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Experimental Pin-on-Disc Testing for Wear Simulation of Metallic and Non Metallic Pin Implant materials

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Abstract—*Purpose- An attempt has been made in this study to replace the traditionally used implant materials, which have constraints and limitations, to name a few like non-bio-compatibility, non-bio activeness, do not help in bone and tissue growth respectively, with a set of new alternative materials.*

Methodology/approach- *Here a set of five different materials comprising of metals, ceramics and polymers were taken into consideration and their tribological properties were analysed under same applied parameters. The different varieties of materials were taken into account in order to have a comparative analysis between them.*

Findings- *From the carried out experiments it was observed that the polymers were the better choice in terms of certain tribological parameters than the other materials under test. Due to their physical properties polymeric materials were found to be mechanically efficient as well as medically bio active.*

Practical implications- *If the traditional metallic materials could be replaced with the polymeric materials it will increase the functionality of the damaged cord section and also improve upon its longevity without causing any side effects.*

Limitations- *Under certain mechanical parameters the considered pin materials were found to be partially worn out which can be improved by putting a layer of bio-coating on them.*

Keywords*: Bio-tribology, osteo-integration, pins on disc, implant materials*

1. INTRODUCTION

Bio tribology is a new field of research within the domain of tribology which encompasses the study of friction, wear and lubrication of engineering materials in biological systems. It is an interdisciplinary study whose goals are to evaluate the biological systems, analyse their functions and properties with an aim to improve the quality of human life span. Owing to various stress and age related problems, human body undergoes degeneration which ultimate leads to reduction in efficiency, which can be overcome by substitution of implant materials. These materials are better known as biomaterials. Usually metallic biomaterials have been used as implant materials which have played a prominent role till now in bioengineering studies. The major drawbacks of metallic implants were their incompatibility with diagnostic medical imaging techniques like MRI and CT scans which are crucial for visualising changes to spinal cord and adjoining soft tissues. However with advancement of time, new materials have come to the limelight for these purposes. The new type of biomaterials that are now in developmental stage as implant materials consist of Polymers, Ceramics, Composites respectively [1-3]. Out of these materials, polymers are organic materials that form large chains made up of similar or dissimilar units. They poses the unique properties of flexibility, light weight, low coefficient of friction, easily manufactured in various compositions with sufficient physical and mechanical properties.

Although there are many polymers that are being used for various research works of implant materials, limited research have been carried out on UHMWPE (Ultra high weighed molecular poly ethylene), HDPE and PTFE respectively.

Good mechanical toughness, wear resistance, surface properties make it a better choice for research purpose. The material fails due to fracture, wear and corrosion mainly**.** However the wear component produces wear debris which during the service life losses its desired properties added with the factor of natural osteolysis [4]. Motion dependent wear plays a critical role in analysis of these polymers. In uni-directional motion, molecular orientation leads to strain hardening of wear surface, which results in wear resistance enhancement as sliding continues. However a human body is subjected to dynamic forces and multi-direction motion. So an implant material has to be subjected to multi-directional motion where both shear and tensile stresses occur in multiple direction. Strengthening in one direction will result in weakening in the perpendicular direction, a property observed in linear polymers [5].

Since polymers undergo Adhesive wear, the classical relationship presented by Archard can be represented as

$$V = \frac{kWS}{H}$$

Where V is wear volume, k is wear coefficient, W is normal load, S is total sliding distance and H is hardness of worn surface respectively and the corresponding variables are in standard units.

There is need of proper lubrication mechanism to overcome the wear and frictional losses. Human joints are complex bearings that operate under both fluid film and boundary lubrication conditions. The lubricant in spinal cord is nucleus pulpous whose content gradually keeps on decreasing with increasing human age [6-7]. Ceramics like Al_2O_3, TiO_2, quartz not only improve mechanical properties but also wear performance of polymer based composite. Hydroxyapatite (HAP) when used as a bone implant material, it improves the bioactivity of human bones [8].

2. EXPERIMENTAL ANALYSIS

An experiment was performed on rotary pin on disc apparatus for materials that can be used as implants and their tribological properties have been studied, analysed to confer upon which one from them can be a better choice.

The carried out experiments involved external lubrication of the pin materials in presence of bovine calf serum (BCS) diluted with distilled water (75%), the value of which has been selected keeping in mind the chemical pH level.

