Optimized Wear Resistance and Toughness of Vitamin E blended, High Temperature Melted, Radiation Cross-linked and Annealed UHMWPE

Doshi, Brinda[1]; Oral, Ebru[1,2,+]; Muratoglu, Orhun[1,2]
[1]Harris Orthopaedic Laboratory, Massachusetts General Hospital, Boston MA 02114
[2]Department of Orthopaedic Surgery, Harvard Medical School, Boston MA 02115
eoral@partners.org

Statement of Purpose: Radiation cross-linking improves the wear resistance of ultrahigh molecular weight polyethylene (UHMWPE) but reduces its toughness [1]. Heating UHMWPE to temperatures much higher than its melting point (~280 - 330°C) after consolidation was shown to markedly increase its toughness; this increase was attributed to the increased inter-granular diffusion of the polymer chains [2].

In this study, our goal was to determine the effect of the irradiation dose on the wear and mechanical properties of vitamin E-blended, high temperature melted, radiation cross-linked and annealed UHMWPEs.

Methods: Sample Preparation: 0.2wt% vitamin E/UHMWPE (GUR 1020) blend was consolidated (Orthoplastics Inc., UK) and melted in a N_2 convection oven at 120°C for 5 hours followed by 310°C for 8 hrs and then irradiated to130, 140, 150, 160, 170, 175 and 180 kGy. These samples were then annealed for 5 hrs at 130°C. Characterization: Crosslink density of the sample (3 mm^3) of the material was determined gravimetrically according to ASTM F2214-02. Crystallinity was determined by heating the sample and a reference at a heating rate of 10°C/min from -20°C to 180°C [2]. Type V tensile specimens (n=5) were stamped out and tested according to ASTM-638. Pin-on-disc (POD) wear testing was performed [ref] and wear was measured gravimetrically every ~0.16 MC. Double-notched impact strength measurements were conducted on samples of 63.5 x 12.7 x 6.35 mm^3 according to ASTM F648. Statistical significance was calculated using student's T test and was significant for $p<0.05$.

Results: The cross-link density did not increase substantially with increasing radiation dose from 130 to 180 kGy ($p>0.05$). The elongation at break (EAB) also did not show a substantial change with increasing radiation dose; from 130 to 180 kGy ($p>0.5$). However, the EAB and wear rate decreased with increasing cross-link density (Table 1).

The ultimate tensile strength (UTS), yield strength (YS) and crystallinity of all vitamin E blended, HTMed, irradiated and annealed UHMWPEs was 42.9 ± 1.7 MPa, 21.9 ± 0.3 MPa and 63.8 ± 1% respectively. The UTS, YS and crystallinity did not show significant changes with changes in any parameter (Table 1).

Conclusions: Based on our previous studies, we used 0.2wt% vitamin E as more than 0.3wt% vitamin E has been shown to hinder cross-linking in UHMWPE [3]. Also, we did HTM at 120°C for 5 hours followed by 310°C for 8 hours to subject the UHMWPE to a slow heating cycle.

Our goal was to study the effect of the radiation dose on the wear and mechanical properties of vitamin E blended, HTMed, irradiated and annealed UHMWPE, which was positively achieved. The insubstantial increase in the cross-link density with increasing radiation dose can be attributed to the high chain scissioning occurring during HTM. The resulting wear rates showed a variation due to weak correlation with radiation dose and cross-link density; making the outcome harder to predict. This suggests that the wear rate is still strongly affected by decreased plasticity in the amorphous phase, but it also suggests that the unique microstructure caused by HTM before irradiation contributes additionally to decreased wear.

The EAB and impact strength decreased insignificantly with increasing radiation dose as HTM imparts increased EAB and toughness prior to irradiation. The significant decrease in wear rate does not affect the EAB and the impact strength presumably due to a change in the network structure post HTM.

Thus, these high temperature melted, radiation cross-linked and annealed UHMWPEs have significantly improved toughness without sacrificing wear resistance

References: [1] Oral et al. Biomaterials 27:917-925 (2006). [2] Fu et al. Polymer 51(12):2721-2731 (2010). [3] Oral et al. Biomaterials 29: 3557-3560 (2008).

Table 1: Effect of radiation dose on mechanical properties, wear and cross-link density.

Sample	UTS (MPa)	YS (MPa)	EAB (%)	Cross-link Density (mol/dm^3)	IZOD Impact Strength (kJ/m^2)	Wear Rate (mg/MC)	Crystallinity (%)
130 kGy	43.5 ± 1.5	22.5 ± 0.4	411 ± 24	0.091 ± 0.002	82.98 ± 1.12	7.85 ± 0.34	64 ± 0.5
140 kGy	43.7 ± 0.5	22.2 ± 0.5	392 ± 9	0.087 ± 0.004	83.55 ± 1.24	2.70 ± 0.24	62.8 ± 1.9
150 kGy	43.7 ± 0.3	22.1 ± 0.2	378 ± 14	0.102 ± 0.002	81.00 ± 1.44	5.29 ± 0.59	63.2 ± 1
160 kGy	42.5 ± 1.15	21.5 ± 0.5	359 ± 8	0.116 ± 0.002	77.4 ± 0.69	2.22 ± 1.28	62.9 ± 1.5
170 kGy	42.6 ± 2.4	22.1 ± 0.5	348 ± 15	0.137 ± 0.015	77.5 ± 0.87	1.77 ± 0.59	64.4 ± 0.5
175 kGy	45 ± 0.9	21.7 ± 0.9	359 ± 7	0.128 ± 0.006	71.2 ± 1.1	0.78 ± 0.11	62.6 ± 1.5
180 kGy	39.5 ± 1.9	21.6 ± 0.1	320 ± 24	0.135 ± 0.003	70.1 ± 0.47	1.41 ± 2.56	64.7 ± 1.1