

Fatigue Crack Propagation of Ultra-High Molecular Weight Polyethylene – Conformity of Compact Tension Specimen Geometry to ASTM E647

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Statement of Purpose: Resistance to fatigue crack propagation (FCP) of ultra-high molecular weight polyethylene (UHMWPE) is of utmost importance in total knee and hip replacement designs that feature locking mechanisms serving as stress concentrations. FCP behavior is of clinical interest as the orthopaedics community has progressed toward using highly crosslinked formulations of UHMWPE that offer improved wear resistance yet are known to be more susceptible to fracture processes (Baker 2003, Oral 2006). For decades, orthopaedic research groups have used linear elastic fracture mechanics (LEFM) to characterize the FCP behavior in UHMWPE (e.g. Rimnac & Pruitt 2008, Baker 2003, Furmanski 2007, Medel 2007). Recently, the community has moved toward using the ASTM E647 standard for testing UHMWPE, even though this protocol was designed for metals. Parameters such as frequency and waveform that can be critical to the FCP in polymers are not specified in the protocol. Standard geometries that meet LEFM conditions and use side grooves that facilitate the monitoring of FCP can be outside the ASTM E647 specification. This study looks at specimen thickness and side grooves that meet plane strain (LEFM) conditions and yet are outside the protocols of E647 with the aim of showing that equivalent FCP behavior in UHMWPE can be achieved.

Methods: Three different configurations of compact tension (CT) specimens were machined from UHMWPE: a thick specimen with side-grooves, and specimens with and without side-grooves whose thickness fell within ASTM E647 specifications (Figure 1 and Table 1).

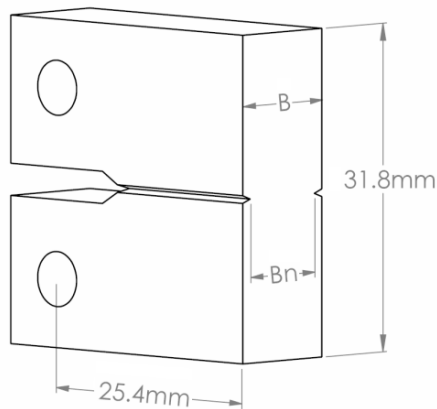


Figure 1. Compact tension specimen with side grooves. Dimensions are listed in Table 1.

Table 1. Total thickness, notched thickness, and effective thickness of each specimen configuration tested, in millimeters.

	B	Bn	Be
Thicker, with side-grooves	10.84	8.8	10.46
ASTM thickness, w/ side-grooves	6.45	4.42	5.81
ASTM E647, w/o side-grooves	5.81	-	-

FCP tests were performed using a LEFM approach. Specimens were loaded with an Instron 8871 servohydraulic load frame (Norwood, MA) using a load-controlled sinusoidal wave function at 5 Hz with a load ratio (R) of 0.1. Samples were kept cool with a constant stream of compressed air. Crack advance was measured *in-situ* using high-resolution digital microscopy. Effective widths for the specimens with side grooves were used in stress intensity calculations, as described in Shih et al (1997). Fatigue results were fitted with a linear regression model and compared using a full versus restricted F-test. **Results:** FCP behavior of UHMWPE specimens that were thicker than the ASTM specification was not significantly different from the performance of specimens that were within the guidelines ($p > 0.5$). There was also no difference of the regression slope between specimens with the side-grooves and those without ($p > 0.5$), although the offset of the regression line was significant ($p < 0.001$).

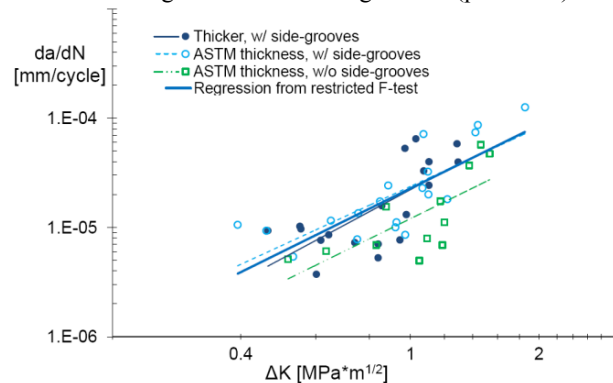


Figure 2. Fatigue crack propagation in different specimen geometries of UHMWPE. N = 5 samples for each side-grooved size and 3 samples with smooth-sides.

Conclusions: ASTM E647 was initially developed for metals and is now employed for FCP characterization of UHMWPE. The testing protocol makes specific requirements for specimen geometry yet there are other configurations that meet LEFM plane strain conditions and provide equivalent FCP results. Further, variables such as stress ratio, waveform, and frequency affect UHMWPE FCP but are not specified in the protocol. Our findings indicate that the ASTM E647 serves as a good guideline but that it may not be sufficient to consistently characterize FCP behavior of UHMWPE.

References:

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