International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 7 No. 1 July 2014, pp. 153-158
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http://www.ijias.issr-journals.org/

Analysis of Wear Rate of Ceramic Material for Total Joint Arthoplasty

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ABSTRACT: In Total Joint Replacement (TJR), ceramic surfaces offer a major benefit of drastically reduced wear rates and excellent long-term biocompatibility with the bone tissue. Among the available ceramic materials for load bearing bio-implant applications, silicon carbide is superior for its better biocompatibility, which can increase the longevity of prosthetic joints. The major cause of revision surgery and implant failure is Osteolysis (aseptic loosening of the prosthetic joint). The product of bearing wear, microscopic particulate debris in the joint space leads to implant loosening. Prosthetic joint mainly consists of acetabular cup, acetabular lining and femoral head. The best material for manufacturing acetabular cup is nickel – base alloy. For manufacturing acetabular lining and femoral head, silicon carbide is the best chosen material. The acetabular cup or knee cap is prone to catastrophic failures due to walking, stumbling etc. A sliding distance test was performed on polished surface of silicon carbide and nickel-base alloy (mirror- like finish, 1µm) by using Reciprocating Friction Monitor (Courtesy; National Institute of Technology, Srinagar) for the evaluation of wear volume and wear coefficient by standard test procedures and equation outlined in ASTM F 603. The test was carried out in ambient temperature. The results obtained showed drastically reduced wear rates. The experiments on Reciprocating Friction Monitor for Silicon carbide and nickel – base alloy showed that the best choice for prosthetic joint replacement would be a combination of two materials; silicon carbide for femoral heads and acetabular lining, and nickel-base alloy for acetabular cup.

KEYWORDS: Prosthetic joint; Wear rate, Aseptic loosening, Silicon Carbide, Nickel base alloy.

1 INTRODUCTION

The tribological properties of low friction, high wear resistance and good biocompatibility make ceramic material the most attractive in hip replacement surgery at the present time. In long term follow up after implantation. the ceramic couple bearings show the lowest wear rate in many reports, which means low wear debris and less osteolysis [1]. The purpose of this paper is to analyse the wear rate properties of silicon carbide and nickel base alloy. Both categories of Ceramics can be used for TJR either oxide ceramics or non-oxide ceramics. In oxide ceramics like aluminium oxide and zirconium oxide can be used. But these show low temperature degradation.While as non-oxide ceramics offer a major benefit of drastically reduced wear rates and excellent long term biocompatibility with the human tissue. The advantage of ceramic on ceramic (COC) was shown by in vitro analysis to reduce wear debris particles that cause osteolysis. The important property of ceramic that caused a lower wear rate was its being hydrophilic[2].Ceramic's hydrophilic properties facilitate an increased wettability of the surface because of the strong hydrogen bonds between the ceramic surface and synovial fluid that results in the synovial film being more uniformly distributed [3].

Silcon carbide has a higher strength, high elastic modulus, ultra low wear rates and to resist deformation when subjected to the loads in the body. SiC has high corrosion resistance of bioinertness and biocompatibility with the human tissue than other oxide and non-oxide ceramics. The superior material properties of SiC offer a new possibilities for eliminating implant failures. The biocompatibility tests performed according to ISO 10993 indicates that Silicon Carbide is biocompatible and did not elicit any adverse effect like acute toxicity, chronic toxicity, mutagenicity, allergenicity, carcinogenicity or localized tissue toxicity to the Prosthetic Joint [4]. Silicon carbide has high hardness and good surface finish for long term wear resistance(low wear) and low friction [5]. Good wetting between the synovial fluid and bearing surface for good lubrication in the body [6].

The wear characteristics of samples of Silicon carbide was determined by using Reciprocating Friction Monitor (Courtesy; Maintenance lab National institute of Technology, sgr). Wear rate as a function of sliding distance were examined to interpret the behaviour of Silicon carbide. Analysis of the experimental results showed that in Prosthetic Joint Replacement, Silicon Carbide offers a major benefit of drastically reduced wear rates and friction stabilization, which can increase the longevity of Prosthetic Joints.

Nickel Base alloy is a nickel and beryllium-free chrome/cobalt alloy.The strong oxide provides optimum metal/ceramic bonding and is suitable for open melting, as well as for the high frequency casting process. One of the remarkable features is the high corrosion resistance. It is cleaned in ultrasonic bath or with a steam cleaner. The composition has been well established for many years and is now commercially available. Wear characteristics of samples of Nickel base alloy was determined by using Reciprocating Friction Monitor. Wear rate as a function of sliding distance were examined to interpret the behaviour of Nickel base alloy. Analysis of the experimental results showed that wear rate in case of nickel base alloy is comparatively higher than Silicon carbide. But the advantage of Nickel base alloy is that it has higher fracture toughness than silicon carbide and can be used for making of acetabular cup, where ductility of the material is of major concern [7].

2 SAMPLE PREPARATION OF SILICON CARBIDE

The silicon carbide, doped with C and B, is prepared through tape casting. The processing method involved several steps: slurry preparation, tape casting, solvent evaporation & sintering. Boron and carbon were also added in order to aid the final sintering treatment and due to them fracture toughness increases. Thin sheets were produced by casting the slurry on a moving Mylar support [8].

3 POLISHING OF SILICON CARBIDE SAMPLES

Silicon Carbide samples are polished by using emery papers of various grit sizes. Firstly, the silicon carbide samples are polished by using an emery paper of Grit size 60. The 60 sized emery paper took all the higher asperities away when rubbed against silicon carbide billets. The SiC samples were cleaned with acetone solution, after drying them in ambient temperature, the samples were rubbed with an emery paper of grit size 80. The 80 sized emery paper took away the asperities which were lying beneath the surface, the samples were once again cleaned in acetone solution and were rubbed against an emery paper of grit size 100. The same processs was repeated by using emery papers of grit size 120, 150, 180, 200, 220 etc.

Figure .1 shows the optical images of polished Silicon Carbide [9]. Figure 1(a) shows smooth surface, the pits are intrinsic holes. Figure.1(b) shows some grains are polished faster than others Figure.1(c) shows surface has waviness. Figure.1(d) tiny scratches exist due to grains felling out. Figure.1(e) shows dry sliding, rough surface with scratches.

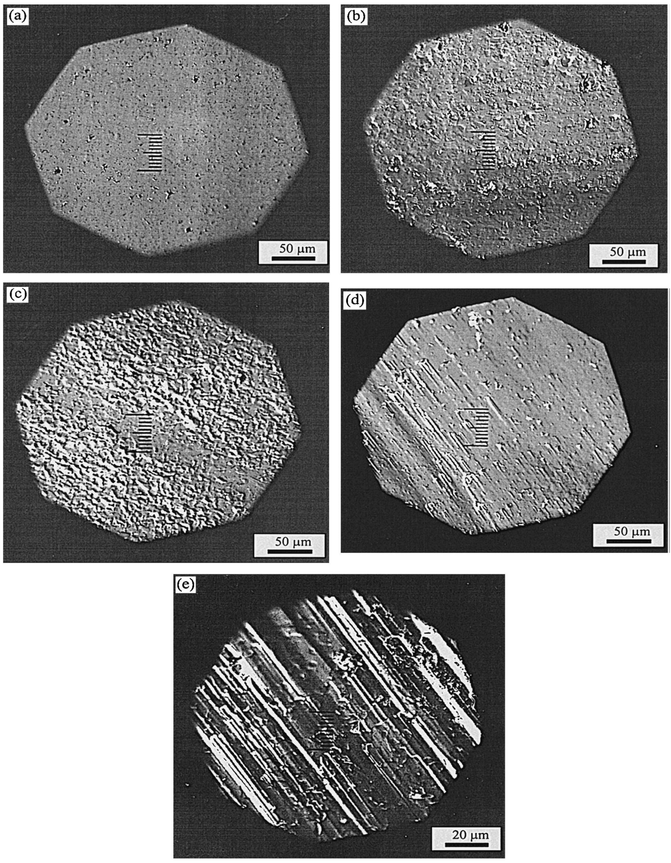

Fig.1: Predicts Nomarski interference optical images of polished SiC surfaces [9]

4 EXPERIMENTAL PROCEDURE

Sliding Distance test was performed on polished surface of ceramics (mirror-like finish, 1µm diamond polish) using Slider Reciprocating Moniter. For the evaluation of Wear volume, standard test procedures and equation outlined in ASTM F 603 is used. The test was carried out in ambient temperature.