In the following Table 1, mechanical properties of the considered pin materials were noted and tabulated down in order to provide a better insight of the materials characteristics.

In the following Table 2 the experimental conditions of the pin on disc machine were tabulated and these test values were made uniform for all set of experiments carried out with different pin materials.

Table 1: Specification of machine for experimental condition

Test Parameter	Test Values
Wear Disc (En31)	100 mm dia, 8 mm thick
Pin Diameter	4 and 6 mm
Wear Track dia	80 mm
Disc Speed	150 rpm
Normal Load	3kgf (29.42N)
Temperature	Ambient room temperature
Test Duration	25 minutes (1500 seconds)

The wear obtained in the pin on disc apparatus indicates the relative wear and frictional values because during interaction some amount of disc counterface material also wears out. Hence in order to obtain exact weight loss of the pins after carrying out of the experiment, they were weighed on a high precision weighing machine. The obtained wear volume loss here gives the exact amount of wear that takes place on the pin. So the difference between the values obtained from pin on disc and weighing machine indicates the approximate wear and weight loss value of the disc material. In the following Table 3 a weighing machine of high precision was considered and its physical parameters and values were jolted down in the form of a table.

Table 3: Specification of weighing machine

Sl. No.	Parameters	Values
1	Readability (g)	0.01
2	Weighing Capacity (g)	4200
3	Repeatability (g)	0.01
4	Linearity (g)	0.02
5	Response time (s)	1.1
6	Calibration and adjustment	Internal

3. ALUMINA

It is a polycrystalline ceramic material which has good tribological properties like wear resistance, chemical and thermal stability, optimum stiffness, biocompatibility and lower weight [9]. Their mode of wear is abrasion. As a bio material its principal aim is to reduce in vivo reactivity. Surface energy of this product is responsible for its high wear resistance.

Fig. 3: Comparison of Wear (μm), Coefficient of Friction, Frictional Force (N) respectively versus Time Duration (sec)

The image of Fig. 1 depicts a front view of the fresh alumina pin sample prior to carrying out the experiment.

The image of Fig. 2 depicts a top view of the same alumina pin sample after carrying out the experiment. It can be seen that there is a mark formed in the pin surface also better known as indent formation.

The image of Fig. 3 depicts three tribological parameters of wear, coefficient of friction and frictional force plotted against time duration respectively.

The graph obtained between wear and time initially shows that there is exponential increase in wear within first two hundred seconds of operation, however after that the wear becomes almost constant indicating that maximum wear has taken place in it for the applied mechanical conditions and the material has failed.

The point of time at which the wear versus time graph starts becoming constant can be termed as threshold point. Hence two hundred seconds is the threshold point for this material.

4. BRASS

Brass is an alloy material made of copper and zinc. It has low frictional force value. Its malleable property allows it to be suitable for many applications. However its corrosion resistance is poor. It is gullible to stress corrosion cracking from chemicals like ammonia.

Thus in order to improve upon this property a layer of alumina is applied on its surface to increase its corrosion resistance [10]. The existence of copper in brass makes it a good germicidal agent and hence can be used as implants in human body reaction studies.

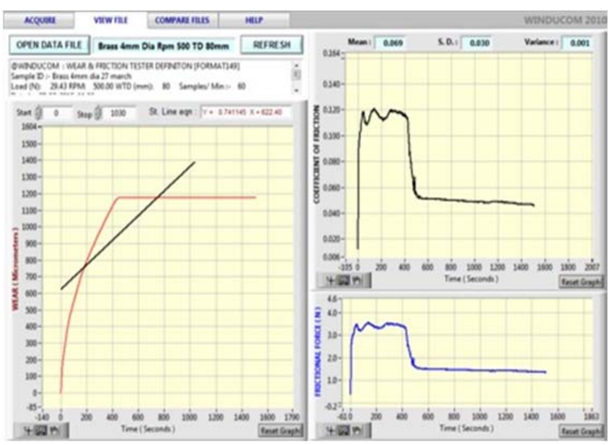

Fig. 6: Comparison of Wear (µm), Coefficient of Friction, Frictional Force (N) respectively versus Time Duration (sec)

The image of Fig. 4 depicts a front view of the fresh brass pin sample prior to carrying out the experiment.

