. "Characteristics of an Improved Magnetic-Implant Guidance System". *Trans. of Biomedical Eng.*, Vol. 42, No. 8, pp. 802-809, 1995.

[4] Yohsuke, K., Tomiyuki, Hideo, T. and Yukiko, Y. "Optimization and Design of Permanent Magnet Devices for Retaining Dental Prosthetic Appliances". *Trans. of Biomedical Eng.*, Vol. 30, pp. 201-206, 1983.

[5] Lightwood, R. "The Remedial Electromagnetic Field: A Review". *J. Biomedical Engineering*, Vol. 11, No. 5, pp. 429-436, 1989.

[6] Heidjann, J., Bohn, C., Lohrer, H. and Nicol, K. "A New Device for Geometrical and Material Properties of the Movement System for Application in Biomechanics", *Proc. of the 2nd World Congress of Biomechanics*, Amsterdam, pp. 63, 1994.

[7] Madronero, A., Pitillas, Manso, F.J. "Pulsed Electromagnetic Field Treatment Failure in Radius Non-United Fracture Healing" *J. Biomedical Engineering,* Vol. 10, No. 5, pp. 463-466, 1988.

[8] Urankar, L. and Oppelt, R. "Design Criterions for Active Shielding of Inhomogeneous Magnetic Fields for Biomagnetic Applications". *Trans. of Biomedical Engineering*, Vol. 43, pp. 697, 1996.

[9] Customerservice@Magneticproducts.com "Bioflex Medical Magnets" accessed January 2002.

[10] Health.Yahoo.com/Alternative-Medicine "Magnetic Field Therapy" accessed February 2002.

[11] info@magneticsolution.com "Magnetic Therapy" accessed June 2000.

[12] Kumagai, K. "Effects of Magnetic Field on Wear of Ferromagnetic Materials". *JSPE*, Vol. 19, No. 1, pp. 43-48, 1985.

[13] Kumagai, K., Takahashi, M. and Kamiya, O. "Wear Behaviour in the Presence of Magnetic Fields for Pin-on-Disc Repeated Dry Wear Tests". *Tribology Int.*, Vol. 25, pp. 91-98, 1992.

[14] Hiratsuka, K., Sasada, T. and Norose, S. "The Magnetic Effect on the Wear of Materials". *Wear*, Vol. 110, pp. 251-261, 1986.

[15] Muju, M.K. and Ghosh, A. "A Model of Adhesive Wear in the Presence of a Magnetic Field". *Wear*, Vol. 41, pp. 103-116, 1977.

[16] Muju, M.K. and Radhakrishma, A. "Wear of Non-magnetic Materials in the Presence of a Magnetic Field". *Wear*, Vol. 58, pp. 49-58, 1980.

[17] Hiratsuka, K. "Wear of Metals in a Magnetic Field in a Boundary Lubrication". *Proc. of the 9th Leeds-Lyon Symposium on Tribology*, Vol. 5, 1992.

[18] O'Connor, M.E., Bentall, R.H.C. and Monahan, J.C. "Emerging Electromagnetic Medicine". *Springer-Verlag*, Germany, 1990.

[19] Bioelectromagnetic Society (BEMS)" bioelectromagnetics@egroups.com (2000).

[20] Ksienski, D.A. "A Minimum Profile Uniform Current Density Electrode". *Trans. on Biomedical Engineering*, Vol. 39, No. 7, pp. 682-692, 1992.