CHARACTERIZATION OF CRYO-TREATED ULTRA HIGH MOLECULAR WEIGHT POLYETHYLENE AND FEM ANALYSIS

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Abstract :This work describes the influence of cryogenic treatment on the mechanical properties of material for artificial knee and hip joints. The cryogenic treatment is an emerging technique for improving wear resistance. Property modification of ultra high molecular weight polyethylene is induced by the cryogenic treatment. Uniaxial tensile, compression test has been carried out to test the strength of the samples. Wear and friction of SS316 L / UHMWPE couples are decreased by the cryogenic treatment. The effects of sliding velocity, contact stress and sliding distance on the sliding wear of UHMWPE were determined.The samples are investigated by the scanning electron microscope. Finite element method has been identified as a useful tool to understand the load transfer mechanics and contact analysis between the two specific materials. This paper proposed a new practical approach in modelling the contact interface between two surfaces UHMWPE and SS 316 L.

Keywords: cryogenic treatment, UHMWPE and SS 316 L.

1. INTRODUCTION

Total hip and knee arthroplasties are common procedures in orthopaedic surgery and both are routine, effective and successful treatment modalities. A current estimate of the rate of total hip replacement worldwide amounts approximately one million per year, with over 250,000 knee replacements. One of the most devastating complications is deep periprosthetic infection. In the future, it is expected that the incidence of the prosthetic joint infections will further increase due to (i) better detection methods for prosthetic joint infections, (ii) the growing number of implanted prostheses in an ageing population and (iii) the increasing residence time of prostheses, which are at continuous risk for infection during their implanted lifetime.. Infection remains a serious problem, as it generally requires multiple operations and not infrequently amputations or mortality remain unavoidable during the treatment of these infections.

Results are studied and the effect of contact stress, sliding velocity, and sliding distance on the wear loss. Also the same is done on the friction coefficient. The wear mechanism of UHMWPE is explored by scanning electron microscope (SEM) to examine the worn surfaces of UHMWPE samples having dry sliding contact with SS 316 L. together with finite element modeling of the contacts to establish the stress conditions in greater detail. The FEA tool ABAQUS is used to solve the contact analysis between the above mentioned.

II. PROBLEM DEFINITION

In this article the material Ultra-high-molecular-weight-polyethylene is studied. Characterization is to be done to the Indian type material by studying its properties. Aseptic loosening of prosthetic components may lead to pain, instability and loss of function and thus constitutes a failure. So that the implant subsides, tilts and/or rotates. The position of the implant eventually becomes overtly changed, which can be seen on regular radiographs when it is more than 2–3 mm. Flat interfaces, when imaged parallel to the surface, may show a radiolucent zone as a sign of soft-tissue interposition at the interface. [1]

III. FEM ANALYSIS

A number of analyses of UHMWPE components from both hip and knee replacements were conducted to predict the effect of load, geometry and material properties on the stress and strain distributions in these components. The distal location of the joint below the centre of gravity of the body causes compressive loads acting on the tibiofemoral joint to be as high as 4-7 times the body weight during day-to-day activities such as walking, running or ascending stairs and even 24 times the body weight during jumping. Combined loading conditions during aggressive athletic activities have not yet been measured and could place large loads on the knee joint..

The evaluation of contact areas and pressure in total knee prostheses is a key issue to prevent early failure. Such quantities can be measured by means of in vitro test but the advantage of CAD–FEM is the possibility of changing the geometrical and parameters of the prostheses and evaluating its different behaviors before manufacturing prototypes.

3.1 Methods

3.1.1 Geometries

Here a simple wear test rig has been simulated with this software. The test rig is pin-on-disc apparatus where the experimental method is said in the experiments of wear test. This setup is made in the form of three dimensional models in the ABAQUS. The dimensions are made in the actual form that how it prevail in the actual setup. Pin having a dimension of 10 mm diameter and length of 16mm.These going to be a simple sketch so that it can be modeled in the same sketch mode, or even it can be digitized and exported to computer-aided design CAD

3.1.2 The analysis was conducted in two parts

First, a direct load was applied to press the pin and the plate into contact and second, an angular velocity /rpm were applied to the plate to generate relative sliding with respect to the plate. Thus the surface traction forces reached a maximum governed by the friction coefficient. The displaced shape of the mesh due to this relative sliding under 160, 196 and 117 N of vertical load is shown.