The image of Fig. 5 depicts a top view of the same brass pin sample after carrying out the experiment. It can be seen that there is a mark formed in the pin surface also better known as indent formation.

The image of Fig. 6 depicts three tribological parameters of wear, coefficient of friction and frictional force plotted against time duration respectively.

The graph obtained between wear and time initially depicts that there is uniform increase in wear within first four hundred seconds of operation, however after that the wear becomes almost constant indicating that maximum wear has taken place in it for the applied mechanical conditions and the material has failed. The coefficient of friction and frictional force graph versus time are however identical with both increase and decrease in curve obtained. The point of time at which the wear versus time graph starts becoming constant can be termed as threshold point. Hence four hundred seconds is the threshold point for this material.

5. HDPE

HDPE is a by-product of petroleum and finds a wide range of medical applications due to large strength to density ratio**.** It is an inert material with low tissue reactivity [11]. It is malleable and has pores on its surface which can help in tissue growth.

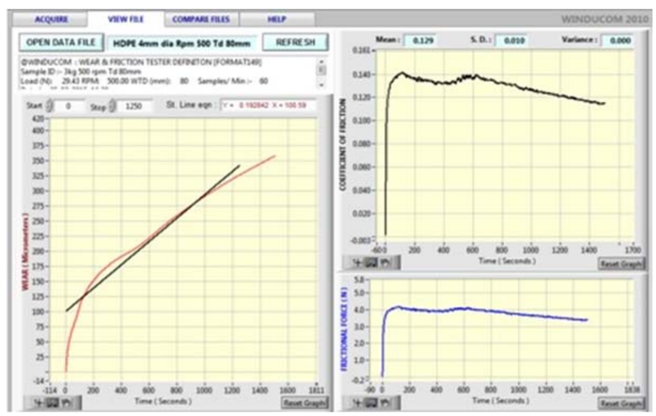

Fig. 9: Comparison of Wear (µm), Coefficient of Friction, Frictional Force (N) respectively versus Time Duration (sec)

The image of Fig. 7 depicts a front view of the fresh HDPE pin sample prior to carrying out the experiment.

The image of Fig. 8 depicts a top view of the same HDPE pin sample after carrying out the experiment. It can be seen that there is a mark formed in the pin surface also better known as indent formation.

The image of Fig. 9 depicts three tribological parameters of wear, coefficient of friction and frictional force plotted against time duration respectively. The graph obtained between wear and time initially depicts that there is uniform increase in wear up to two hundred seconds of time duration but after that it exponentially increases. However the magnitude of wear is relatively very less. This polymeric material did not have any threshold point for the given mechanical conditions. Obtained values of coefficient of friction and sliding distances are tabulated later.

6. SS 304

Stainless steel is a versatile material having lots of applications. It has been in use for medical applications for a long period of time. It is a highly ductile material and can be moulded according to any desired shapes for optimum use [12].

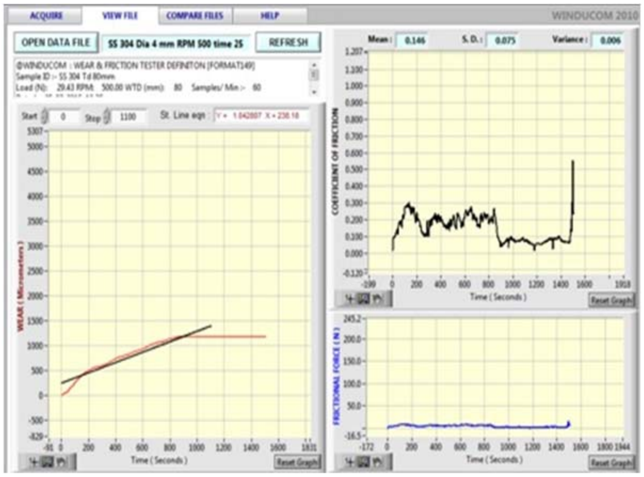

Fig. 12: Comparison of Wear (µm), Coefficient of Friction, Frictional Force (N) respectively versus Time Duration (sec)

The image of Fig. 10 depicts a front view of the fresh SS 304pin sample prior to carrying out the experiment.

The image of Fig. 11 depicts a top view of the same SS 304 pin sample after carrying out the experiment. It can be seen that there is a mark formed in the pin surface also better known as indent formation.

