Fatigue and Wear Performance of a High Temperature Treated and Cross-Linked Polyethylene

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Statement of Purpose: Cross-linked ultra-high molecular weight polyethylene (ultra-high) has demonstrated less wear than conventional ultra-high. Crosslinking is typically performed using moderate to high doses of irradiation. However, the residual free radicals from the irradiation process must be eliminated to prevent oxidation. Thermal treatments, such as remelting or annealing, are commonly used to eliminate free-radicals and can result in a non-uniform microstructure that could affect the long-term performance of the orthopedic polymer[1]. A novel high-temperature treatment of ultra-high has demonstrated the potential to achieve an overall homogeneity in the microstructure and concomitant material properties[2]. It is hypothesized that uniform microstructure in ultra-high should improve wear performance without sacrificing resistance to fatigue crack propagation.

Methods: GUR1020 extruded bars were irradiated at 50 kGy and subsequently either thermally cross-linked with a high temperature treatment (HTT) at 240°C or remelted at 150°C. Fatigue crack propagation tests were performed using a fracture mechanics approach on 5-7 compact tension specimens for each material group. Fatigue tests were performed on an Instron 8871 servohydraulic load frame (Norwood, MA) using a load-controlled sinusoidal wave function at 5 Hz with R=0.1. Crack advance was measured in-situ using high-resolution digital microscopy. Fatigue results were fitted with a linear regression model and compared using a full versus restricted F-test. Fractography was performed using an environmental scanning electron microscope (SEM) (Hitachi TM-1000, Schaumburg, Illinois). Swell ratio was measured using hot xylene at 130°C for 4 hours (ASTM D2765, Method C). A 6-station pin-on-flat wear machine was used for wear tests (ASTM F732 and F2025 methods). Ultra-high specimens were tested against Co-Cr-Mo alloy lubricated with bovine serum at 3.45 MPa constant load and 50 mm/s sliding speed.

Results: The HTT ultra-high had slightly less resistance to fatigue crack propagation than the remelted ultra-high (Figure 1). Statistically, the slopes of both fatigue resistance lines were nearly identical ($p = 0.988$, 95% CI: 5.25 to 7.11). The equivalence of slopes indicates that the micromechanisms of crack advance are the same. However, the intercepts were statistically different ($p = 0.0001$.) This finding implies that cracks can propagate at lower values of Paris regime stress intensity for the HTT material. In an equivalent loading environment, a stress intensity of 1.3 MPa√m sustained for 100,000 cycles would propagate a flaw by 0.6 mm and 1.5 mm, in the remelted and HTT ultra-high, respectively. Ultimate fracture behavior, however, is dependent upon both fracture toughness and fatigue threshold behavior. Fractography analysis of the both materials revealed evidence of ductile tearing at a magnification of 300X (Figure 2). No difference in micromechanism was detected. Wear data showed the HTT material to have a lower wear rate than the untreated or remelted ultra-high (Table 1). Swell ratio data confirmed that the HTT produced a significantly higher crosslinking density (lower ratio) than remelting did; increased crosslinking has been shown to result in lower wear rates.

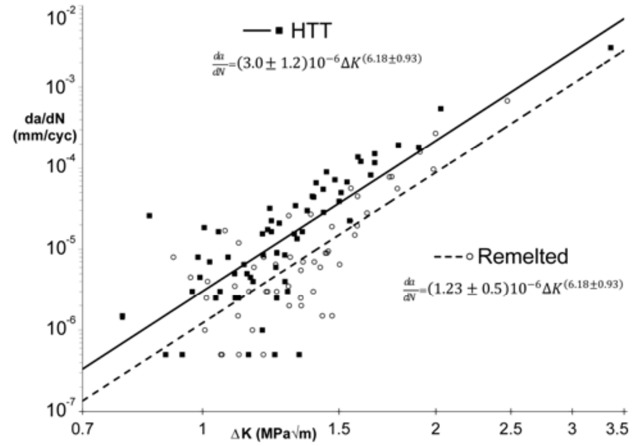

Figure 1: Fatigue crack propagation of high temperature treated and remelted ultra-high (with approximate bounds of 95% confidence interval)

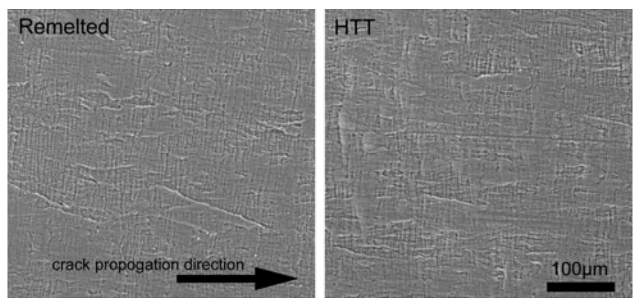

Figure 2: 300X magnification SEM images of the fractured surface of the remelted and HTT ultra-high.

Table 1: Cross-linking and wear performance of tested materials (N = 3 samples per material)

	Swell ratio	Wear rate (mg/MM cycle)
Untreated Ultra-High	10.4 ± 0.6	3.38 ± 0.89
Irrad. at 50 kGy; remelted at 150°C	4.3 ± 0.6	2.11 ± 0.12
Irrad. at 50 kGy; HTT at 240°C	3.3 ± 0.1	1.29 ± 0.05

Conclusions: Improving the performance of one aspect of a material, such as wear, often comes as a tradeoff with a decrease in performance in another aspect, such as fatigue resistance. We have demonstrated a processing technique that improves wear performance of cross-linked ultra-high without a large tradeoff in crack propagation behavior.

References: (1) 2009 ORS Annual Meeting, Paper no. 2307 (2) US patent appls 11/463,423 and (3)12/076,969.

Acknowledgement: Special thanks are given to Meditech Inc. and Orthoplastics Ltd.for providing materials