3.2 Finite element methods

The overclosure was constrained to be nonpositive at each slave node. As a result, unknown nodal forces were introduced in the weak statement of equilibrium and were solved for in the equilibrium iteration. These nodal forces played the role of Lagrange multipliers conjugate to the overclosure constraint. During compressive loading, all three rigid-body translations and rotations of the UHMWPE pin. A compressive force of 100 N was applied through the distal tibia at 0 degrees of flexion, normal force.

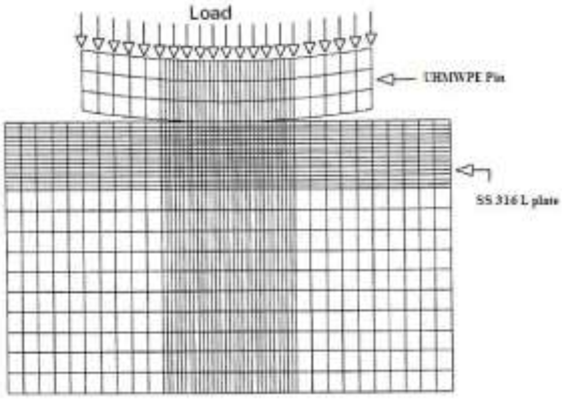

Figure1. FEA mesh model of contact pair

A three-dimensional solid model of the entire UHMWPE/SS 316 L contact-surface pair was constructed and meshed. The mesh size is also related to how well the hexahedral finite element mesh approximates the solid model. Two dimensional view of the contact pair is shown in the figure In general the surface of the discretized finite element mesh does not match that of the solid model. Although distances between these surfaces have been shown potentially to be sizable, the small finite element mesh size in conjunction with the smoothness of the surfaces in the solid model reduced these differences.

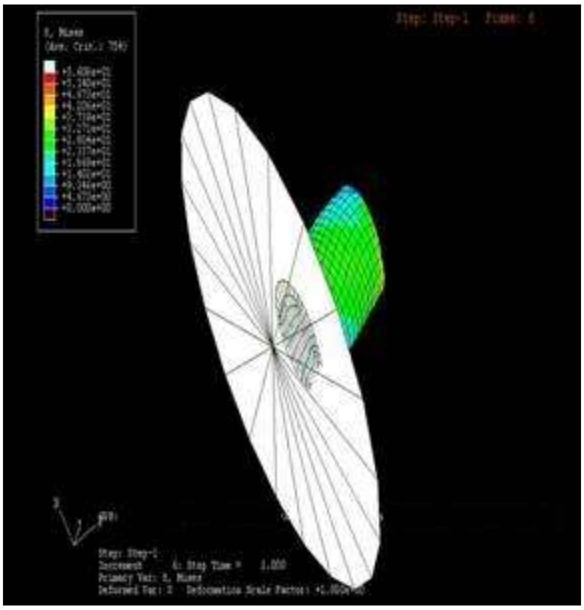

Figure 2. Vonmises stress when the load is maximum

ABAQUS has been used to solve the contact analysis[5]. Figure explains the stress distributions in the UHMWPE. The contact surface is shown and the stress at that interference o the slave node and the master node are in contact can be seen in the respective figures. Simply the compressive stress when the normal load acts on the pin the stress distributes into the pin. Here the contact analysis is surface-to-surface type. The plate is assumed to be the analytically rigid.[2]

IV. TREATMENT & EXPERIMENTS

Combining optimized lubrication, correct mechanical configuration and cryogenic treatment of wearing parts results in the maximum performance of lubricated components can significantly extend component life.