The image of Fig. 12 depicts three tribological parameters of wear, coefficient of friction and frictional force plotted against time duration respectively. The graph obtained between wear and time initially depicts that there is uniform increase in wear within first eight hundred seconds of operation, however after that the wear becomes almost constant indicating that maximum wear has taken place in it for the applied mechanical conditions and the material has considerably failed. The coefficient of friction and frictional force graph versus time however depict non uniform obtained curve. The coefficient of friction and sliding distances are tabulated later.

7. UHMWPE

It is a self-lubricating polymer highly resistant to wear [13-14]. Optimum mechanical properties and biocompatibility makes it a good selection for implants.

The image of Fig. 13 depicts a front view of the fresh UHMWPE pin sample prior to carrying out the experiment.

The image of Fig. 14 depicts a top view of the same UHMWPE pin sample after carrying out the experiment. It can be seen that there is a mark formed in the pin surface also better known as indent formation.

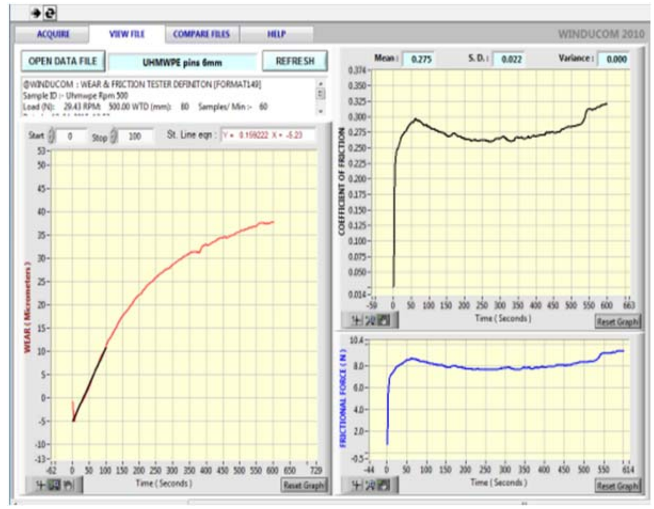

Fig. 15: Zoomed image of Wear (µm) and Frictional force (N) respectively versus Time (sec)

The image of Fig. 15 depicts three tribological parameters of wear, coefficient of friction and frictional force plotted against time duration respectively.

The graph obtained between wear and time depicts that there is uniform wear throughout the time duration of experiment. However the magnitude of wear is relatively very less. This polymeric material did not have any threshold point for the given mechanical conditions.

Obtained values of coefficient of friction and sliding distances are tabulated later. The coefficient of friction and frictional force graph versus time are however identical in terms of curve obtained.

