Comparison of chemical and mechanical properties of UHMWPe and HDPe after irradiation and annealing

Marc Hooper, Marlon Ridley, Scott Bible, and Jon Moseley
Wright Medical Technology 5677 Airline Road, Arlington, TN 38002

Statement of Purpose: Cross-linked Ultra high molecular weight polyethylene (UHMWPe) has been shown to be a low-wear articulating surface in acetabular components. A key step in the production of cross-linked UHMWPe for use in implants is thermal treatment (annealing) near or above the melting point to eliminate residual free-radicals created during irradiation. This technique was used for e-beam irradiated high density polyethylene (HDPe) by both Dole[1] and Gielenz[2] in order to eliminate residual free radicals and prevent oxidation.

The purpose of this investigation was to determine whether the methods described by Gielenz would result in similar changes in the mechanical and chemical properties of UHMWPe as compared with HDPe.

Materials/Methods: Compression molded blocks of UHMWPe (GUR 1020) and HDPe (Rochling Eng. Plastics) were γ or e-Beam irradiated at doses of 5, 10, and 25Mrad. Specimens were annealed according to the method described by Gielenz (5 hours @ 180°C). Also included were controls that were either un-irradiated, un-annealed, or both. Test specimens were machined from the blocks, avoiding excessive heating. Tensile and IZOD impact tests were conducted according to ASTM D638 (Type IV dogbone) and ASTM F648, respectively. Specimens were also aged under accelerated conditions (80°C for 30d or 70°C-5 atm O_2 for 14d) and analyzed for oxidation. Oxidation index was measured with Fourier Transform Infrared (FTIR, Nicolet Magna-IR) according to ASTM F2102, and Electron spin resonance (ESR, Bruker EMX X-band) was used to measure free radical concentrations.

Results and Discussion: Yield strength for annealed materials is plotted vs. radiation dose in Fig 1. In both HDPe and UHMWPe the yield strength was moderately lower for the 5 MRad irradiated groups compared to unirradiated controls. Subsequent changes as the dose was increased from 5 to 25MRad were much smaller, with essentially no change between 10 and 25 MRad.

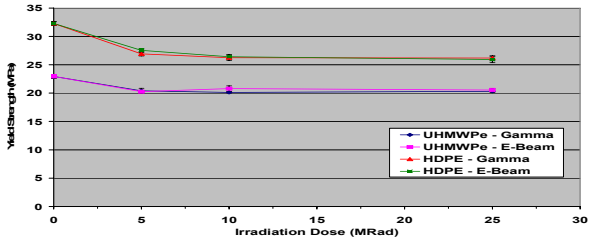

Figure 1. Yield strength vs. dose

The trends for modulus as a function of radiation were virtually identical to those for yield strength for both HDPE and UHMWPE. Ultimate tensile strength (UTS) was significantly different between UHMWPe and HDPe for the 0 and 5MRad groups (HDPe < UHMWPe), but not at the higher doses of 10 and 25MRad.

Elongation at break was highly variable. UHMWPe specimens demonstrated a steady decrease in percent elongation with increasing dose. For HDPe, there was an initial increase in elongation at break between the unirradiated controls and the 5 MRad specimens, which did not occur with UHMWPe. As irradiation dose was increased, the elongation at break for HDPe and UHMWPe decreased in a manner similar.

Impact strength as a function of radiation dose is shown in Fig 2. Impact strength demonstrated a trend similar to that shown for elongation. For UHMWPe impact strength decreased with increasing dose, with the largest difference seen between 0 and 5 MRad. In contrast, HDPe exhibited a significant increase in impact strength upon irradiation. The increase was largest at 5MRad, and with higher radiation doses the impact strength decreased slightly. As with the tensile properties, there was no effect of radiation type on impact strength.

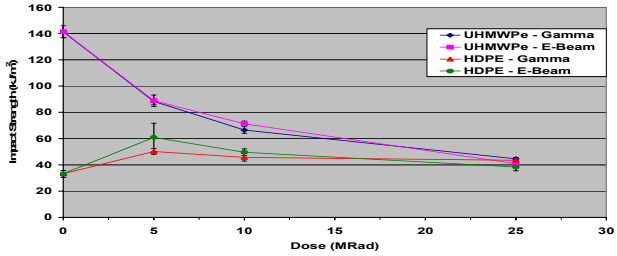

Figure 2. Impact strength vs. dose

ESR measurements showed that free radicals are created at similar concentrations in both UHMWPe and HDPe by irradiation treatment. Non-annealed groups had a substantial amount of free radicals present (>10^{16} spins/g). The concentrations for annealed UHMWPE and HDPE were below the detection limit (~10^{13} spins/g).

FTIR analysis of accelerated aged specimens showed no measurable oxidation in any annealed specimen. The non-annealed samples γ-irradiated at 10 MRad had maximum oxidation index of 2.0 for UHMWPE and 0.32 for HDPE at a depth of 75μm below surface.

Conclusions: The observed changes in chemical and mechanical properties for UHMWPe irradiated and annealed according to Gielenz were in agreement with the published literature for cross-linked polyethylene. The trends in property changes with increasing radiation dose were similar between UHMWPe and HDPe, although there were notable exceptions in the initial changes in elongation at break and impact strength. Gamma and E-beam radiation were virtually identical in their effects on all properties measured for UHMWPe and HDPe.

References:

1) Dole M. Radi. Phys. & Chem. 1979;14:711-720
2) Gielenz G. Collo. & Poly. Sci. 1982;260:742-753