4.1Experiments

4.1.1Tensile test:

. The specimen as prepared by the ASTM standards is fixed into the jaws tightly. Once the sample is fixed the machine is always ready to use. The gauge length (G) is marked and identified in the specimen fixed as 50mm. The machine is under computer interface. The data required to the software installed in to the computer has been given manually such as narrow cross section (W), width and the thickness (T). Out of which the software can able to calculate the required data’s. The crosshead-movement is at the rate of 5mm/min. The specimen starts taking the increasing load, having elongation in the specimen. This change in gauge length and the corresponding load were then used to plot the true stress-true strain curve of the UHMWPE making the usual assumption of constant volume during plastic deformation.. When the load is to be ultimate the material starts developing cracks and this develops up to the edge of the specimen leading the material to fail at the breaking stress in terms of N/mm^2..

4.1.2 Wear testing methods

The methods may be divided into two types those where the sliding surfaces are symmetrically disposed, in which the wear rates or two surfaces of identical materials should be the same, and the more common arrangement where the system is inherently asymmetric, in which the two sliding bodies, even of the same material, will almost certainly experience different rates of wear for reasons discussed below. Symmetrical arrangements are not often used to study wear: examples are the ring-on-ring (or two discs) devices, with contact either along a line or face to face. Such devices are only truly symmetrical if both components are rotated.

The pin-on-disk wear tests used in our study cannot replicate all the tribological conditions found in the artificial hip/knee.

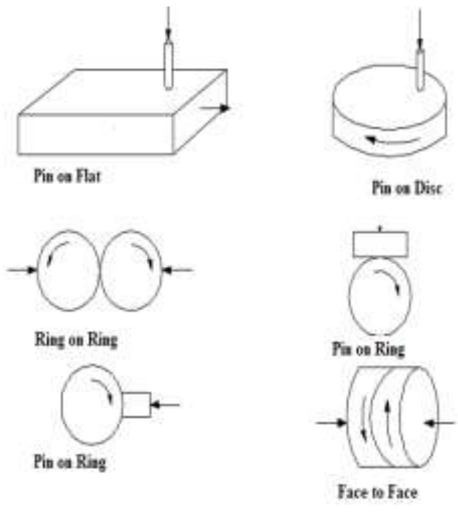

Figure 3. Geometries Employed in Sliding Wear Test.

4.1.3 Wear test rig:

The Materials pin and the disk are made in the required form and this has to be fixed into the correct position in the equipment holder mainly the pin and disk holders. Before the specimens are to be fixed up onto the holders they are to cleaned ultrasonically and the initial weight of the pin is to be found out. The disk specimen is cleaned ultrasonically by means of Acetylene so that the dust and the foreign particles can be removed easily. The pin should be in the firm position so that it should not be slipped due to the vertical load. During loading see to it that in unloaded condition. The test is carried out as per the procedure mentioned in the above part. After the testing has been done the samples are removed and the weight loss is measured in the specimen. By comparing the initial and the final weight the difference in them. With the volume of wear calculated from the mass loss of the sample and the density of the sample.

Figure 4 . Wear test rig-UHMWPE in pin holder and SS 316 L disc in the disk holder

The results from the wear tests can be presented in three forms, the volume of material lost due to wear, the wear rate or the wear factor. The volume of material lost due to wear is simply the primary data from the experiment and does not account for the experimental conditions. Hence it is of limited use when comparing different test conditions. The wear rate can be defined as the volume of material lost due to wear per unit of sliding distance (Equation 1) and is the gradient of the wear volume versus sliding distance graph. Thus the effect of sliding distance can be removed

$$\text{wear rate} = \frac{\text{Volume loss due to wear}}{\text{Siliding distance}} \_\_\_\_ \mathit{Equation}(1)$$

$$= \frac{\text{mm}^3}{\text{m}}$$

The wear factor, as defined in Equation 2, is derived from the wear rate but also accounts for the magnitude of the applied load. The wear factor can also be thought of as the gradient of the wear rate versus load graph. Conventional wear theory suggests that the wear factor is a constant for a given material combination and sliding conditions and is thus independent of the load or sliding distance.

$$\text{Wear Factor} = \frac{\text{Volume loss due to wear}}{\text{Siliding distance X Load}} \_\_\_\_ \mathit{Equation}(2)$$

$$= \frac{\text{mm}^3}{\text{N m}}$$

4.1.4 Compression test

Experimental Method: ASTM D395 B

The specimen is compressed to 10% of its original height, using spacers to accurately measure the compression. Compression set is the permanent deformation remaining after release of a compressive stress.