8. SEM IMAGES

Alumina

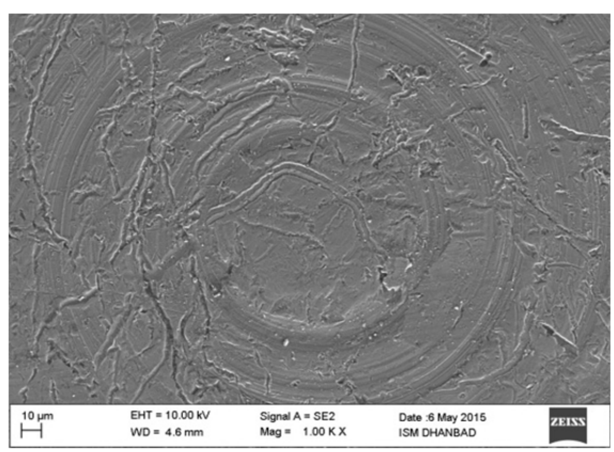

Fig. 22: New material

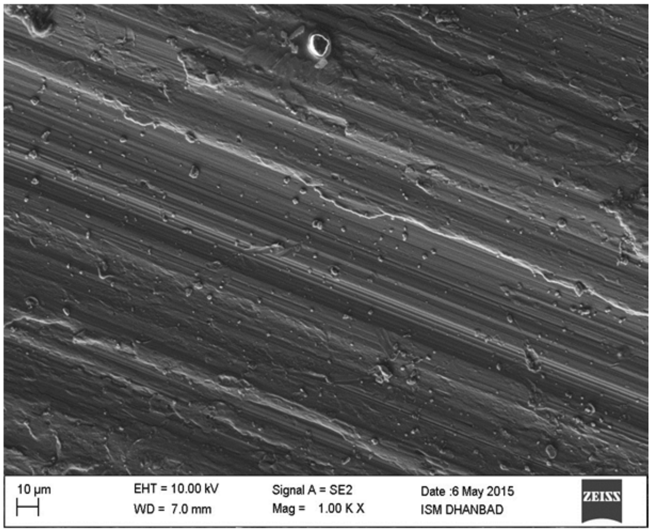

Fig. 23- Worn out material

Brass

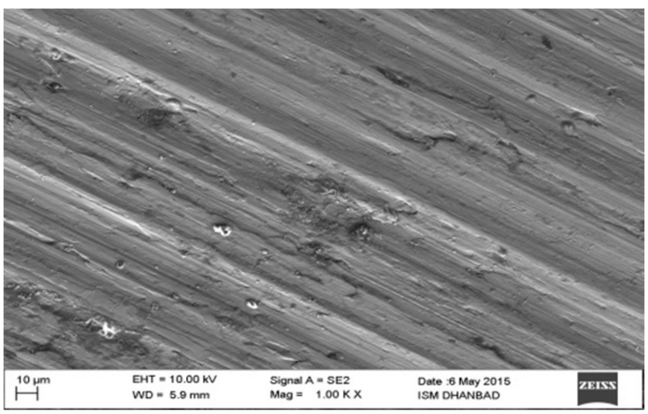

Fig. 24- New material

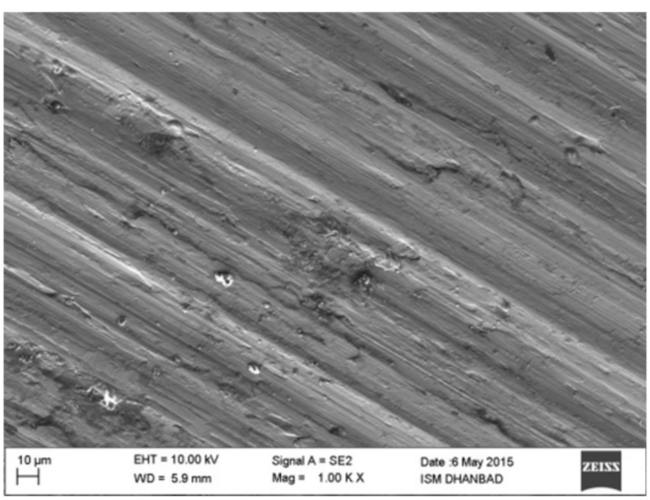

Fig. 25- Worn out material

HDPE (High Density Poly Ethylene)