A. Experiment No 1: Wear volume and Sliding distance (Ni-Base Alloy)

By using Pin on Disc experiment on Reciprocating Friction Slider (Courtesy Tribology Lab, NIT, Sgr.). The specifications of the Reciprocating Friction Slider is given below:

Spindle speed = 1200rpm

Specimen 1 = SiC Disc

Specimen 2 = Ni-base alloy Pin

Normal Load = 20N

Stroke length = 2mm

Specimen temp = 35ºC

Oil drip temp.= 50ºC

Frictional Force trip = 250ºC

Normal load trip = 350ºC

Test frequency = 20 Hz

Test Specifications

Mass of pin before test = 4.3700g

Mass of pin after test = 4.3687g

Δm = 0.0013g

Sliding distance in this case would be:

N =1200rpm

T = 20min

Velocity of slider= (1200×4)/60 = 0.080m/s

Sliding Distance = Velocity ×time

= 0.08×20×60 = 96m

Wear volume = m/ρ

= 0.0013/6.45

= $2.01\times10^{-4}\ mm^3$.

Repeated tests were performed for various sliding distances and wear volume for nickel base alloy was calculated.

Table. 1: Data of wear volume Vs Sliding distance for Ni base alloy:

S.No	Sliding Distance(m)	Wear Volume (mm^3)
01.	96m	$2.01\times10^{-4}\ mm^3$
02.	144m	$3.21\times10^{-4}\ mm^3$
03.	192m	$3.67\times10^{-4}\ mm^3$
04.	240m	$4.23\times10^{-4}\ mm^3$
05.	288m	$4.75\times10^{-4}\ mm^3$
06.	336m	$5.22\times10^{-4}\ mm^3$

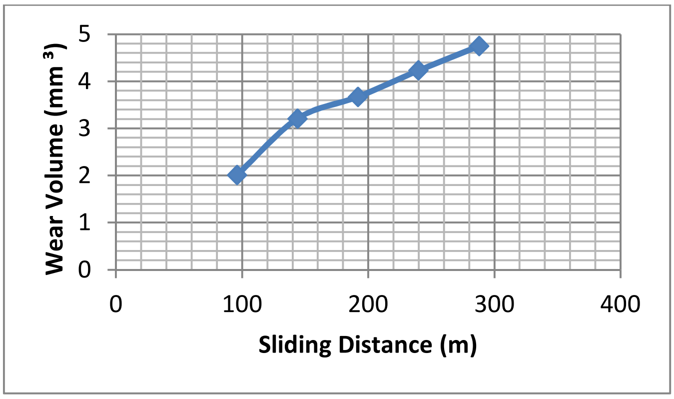

Fig. 2:Variation of Wear volume with sliding distance in Ni-Base alloy

(B) Experiment No 2 Wear Volume And Sliding Distance For Sic

By using Pin on Disc experiment on Reciprocating Friction Slider (Courtesy Tribology Lab, NIT, Sgr.). The specifications of the Reciprocating Friction Slider is given below:

Spindle speed = 1200rpm

Specimen 1 = SiC Disc

Specimen 2 = Ni-Alloy Pin

Normal Load = 20N

Stroke length = 2mm

Specimen temp = 35ºC

Oil drip temp.= 50ºC

Frictional Force trip = 250ºC

Normal load trip = 350ºC

Test Specifications

Mass of SiC Disc before test = 3.8745g

Mass of SiC Disc after test = 3.8744g

Δm = 0.0001g

Sliding distance in this case would be:

N =1200rpm

T = 20min

Velocity of slider= (1200×4)/60 = 0.080m/s

Sliding Distance = Velocity ×time

= 0.08×20×60 = 96m

Wear volume = m/ρ

= 0.00001/3.11

=$3.2 \times 10^{-5}\ mm^3$

Table.2: Data of wear volume Vs Sliding distance for SiC

S.No	Sliding Distance (m)	Wear volume (mm^3)
01.	96m	$3.21 \times 10^{-5}\ mm^3$
02.	144m	$6.2 \times 10^{-5}\ mm^3$
03.	192m	$7.1 \times 10^{-5}\ mm^3$
04.	240m	$9.21 \times 10^{-5}\ mm^3$
05.	288m	$10.1 \times 10^{-5}\ mm^3$
06.	336m	$12.1 \times 10^{-5}\ mm^3$
07	380m	$13.2 \times 10^{-5}\ mm^3$

Repeated tests were performed for various sliding distances and wear volume for silicon carbide was calculated.