Specimen size:

Thickness is 12.5mm +/- 0.5mm
Diameter is 29.0mm +/- 0.5mm

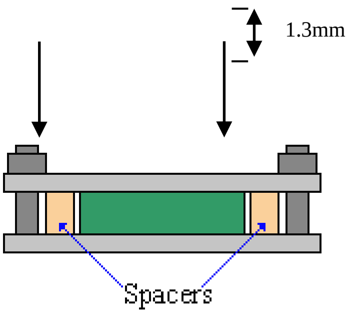

Figure 5. Compression set at 10% deformation of its length

V. RESULTS AND DISCUSSIONS

Sets of UHMWPE samples after the treatment are taken along with untreated samples for the tensile tests. The untreated specimens are initially taken to the testing centers for reporting the tensile strength by means of uniaxial tensile tests. Then the second set of reading is taken for the treated sample. The Universal Testing Machine which is specially interfaced with the computer to produce the stress-strain curve. From the stress- true strain results shown in figures , it can be seen that the flow stress of UHMWPE at any given strain increases with increasing testing

Table 1: stress- true strain

velocity (i.e., average strain rate). It produces very less elongation as the load is given, moving the cross head at the rate of 5mm/min.when comparing the same with the treated sample. The graph shows more elongation (more than 600%).Tensile test datas are shown in table , Considerable differences is shown in their tensile strength. The average value is given for the untreated sample.

5.1 Tensile test results

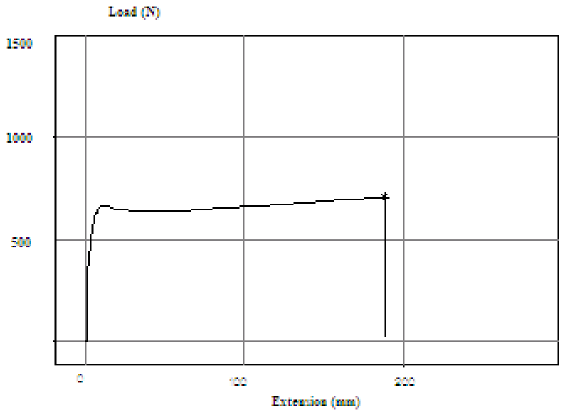

Figure 6. Tensile test graph for untreated UHMWPE material

Table 2 :TENSILE TEST RESULT VIRGIN MATERIAL:

S. No	Maximum Load (N)	Tensile Strength (N/mm²)	Elongation at break %
1	7054.052	36.567	375.949

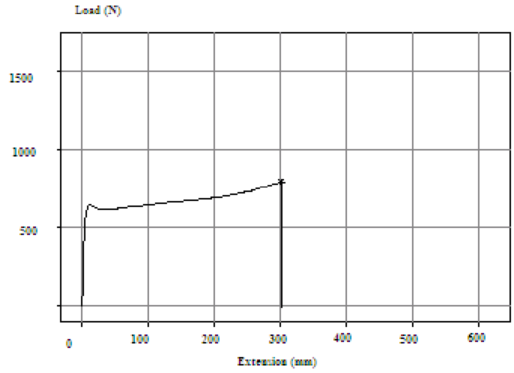

Figure 7. Tensile test graphs for Cryogenic Treated Material-1

S. No	Maximum Load (N)	Tensile Strength (N/mm²)	Elongation at break %	Percentage Difference %
1	7880.101	40.849	601.916	11.7
2	7660.00	40.120	586.123	9.7

The table 2 gives the values of the maximum load and the tensile strength and the percentage difference comparing it from the untreated one. Increase in Tensile strength is by 12 and 10% (approx).The cryogenic treatment results in the increase in the strength. The important area on where the results putting its light on the elongation of the material compared with that of the untreated sample. A very huge amount of elongation is observed in the treated sample. The elongation in the graph indicates that the material takes more load and time to break. Considerable increase in breaking load has been seen in the treated sample compared to that of the untreated.

