

# FATIGUE CRACK INCEPTION AND PROPAGATION RESISTANCE OF HIGHLY CROSSLINKED AND POST PROCESSED UHMWPE IN A PHYSIOLOGICALLY RELEVANT ENVIRONMENT

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**Introduction:** Fracture and wear damage of ultra high molecular weight polyethylene (UHMWPE) used in total joint replacements is influenced by its fatigue fracture properties [1]. Crosslinking of UHMWPE, while beneficial for wear resistance, is detrimental to fatigue crack propagation resistance (FCP). We have previously shown that radiation crosslinking followed by thermal treatment decreases the overall FCP resistance of UHMWPE in lab air [2]. Fluid absorption studies indicate that the steady-state rate of fluid absorption is lower in highly crosslinked than conventional UHMWPE; and, the absorption rate at 37°C is twice that at room temperature [3]. Accordingly, we hypothesized that the FCP behavior of conventional and crosslinked UHMWPE would be influenced differently by a 37°C fluid environment, relative to room temperature air. The objective of this study was to examine the fatigue crack inception and propagation behavior of conventional and highly crosslinked and thermally treated UHMWPEs in a physiologically relevant aqueous environment at 37°C.

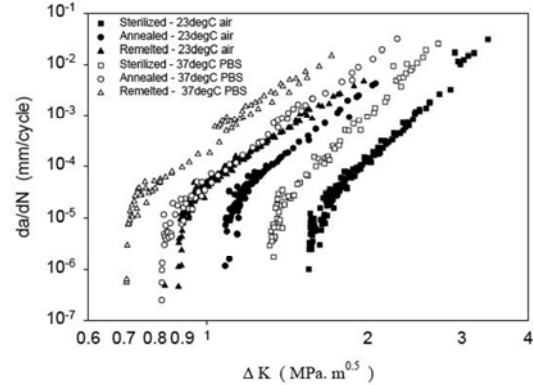
**Materials and Methods:** Ram extruded, GUR 1050 UHMWPE (Perplas Medical Ltd, Lancashire, UK) was tested in 3 treatment conditions: conventional (sterilized, 30 KGy); highly crosslinked and annealed (100kGy, 130°C); and, highly crosslinked and remelted (100kGy, 150°C).  $\gamma$  radiation was used for sterilization and crosslinking. Disk shaped compact tension specimens were machined from transverse cross-sections of the extruded rods such that the crack propagated in the transverse plane of the rod. Specimens were precracked by pressing a fresh razor blade into the notch. Specimen dimensions were based on ASTM E399 guidelines (Width = 40 mm, thickness = 10mm) [4]. Specimens were tested in a servo-hydraulic materials testing machine (Instron 8501, Canton, MA) under 2 environments: Lab air (n = 3/group) and a phosphate buffered saline (PBS) bath (n = 2/group) at 37°C. Specimens tested in the PBS bath were first soaked in PBS at 37°C for 2-4 weeks. Specimens were kept submerged in a PBS bath maintained at 37°C throughout the test. For all tests, constant load range ( $\Delta P$ ) cyclic loading was applied with an Rratio = 0.1 and a frequency of 4Hz. Crack growth was monitored visually using a traveling microscope. Fatigue crack growth rate (da/dN, mm/cycle) was calculated using the secant method [5]. Cyclic stress intensity ( $\Delta K$ , MPa $\sqrt{m}$ ) was calculated using  $\Delta K = (\Delta P/B\sqrt{W})f(a/W)$  where  $\Delta P$  = load range, B =specimen thickness, W = specimen width, and f(a/W) is a geometrical correction factor (a= crack length) [4]. Linear regression analysis was performed in the Paris regime (da/dN = C( $\Delta K$ )<sup>m</sup>, da/dN > 10<sup>-6</sup>mm/cycle) of the da/dN vs  $\Delta K$  curve. The exponent, m, and the coefficient, C, of the Paris relationship were determined for each specimen [5]. Statistical comparisons of exponent and coefficient between material groups were performed using the linear test method (p < 0.05 taken as significant). Fatigue crack growth in the threshold regime was also evaluated, using  $\Delta K_{inception}$ , the  $\Delta K$  required to produce a da/dN < 10<sup>-6</sup>mm/cycle [6].