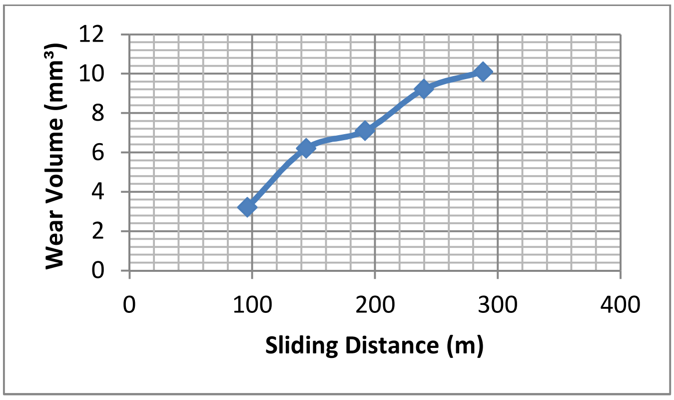

Fig. 3: Variation of Wear volume with sliding distance in SiC.

5 CONCLUSION

The major cause of concern for total joint replacement (TJR) is Osteolysis (loosening of prosthetic Joint). Osteolysis is a significant cause of aseptic loosening and is the biggest cause of revision surgery. The aim of the project is to introduce a non oxide ceramic material- Silicon Carbide, which have good biocompatibility with the human tissue and considerably less wear rates. The femoral head could be made of silicon carbide-because maximum rubbing during any human activity occurs between femoral head and inner acetabular lining. The acetabular cup could be made up of Nickel base alloy- because it has much higher toughness as compared to Ceramics. Outer cup or acetabular cup made of nickel base alloy would be less prone to breakage, due to its higher fracture toughness. While as inner lining or acetabular lining and femoral head made of silicon carbide would result in drastically reduced wear rates.

REFERENCES

[1]. Willert HG, Bertam H, Buchhorn GH. Osteolysis in Alloarthroplasty of the hip: The role of ultra- high monolecular weight polyethylene wear particles. *Clin Orthop Relat Res* 1990;258:95-107.

[2]. Ceramic on ceramic bearing Sukree khumrak, Bangkok medical journal vol.4.

[3]. Capello WN, D'Antonio JA, Feinberg JR, et al. Ceramicon- ceramic total hip arthroplasty: update. *J Arthroplasty*

[4]. Chevillotte C, Pibarot V, Carret JP, et al. Hip squeaking: A 10 years Follow up Study. *J Arthroplasty* 2012;27: 1008-13

[5]. Nevelos JE, Ingham E, Doyle C, et al. Wear of HIPed and non-HIPed alumina-alumina hip joints under standard and severe simulator testing conditions. *Biomaterials* 2001;22:2191-7.

[6]. Hannouche D, et al. Ceramics in Total Hip Replacement. *Clin Orthop Relate Res* 2005;430:62- 71.

[7]. Chevillotte C, Trousdale RT, Chen Q, et al. Hip Squeaking : A Biomechanical study of Ceramic-on- Ceramic Bearing Surfaces. *Clin Orthop Relat Res* 2010;468:345-50.

[8] Walter WL, Insley GM, Walter WK, et al. Edge loading in third generation alumina ceramic-on- ceramic bearings: stripe wear. *J Arthroplasty* 2004;19:402-13.

[9]. Tribochemical polishing of silicon carbide in oxidant solution Zhize Zhu), Viktor Muratov, Traugott E. Fischer.Department of Materials Science and Engineering, Steĺens Institute of Technology, Hoboken, NJ 07030, USA .