5.2 Compressive strength test results

Compression strength is calculated using the same uniaxial tensile test machine. The specimen both treated and the untreated are considered as two sets and the tests are conducted by producing deformation in the material Compression set at 10% deformation is taken. The material is compressed to 10% of its length the average values are presented in the table. Increase in the compressive strength of 7.2% is seen on the treated material compared to that of the untreated sample .The values shown here, the difference is very low. The increase in compressive stress in the influence of the cryogenic treatment is not so high. The curves are plotted with the help of software in interface computer .

Table3 : COMPRESSION STRENGTH AT 10% ELONGATION-CRYOGENIC TREATED & UNTREATED:

S. No	Sample Type	Deflection at Maximum Load (mm)	Compressive Strength (N/mm²)	Percentage difference %
1	TREATED	1.299	36.706	7.19
2	UNTREATED	1.300	34.244	

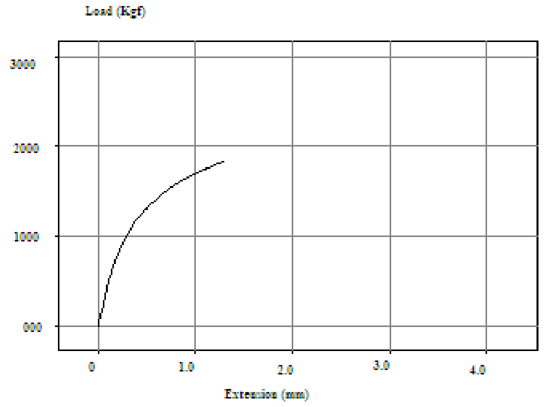

Figure 8. Compression set at 10 % elongation for untreated Material.

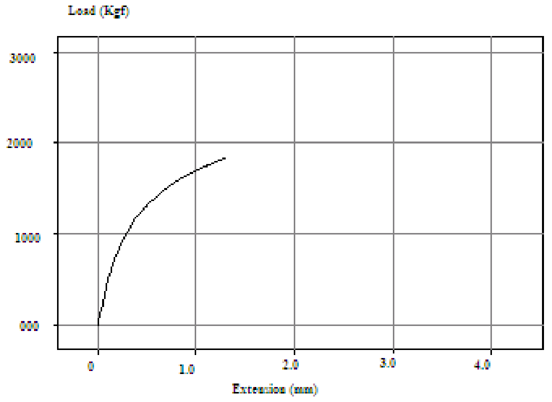

Figure 9. Compression set at 10 % elongation for Cryogenic treated Material.

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5.3 Wear test results:

Wear test is carried to the samples of both grades treated and untreated. At various load conditions the test has been conducted. Various effects of contact stress, sliding velocity, and sliding distance on the friction coefficient and the wear rate is shown. The result has been studied.