**Results:** For each material, the exponent (m), and the coefficient (C) did not vary significantly between specimens; thus, the data from specimens for a given material were pooled.

	Sterilized (30KGy)		Annealed (100KGy, 130°C)		Remelted (100KGy, 150°C)	
	23°C air	37°C PBS	23°C air	37°C PBS	23°C air	37°C PBS
m	9.48	10.85	8.22	7.82	6.87	7.21
C	1.87 x 10 <sup>-7</sup>	6.02 x 10 <sup>-7</sup>	1.06 x 10 <sup>-5</sup>	5.47 x 10 <sup>-5</sup>	5.14 x 10 <sup>-5</sup>	3.22 x 10 <sup>-4</sup>
$\Delta K_{inception}$	1.59	1.32	1.12	0.86	0.91	0.71

**Table 1.** Exponent (m), and coefficient (C, (mm/cycle)/(MPa $\sqrt{m}$ ) m) for da/dN = C( $\Delta K$ )<sup>m</sup>;  $\Delta K_{inception}$  (MPa $\sqrt{m}$ ) for the UHMWPE materials.

In both Lab air and the 37°C PBS bath, the highly crosslinked materials (annealed and remelted) had reduced fatigue crack inception when compared to the sterilized material (Table 1, Figure 1).



**Figure 1.** da/dN vs  $\Delta K$  for sterilized and highly crosslinked (annealed and remelted) UHMWPE materials in Lab air (solid symbols) and in a 37°C PBS bath (open symbols).

$\Delta K_{inception}$  of the annealed and remelted crosslinked materials was 30% and 43% lower, respectively, compared to the sterilized material in Lab air and 35% and 46% lower, respectively, compared to the sterilized material in the 37°C PBS bath. In both environments, the two highly crosslinked materials demonstrated a significantly lower exponent (m) and coefficient (C) in the Paris regime compared to the sterilized material (p=0). The data also suggested that the exponent (m) was less sensitive (p=0.25) to testing temperature for the highly crosslinked materials than for the sterilized material. That is, in the 37°C PBS bath, both the highly crosslinked materials showed no significant change in exponent (m) compared to lab air, whereas the sterilized material showed a significant increase of 14% (p=0.0) in exponent (m) compared to lab air.

**Discussion:** This study indicates that, at 37°C in an aqueous PBS bath, fatigue crack inception and growth are decreased in conventional (sterilized) and highly crosslinked (annealed and remelted) UHMWPEs. A similar observation was noted by Baker et al. for conventional UHMWPE; the decrease for conventional UHMWPE was attributed to enhanced crack-tip fracture mechanisms at elevated temperature that makes the material less tolerant to fatigue crack inception [6]. In this study, the relative (%) decrease in  $\Delta K_{inception}$  from the sterilized material to the highly crosslinked materials did not appear to be affected by temperature or environment. Once initiated, crack growth was significantly slower (lower m, p=0.0) for the highly crosslinked materials compared to the sterilized material irrespective of testing environment. Most of the FCP studies conducted on UHMWPE have been performed in lab air, which overestimates the fatigue behavior relative to the body environment. The findings from this study indicate that in a more physiologically-relevant fluid environment at 37°C, the resistance to fatigue crack inception and growth is reduced for conventional and highly crosslinked UHMWPEs. Clinically, UHMWPE implants are more likely to be susceptible to fatigue crack inception and growth than might be expected from tests conducted in lab air.

**References:** 1. McKellop, HA, Total Hip Rev. Surg, 1995; 2. Gencur SJ et al, Biomaterials in press; 3. Blanchet TA et al, J Tribology, 124, 2002; 4. ASTM E 399; 5. ASTM E647; 6. Baker DA et al, Polymer, 41, 2000.

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