EFFECT OF RADIATION DOSE ON THE PHYSICAL PROPERTIES OF CROSSLINKED UHMWPE

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Introduction: Crosslinked ultra high molecular weight polyethylene (UHMWPE) is being investigated as an extremely wear resistant orthopaedic bearing material. In hip simulator wear tests, McKellop(1) and Gul(2) have shown improved wear resistance of crosslinked UHMWPE as a function of radiation dosage or crosslink density. Doses greater than 150 kGy had no measurable wear. This material has the obvious advantage of increasing the longevity of implants by eliminating particle induced osteolysis and implant loosening. However, the radiation crosslinking process may impact other material characteristics, such as impact strength, tensile properties and oxidation resistance, which contribute to the success of an implant bearing material. The objective of this study was to measure the effect of radiation dose on those properties, other than wear, of radiation crosslinked UHMWPE.

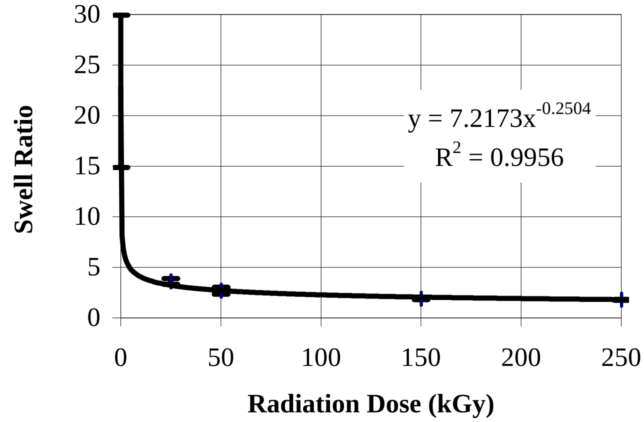
Methods: Three inch diameter, ram extruded rods of Hoechst Celanese GUR 4150 UHMWPE were packaged in evacuated heat sealed foil/plastic pouches and exposed to gamma radiation doses of 25, 50, 150 and 250 kGy. The packaged rods were then heat treated at 200C for 48 hours and cooled slowly to ambient temperature. The rods were machined into various test specimens with a minimum sample size of 3 for each radiation dose. Density tests were performed in accordance with ASTM 1505. Melting temperatures and heats of fusion were determined by differential scanning calorimetry (DSC) using a DuPont Model 2000 thermal analyzer. Swell ratio tests conformed to ASTM D2765, Method C. Impact strength testing conformed to ASTM F648 Annex A1 using double notched Izod specimens. Tensile properties were measured in accordance with ASTM F648 and ASTM D638. Oxidation was measured per Ref. 3. The zero dose specimens were machined from as received ram extruded GUR 4150 UHMWPE rods from PolyHi Solidur.

Results: Swell ratio, impact strength and elongation to break were the only properties greatly affected by radiation dose, as shown in plots 1, 2 and 3. The square of the correlation coefficients (R^2) for radiation dose versus swell ratio, impact strength and elongation were .996, .996, and .997 respectively. The error bars shown in the plots correspond to ± one standard deviation. Radiation dose had little or no effect on the averages of the following UHMWPE properties: melt temperature (138C), heat of fusion (148 J/g), density (0.933 g/cc), yield strength (22 MPa) and oxidation (0.07 carbonyl area/mil of thickness). The modulus of elasticity showed a decrease from 951 to 683 MPa with the initial dose of radiation, then remained constant through the rest of the radiation range. Ultimate strength increased from 32 MPa to 41 MPa at 50 kGy, then decreased to 30 MPa with higher doses.

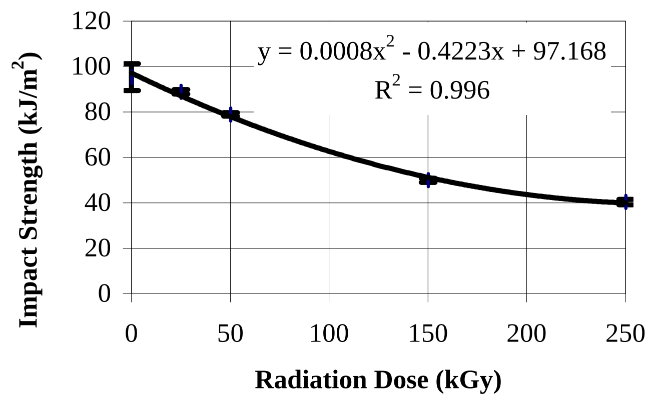
Discussion: The effect of radiation on the physical properties of crosslinked UHMWPE was measured. Swell ratio, impact strength and elongation correlated strongly with radiation dose. Since crosslinking was previously shown to correlate well with radiation dose(4), and the swell ratio is a measure of crosslinking, the excellent correlations between radiation dose and swell ratio was expected. The excellent correlation between radiation dose and both impact strength and elongation were unexpected. The plots developed from this test are good predictors of impact strength and elongation for UHMWPE, given radiation doses less than 250 kGy. Large radiation doses caused decreased impact strength and elongation. UHMWPE exposed to these doses should be evaluated carefully in applications where these properties are important for the success of an implant.

References
1. McKellop, H., Harvard Med. School Hip Course (1996)
2. Gul, R.M., et al, Transactions of the 44th Annual Meeting of the Orthopaedic Research Society, P. 99-17, 1998.
3. Sanford, W.M., et al; Transactions of the 41st Annual Meeting of the Orthopaedic Research Society, P. 119-20, 1995.
4. Muratoglu, O.K., et al, Transactions of the 44th Annual Meeting of the Orthopaedic Research Society, P. 782, 1998.

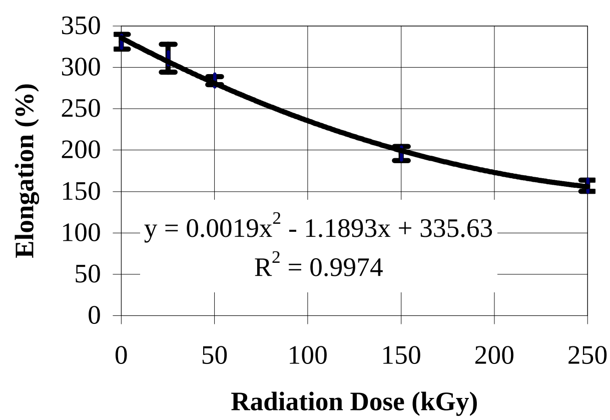
Plot 1: Swell Ratio vs Radiation Dose



Plot 2: Impact Strength vs Radiation Dose



Plot 3: Elongation vs Radiation Dose



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