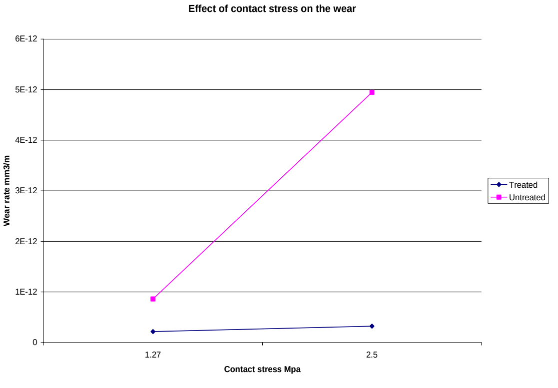


Figure 10. Effect of conduct stress

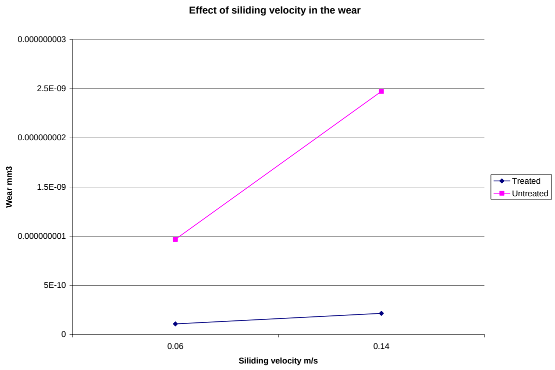


Figure 11. Effect of sliding velocity

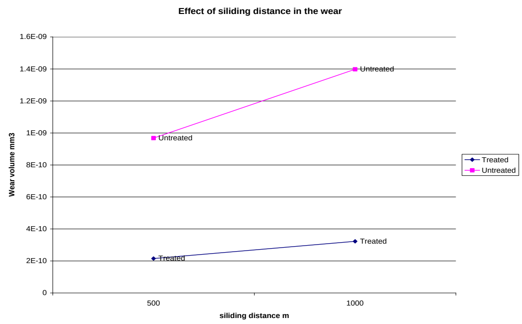
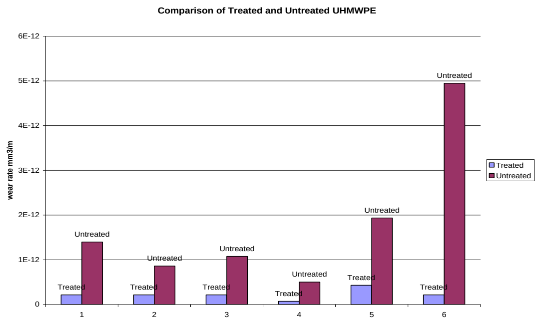


Figure 12. Effect of sliding distance



1- 2.50Mpa,0.14m/s, 1000m
2- 1.27Mpa,0.06m/s, 500m
3- 2.04Mpa,0.1m/s,500m

Figure 13. Comparative wear performance of Treated and Untreated UHMWPE.

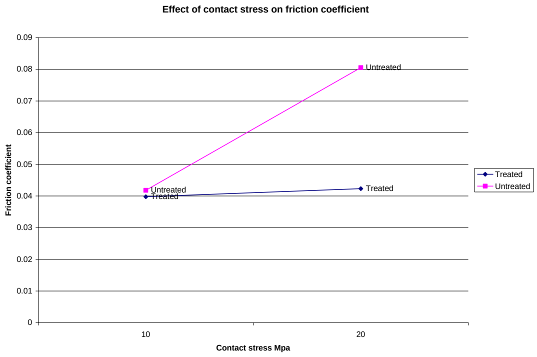


Figure 14. Effect of contact stress on friction co-efficient

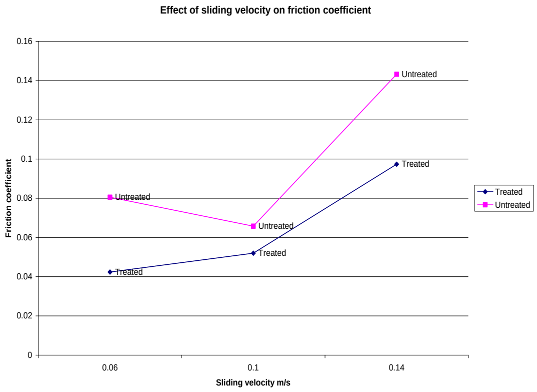


Figure 15. effect of sliding velocity on friction co-efficient

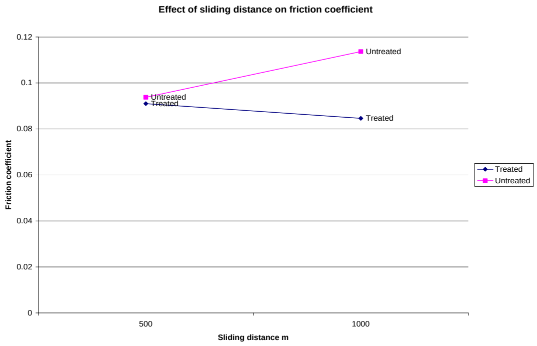


Figure 16. effect of sliding distance on friction co-efficient

VI. SCANNING ELECTRON MICROSCOPE

Scanning electron microscope (SEM) was carried out with JSM 840 scanning microscope. The samples were coated with a very thin gold film to make them electrically conductive. The gold coating is performed on the sample after the thin aluminum foil is made to wind on the cylindrical surface. The fine coating is given with the help of JFC 1100E. Generally the acceleration used voltage was 20Kv.Generally the photo magnification is of 250 to 40000 times. At least three scans were made per test.

