INTRODUCTION: Ultra-high molecular weight polyethylene (UHMWPE) is used worldwide as a bearing material in orthopaedic implants. UHMWPE wear debris generated by articulation against metallic implant counterfaces is a major factor limiting the lifespan of joint prosthetics [1]. In vitro joint simulator studies have shown that wear resistance can be enhanced by radiation crosslinking UHMWPE [2,3]. However, crosslinking can also reduce mechanical properties including Young’s modulus, ultimate tensile stress, strain-to-break, J-integral fracture toughness [4,5,6], and fatigue crack propagation resistance [7]. In contrast, Hylanertm (Depuy-Dupont Orthopaedics) which employed a high pressure crystallization process had a higher Young’s modulus, resistance to creep deformation [8] and resistance to fatigue crack propagation [9] than conventional UHMWPE due to its substantially higher crystallinity (65-71% for Hylanertm versus 45-55% for conventional UHMWPE). However, Hylanertm did not show a substantial increase in resistance to wear compared to conventional UHMWPE [10]. We hypothesized that high pressure crystallization performed on crosslinked UHMWPE would improve the mechanical properties of UHMWPE by increasing its crystallinity while maintaining a high resistance to wear. Such a UHMWPE material would be more suitable for application in joints where both resistance to wear and superior mechanical properties are essential. In this study, we fabricated UHMWPE bars using high pressure crystallization on both uncrosslinked and crosslinked UHMWPE and characterized their morphology using differential scanning calorimetry (DSC) and low voltage scanning electron microscopy (LVSEM). The results showed that the crystallinity of crosslinked UHMWPE can be increased by at least 10% using high pressure crystallization.

METHODS: GUR 1050 (Hoechst-Ticona, Bayport, TX) UHMWPE rodstock (PolyHi Solidor, Ft. Wayne, IN) was gamma-irradiated at doses of 50 kGy and 100 kGy (Somero, Norcross, GA). Following irradiation, UHMWPE was melt-annealed in a vacuum oven at 170 °C for 4 hours and slowly cooled to room temperature. Both as-received rod stock and unirradiated rod stock subjected to an identical thermal history as the irradiated rod stock were used as controls. All UHMWPE samples were machined into 12.5mm diameter x 3.75cm length bars. A high pressure cell with a 12.5mm diameter cylindrical cavity was constructed. The cell was loaded with a UHMWPE bar, and then heated to either 160 °C or 240 °C at atmospheric pressure using cartridge heaters regulated by a temperature controller. Temperature was maintained for 1 hour to allow for complete equilibration before 500 MPa of pressure was applied to the cell using a Carver hydraulic laboratory press. Samples were crystallized for 1 hour at 500MPa and then slowly cooled to room temperature at 500 MPa. Finally, pressure was reduced to atmospheric pressure, the sample was unloaded, and the morphology was characterized using DSC and LVSEM. DSC was performed using a Perkin Elmer Pyris instrument. Percent crystallinity was calculated by normalizing the heat of fusion of each sample to that of polyethylene crystal (293 J/g) and by taking the average of 3 crystallinity measurements for each sample type. A JEOL 6320F LVSEM operating at 2 kV and a working distance of 4mm was used to image etched [11] fracture surfaces of all UHMWPE samples.

RESULTS: LVSEM micrographs of high pressure crystallized crosslinked and non-crosslinked permanganic acid etched fracture surfaces revealed substantially thicker lamellae for conventional UHMWPE (Figure 1), confirming the effectiveness of the process used in this study. DSC thermographs revealed that both melting temperature and crystallinity increased as crystallization temperature for the high pressure process was increased from 160 °C to 240 °C. While the crosslinked high pressure UHMWPE samples did not achieve crystallinitities as high as uncrosslinked high pressure samples (76% and 81%), high pressure crystallized crosslinked samples did result in crystallinitities that were approximately 10-15% higher than atmospheric pressure crystallized crosslinked samples (p<.005, ANOVA with Fisher’s PLSD post-hoc test) (Table 1).

DISCUSSION: The high pressure process employed in this study (500 MPa and crystallization temperatures of 160 °C and 240 °C) resulted in crosslinked UHMWPEs with crystallinitities of approximately 64-68%, which is within the range of the crystallinity of Hylanertm. Additionally, crosslinked samples subjected to high pressure crystallization were associated with higher melting temperatures, compared to their respective crosslinked controls, indicating that the additional crystallinity was a result of lamellar thickening. Crosslinked UHMWPE with a higher degree of crystallinity may be more desirable in clinical applications than commercially available crosslinked materials as they could combine the advantages of high wear resistance associated with crosslinking, along with maintaining superior mechanical properties characteristic of higher crystallinity UHMWPEs. Currently, we are investigating the wear performance, resistance to creep and fatigue properties of these crosslinked, high crystallinity UHMWPEs.

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REFERENCES: