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# Surface mechanical and time-dependent properties and tribological response of $N_2^+$ irradiated UHMWPE for medical applications

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**Abstract** – Depth sensing indentation tests were carried out to determine elastic modulus, universal hardness, friction coefficient, wear volume, and creep response of a commercial grade UHMWPE irradiated with $N_2^+$. It was demonstrated that this irradiation treatment increases the UHMWPE elastic modulus and hardness, reduces the apparent friction coefficient, diminishes the creep amount and improves its nanowear behavior.

An important application of UHMWPE in the medicine field concerns the interface of mobile joints such as hip and knee prostheses. Unfortunately, its wear, and the resultant wear debris inducing osteolysis, is now recognized as one of the major causes of premature failure of the joints. The swift heavy ion irradiation technique (SHI) has been recently proposed as a useful technique to modify the surface layers of UHMWPE [1]. In the present work, a thorough surface mechanical and tribological characterization was performed on a commercial grade UHMWPE before and after irradiation with $N_2^+$ (33Mev, fluence $1x10^{12}cm^{-1}$) by means of depth sensing indentation techniques. Experiments were conducted using a Hysitron Triboindenter at nano and micro scales.

Indentation tests were performed to determine elastic modulus and universal hardness as a function of penetration depth (Figure 1). At very low penetration depths (<2μm), a large scatter of the properties values was observed. We demonstrated that this scatter is not due to surface roughness, but to the influence of amorphous and crystalline domains [2], which exhibit different contact deformation. At larger penetration depths (>10μm) the mechanical response became homogeneous. After irradiation, the UHMWPE surface showed higher reduced elastic modulus and hardness values than the untreated UHMWPE. According to calculations made by the Stopping and Range of Ions in Matter software, the projected ion range is 40 μm in agreement with the penetration at which changes in properties were observed.

The creep response was investigated by applying step loads. The amount of creep $C_{IT(0.001/2/56)}$ (ISO 14577-1 2002E), decreased from 24 to 15% after irradiation, consistently with the increase in elastic modulus.

Nanoscratch tests were carried out to compare the apparent friction coefficient, which was reduced from 0.23 to 0.16 after irradiation. Several nanowear tests were performed using the SPM module (Figure 2). $N_2^+$ irradiation at the given fluence was able to reduce the wear volume by about 77%.

Usual γ-irradiation techniques also modify the bulk structure of the polymer leading to improved wear but poor fatigue and long deformation properties. In contrast, our results suggest that $N_2^+$ irradiation at high energy and low fluence is able to modify the surface properties of UHMWPE improving its wear behavior without affecting its desirable bulk properties.

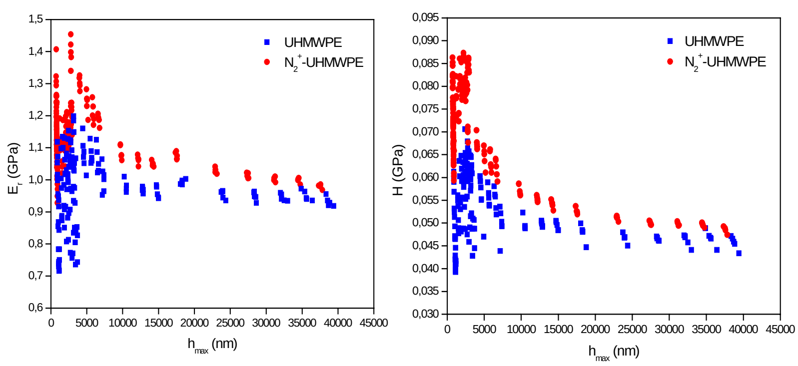


**Figure 1:** Reduced elastic modulus and hardness as a function of maximum penetration depths.

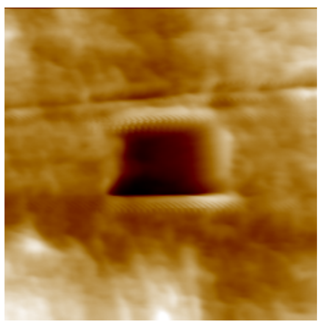

**Figure 2:** SPM image of the worn area in UHMWPE

## References

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[2] J. Zhou, A. Chakravartula, L. Pruitt and K. Komvopoulos. Transactions of the ASME, Vol.126, (2004), 386-394.