6.1Sem results

The SEM studies were performed on treated and the untreated samples are shown in the figure Particles were observed to be quite separated from each other. However, cryogenic treated particles were found to be agglomerated, A very dense network of microfibrils originating from each particle was a remarkable and distinct feature of treated samples. Such microfibrils were rarely seen in the case of untreated samples, The surface texture of worn surface of the untreated polymer appeared to be quite smooth ,compared to the rough topography of the cryogenic treated surface. The enhanced roughness of the surface could be due to the contraction at cryogenic temperatures and uneven expansion when it was brought back to the ambient temperature. The residual stresses developed in the polymer owing to the difference in temperature and residual strains developed due to the contraction force might have been responsible for these topography changes.

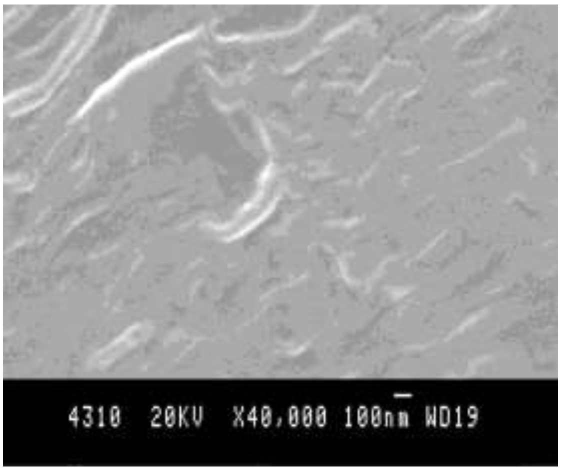


Figure 17.Virgin UHMWPE (Untreated Sample)

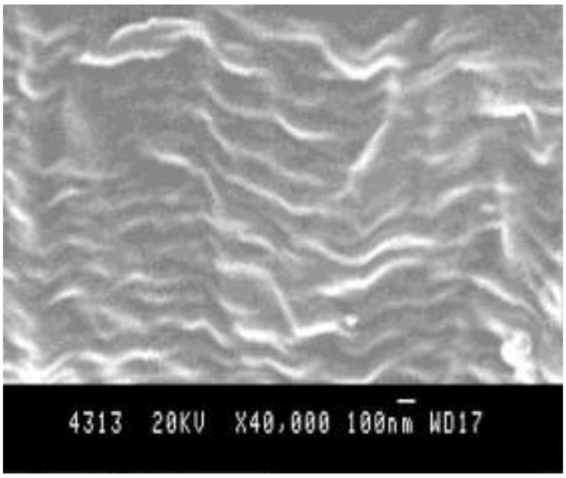


Figure 18. UHMWPE (Treated Sample)

The SEM was found to be useful in correlating wear performance with morphological changes due to cryogenic-treatment. In the case of metals, improvement in hardness and hence, wear performance due to cryogenic-treatment has been reported by [2]. In the present studies, a similar trend was observed in the case of selected polymer.