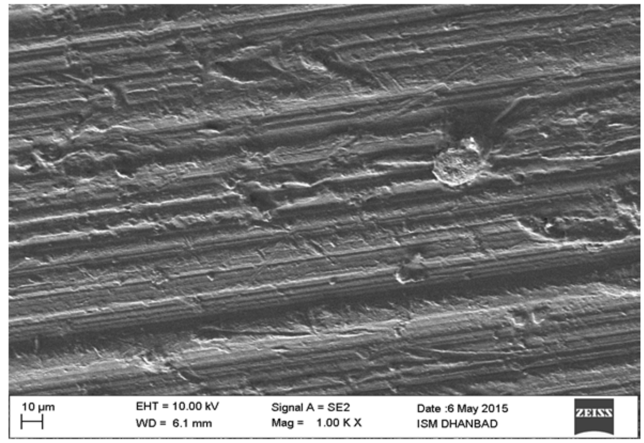

Fig. 26: New material

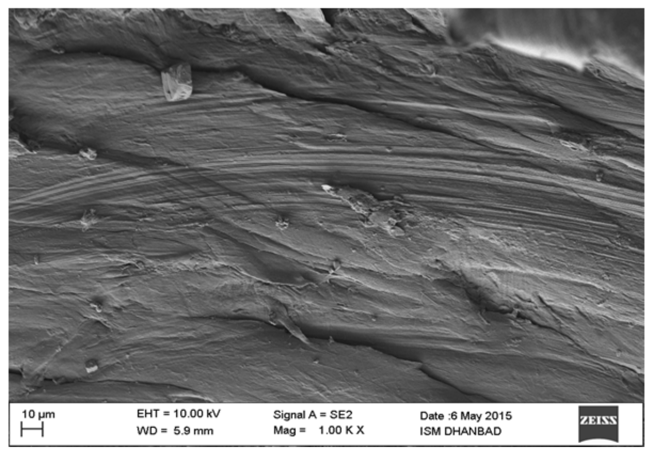

Fig. 27: Worn out material

SS304

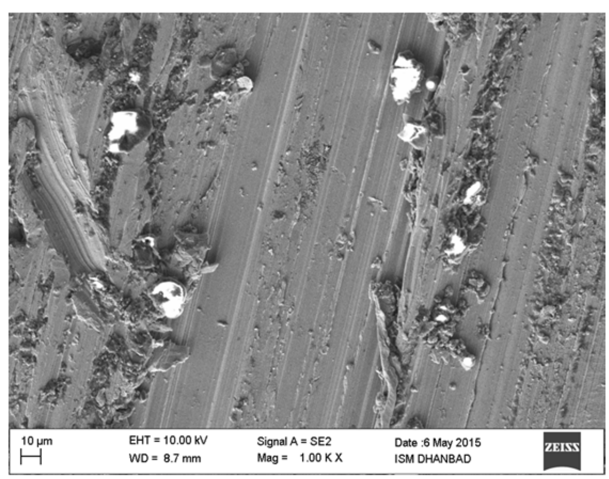

Fig. 28: New material

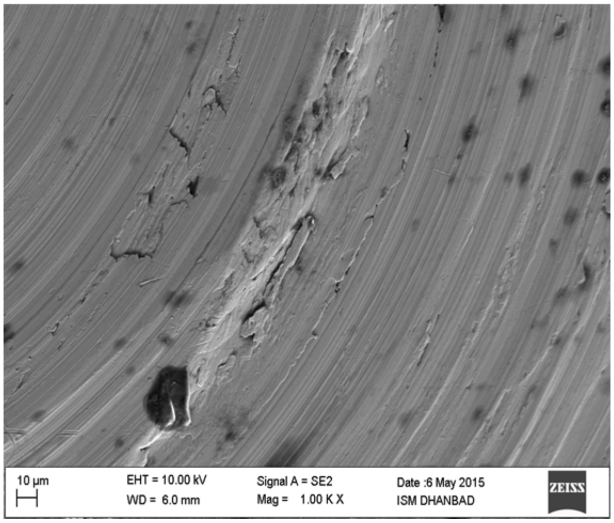

Fig. 29: Worn out material

UHMWPE

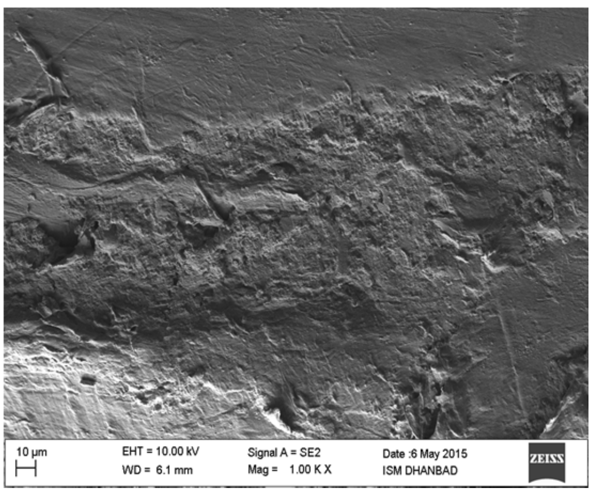

Fig. 30: New material

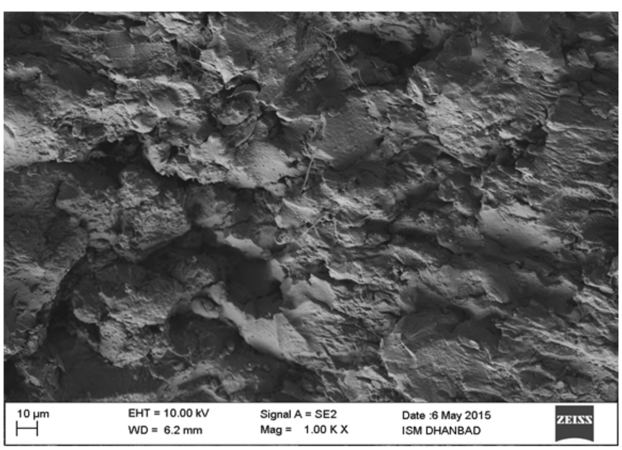

Fig. 31: Worn out material

9. RESULTS AND DISCUSSION

After the fresh pins have worn out, values of Wear, Frictional Force and Coefficient of Friction obtained were observed and noted down. However these values are not the absolute values of the wear parameters of the concerned pin, since a negligible amount of pin debris were accumulated on the wear disc during operational period of time [15-17]. Hence to appropriately verify the wear properties of the desired pin it is necessary to calculate volumetric loss of the pin.

Weight loss calculation is given:

Volume Loss = $\frac{Mass\ loss\ of\ pin}{Density\ of\ pin}$

Also frictional force formula is given by:

Frictional force = coefficient of friction ×normal applied load

Mathematical coefficient of friction =

$$\frac{frictional\ force}{normal\ applied\ load(29.43\ N)}$$

Table 4: Variation of tribological parameters of pin materials

Material	Wear (µm)	Friction Force (N)	Exp. coeff. of friction
Alumina	1167	4.9	0.176
Brass	1176	1.4	0.069
HDPE	357	3.4	0.129
SS 304	1179	6.1	0.146
UHMWPE	41	9.4	0.275

In Table 4 all the obtained the experimental tribological parameters of respective pin materials were jolted down and tabulated for easier analysis.

So these obtained calculated values can be tabulated against the experimental values to conclude upon which pin material has better wear frictional force and coefficient of friction values comparatively. It was found that polymeric materials were a better lot of materials relatively from the others in terms of various tribological parameters.

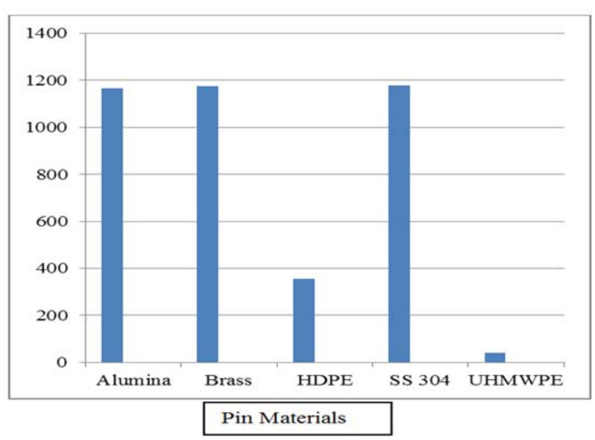

Fig. 22: Graphical representation of worn out pin materials

10. CONCLUSIONS

It was experimentally found that polymeric materials were better in terms of few tribological aspects like wear, whereas the same was not completely applicable for frictional force, coefficient of friction and sliding distance parameters. However with the sole aim of reducing wear it was observed that polymers were indeed the better choice of materials for being an implant material.

Polymeric materials did not have a specific **threshold wear** value where the wear starts becoming constant, implying even with gradual course of time, they can still manage to withstand higher loads. This could be attributed to their **self-lubricating property**.

Although other types of materials need some sort of coating on their surface for efficient functioning, the same justification was not applicable for polymeric materials. However if specific coating is done, it would be even more beneficial for optimizing tribological parameters.

Polymeric materials were also found to satisfy conditions of biocompatibility, Osseo integration and bio inertness respectively.

Another interesting fact was that the loss in weight amid all the materials was found to be with polymers. This explains that for same identical conditions the wear parameter was least for polymers followed by other materials.

But in the present various alternative materials are being used whose selection are done on the basis of biocompatibility and not on the basis of unexpected happenings. Improvements in surface properties are the reasons for the use of this new alternative material.

This study tried to highlight the importance of various other types of implant materials like polymers, ceramics, composites that can be alternatively used, their properties and usage and hopes that this study material is useful for medical researchers working in the bioengineering field.

