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

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Introduction 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 increased its toughness; this was attributed to the increased inter-granular diffusion of the polymer chains [3]. During High Temperature Melting (HTM), a large number of terminal vinyl groups are created, which, when irradiated, result in a uniquely cross-linked structure with improved wear resistance and toughness [4]. Our goal was to determine the relationship between the HTM melting temperature, irradiation dose, post-irradiation annealing below the melting point and the wear and mechanical properties of vitamin E-blended, high temperature melted and radiation cross-linked UHMWPEs. **Methods** Medical grade 0.1 and 0.2wt% vitamin E blended GUR1020 UHMWPE was consolidated into pucks (6.7 cm in diameter and 5.6 cm in length). These pucks were melted in a nitrogen convection oven for 6 hrs at 300, 310 or 320°C and cooled at a rate of ~2.5°C/min. They were then irradiated at a rate of 25 kGy/pass to 125, 150 or 175 kGy. One set of 0.1wt% vitamin E-blended pucks were further annealed at 130°C for 5 hours. Cross-link density was measured by swelling 3 mm cubes in xylene at 130°C. It was further calculated as previously described [5]. Crystallinity was determined using a Q-1000 Differential Scanning Calorimeter at a heating rate of 10°C/min from -20°C to 180°C as previously described [3]. Type V tensile specimens (n=5) according to ASTM-638 were stamped out of 3.2 mm thick sections and tested with a crosshead speed of 10 mm/min. Thin sections (150 µm) were cut from an inner surface of the samples. Pin-on-disc (POD) wear testing was performed on cylindrical pins (dia. 9 mm, height 13 mm) as previously described at 2 Hz [5]. Statistical significance was calculated using a Student t-test. **Results** The cross-link density did not increase with increasing radiation dose from 125 to 150 kGy (p= 0.54) or 150 to 175 kGy (p= 0.48). The elongation at break (EAB) also did not show a change with increasing radiation dose; from 125 to 150 kGy (p= 0.62) and from 150 to 175 kGy (p= 0.15). However, the wear rate decreased with increasing cross-link density (Fig 1). These results suggest that the wear rate is still affected by decreased ductility in the amorphous phase, but also by the unique microstructure caused by HTM before irradiation.

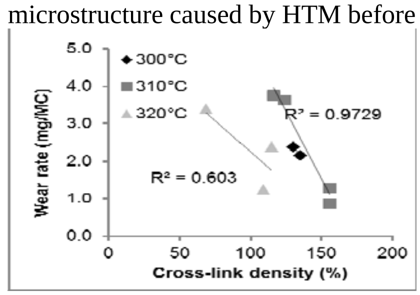

Fig. 1: The wear rate as a function of crosslink density for 0.1wt% vitamin E-blended, high temperature melted and irradiated UHMWPEs.

Post-irradiation annealing decreased wear (p= 0.64, Fig 2a) and EAB slightly (p=0.59; Fig 2b). The ultimate tensile strength (UTS), yield strength (YS) and crystallinity of all UHMWPEs was 44.5 ± 3.8 MPa, 24.5 ± 0.8 MPa and 65.8 ± 2% without significant changes with processing. The resulting wear rates ranged were 0.9 to 3.8 mg/MC; this variation was expected since the wear of this material had a weak correlation with radiation dose and cross-link density; making the outcome harder to predict.

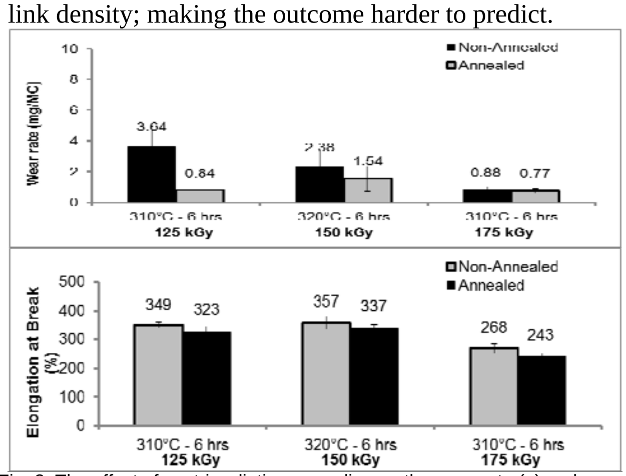

Fig. 2: The effect of post-irradiation annealing on the wear rate (a) and elongation at break (EAB) (b) of 0.1wt% vitamin E-blended, high temperature melted and irradiated UHMWPEs.

Since the UTS, YS and crystallinity are not affected by HTM or irradiation significantly, toughness is directly related to increased elongation. Thus, these high temperature melted, radiation cross-linked UHMWPEs may have improved toughness compared to their conventionally irradiated counterparts without sacrificing wear resistance. **Significance** Vitamin E blended, high temperature melted and irradiated UHMWPE is a feasible alternative for joint bearing surfaces due to its low wear rates and increased toughness compared to current highly cross-linked UHMWPE.

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