Figure shows the SEM images worn surface of UHMWPE pin after 1000m sliding distance. The appearance of worn surface of treated sample is very smooth compared to that of the untreated sample. The wear surface is finished and there are plow traces along sliding direction and a lot of deep micro-crack distribution on the worn surfaces for the untreated UHMWPE[3] . Grooves on the worn surface on the untreated sample which indicate that abrasive wear was predominant But the treated samples have a very good resistance to the counter surface SS 316 L which produces a smooth surface

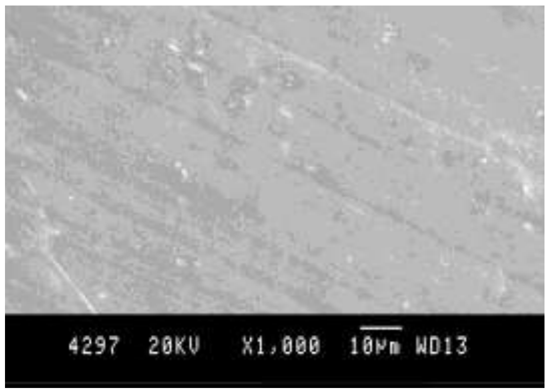


Figure 19 .Worn surface-Treated

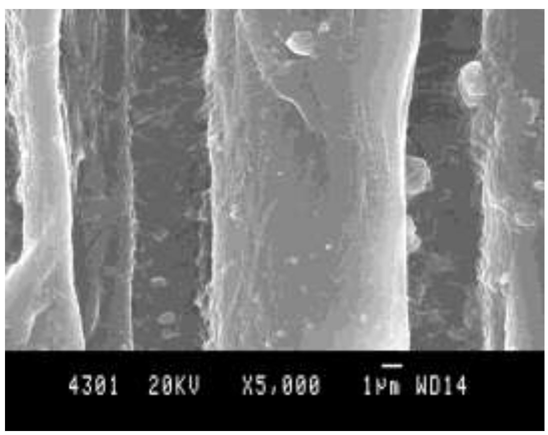


Figure 20. Worn surface-Untreated

VII. CONCLUSION

- Obtained results indicate that an UHMWPE polymer suffers of strong modifications when subjected to cryogenic treatment. Treatments of polymeric surface smoothes the implanted area reducing the surface roughness and the friction.
- The cryogenic treatment has proved to be an effective technique enhancing abrasive wear performance
- The lowest specific wear rate was observed.
- In general, the wear rate is influenced by the cryogenic treatment.
- The specific wear rates of untreated UHMWPE, is $10^{-12}mm^3/m$ and for the cryogenically treated UHMWPE is $10^{-14}mm^3/m$.

- The sliding speed should be sufficient low in order to restrict the temperature rise of the polymers used. This temperature rise results in a considerable increase in the friction coefficient values.
- In the sliding wear of UHMWPE, sliding velocity exerts greater influence on the sliding wear than the applied load.
- Elongation in the sample is more while conducting tensile test in uniaxial testing machine 12% increase in the tensile strength is observed.
- 7% increase in the compression strength while compressive set in the LR 100K
- The underlying motivation for this finite element analysis study was to develop a computational tool that could ultimately be used to identify variables important in the design and/or selection of meniscal replacements.

In conclusion, the new properties given to the UHMWPE surface by cryogenic treatment are very interesting to improve the functionality of mobile prostheses. Cryogenic treatment reduces the wear and increases the surface hardness of the polymer

REFERENCES

[1] P. S. M. Barbour, D.C.Barton, J. Fisher,(1997),*The influence of stress conditions on the wear of UHMWPE for total joint replacements ,Journal Of Materials Science: Materials In Medicine 8* ,pp. 603 -611.

[2] Brian Kwan Ping Wong, Sujeet K. Sinha, Joyce Pei Ying Tan, and Kai Yang Zeng,(2004),*Nano-wear mechanism for ultra-high molecular weight polyethylene (UHMWPE) sliding against a model hard asperity, Tribology Letters, Vol. 17, No. 3* pp. 613-622.

[3]HarveyL.Stein,P.E,Ticina,LLC.(1999),*Ultra High Molecular Weight Polyethylene,(UHMWPE)*,ASM International.

[4] Hibbitt, Karlsson & Sorensen 2002., Inc., Pawtucket, RI; *ABAQUS user Manual version 6.4.*

[5] Hsu-Wei Fang,Stephen M. Hsu,Jan V. Sengers,(2003), *Ultra-High Molecular Weight Polyethylene Wear Particles Effects on Bioactivity NIST Special Publication 1002.*