REFERENCES

[1] Jayant kata, Zhongmin Jin, Eileen Ingham, John Fisher, Bio tribology of Articular cartilage- A review of the recent advances, Medical Engineering and Physics, 30 (2008) 1349-1363

[2] Karin S. Straley, Cheryl Wong Po Foo and Sarah C. Heilshorn, Biomaterial Design Strategies for the Treatment of Spinal Cord Injuries, Journal of Neurotrauma 27:1–19 (January 2010).

[3] Qizhi Chen, George A.Thouas, Metallic implant biomaterials, Materials Science and Engineering R 87 (2015) 1–57.

[4] Mohammad Asaduzzaman Chowdhury, Dewan Muhammad Nuruzzaman, Biplov Kumar Roy, Palash Kanti Dey, Mohammad Golam Mostafa, Mohammad Shahidul Islam and Md. Rashed Mia, Experimental Investigation on Friction and Wear of Stainless Steel 304 Sliding Against Different Pin Materials, World Applied Sciences Journal 22 (12): 1702-1710, 2013.

[5] X.L. Xie, C.Y. Tang, Kathy Y.Y. Chan, X.C. Wu, C.P. Tsui, C.Y. Cheung, Wear performance of ultrahigh molecular weight polyethylene/quartz composites, Biomaterials 24 (2003) 1889–1896.

[6] Katja M.R. Nuss and Brigitte von Rechenberg**,** Biocompatibility Issues with Modern Implants in Bone - A Review for Clinical Orthopedics ,The Open Orthopaedics Journal, 2008, 2, 66-78, 1874-3250.

[7] Mr.Kiran Deore, Ms.Lalita Aage, Prof.Manoj Hajare, Testing of Wear Rate Frictional Force and Coefficient of Friction Computationally Using Pin on Disk, International Journal of Engineering Trends and Technology (IJETT) – Volume 20 Number 5 – Feb 2015

[8] J.B. Park, R.S. Lakes, Biomaterials:An Introduction, Springer, New York, 2007.

[9] S.H. Teoh, Fatigue of biomaterials: a review, International Journal of Fatigue 22 (2000) 825–837.

[10] S.M. Kurtz, The UHMWPE Biomaterials Handbook: Ultra-High Molecular Weight Polyethylene in Total Joint Replacement and Medical Devices, Academic Press, Burlington, Wash, USA, 2nd edition, 2009.

[11] O. K.Muratoglu, C. R. Bragdon, D. O. O'Connor et al., "Unified wear model for highly crosslinked ultra-high molecular weight polyethylenes (UHMWPE)," *Biomaterials*, vol. 20, no. 16, pp.1463–1470, 1999.

[12] H. McKellop, F.W. Shen, B. Lu, P. Campbell, and R. Salovey, "Development of an extremely wear-resistant ultra high molecular weight polyethylene for total hip replacements," *Journal of Orthopaedic Research*, vol. 17, no. 2, pp. 157–167, 1999.

[13] A. A. Edidin, L. Pruitt, C.W. Jewett, D. J. Crane, D. Roberts, and S. M. Kurtz, "Plasticity-induced damage layer is a precursor to wear in radiation- cross-linked UHMWPE acetabular components for total hip replacement," *Journal of Arthroplasty*, vol. 14, no. 5, pp. 616–627, 1999.

[14] A. Wang, A. Essner, V. K. Polineni, C. Stark, and J. H. Dumbleton, "Lubrication and wear of ultra-high molecular weight polyethylene in total joint replacements," *Tribology International*, vol. 31, no. 1–3, pp. 17–33, 1998.

[15] T.J.S. Puolakka, J. T. Keranen, K. A. Juhola et al., "Increased volumetric wear of polyethylene liners with more than three years of shelf-life time," *International Orthopaedics*, vol. 27, no. 3, pp.153–159, 2003.

[16] S.M. Kurtz, W. Hozack, M. Marcolongo, J. Turner, C. Rimnac, and A. Edidin, "Degradation of mechanical properties of UHMWPE acetabular liners following long-term implantation," *Journal of Arthroplasty*, vol. 18, no. 7, pp. 68–78, 2003.

[17] S.M. Kurtz, W. J. Hozack, J.J. Purtill et.al., "Significance of in vivo degradation for polyethylene in total hip arthroplasty," *Clinical Orthopaedics and Related Research*, vol. 453, pp. 47–57, 2006.