Static fracture J-R resistance of ultra high molecular weight polyethylene using a single specimen normalization method

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Introduction: Knowledge of the static and fatigue fracture resistance of ultra high molecular weight polyethylene (UHMWPE) is important for the design of total joint replacement components. The crack growth resistance curve (J-R curve) has been used successfully to characterize the resistance of ductile polymers to stable crack growth (1). However, the multiple specimen method approach recommended by ASTM D6068 to obtain a J-R curve for polymers is time and material intensive. Recently, a single specimen method for J-R curve determination based on load normalization was successfully applied to UHMWPE (2). That study used a deformation relationship based on the LMN function. However, studies conducted in other semicrystalline polymers recommend a power law based deformation relationship (3,4). The objective of this study was to use the single specimen normalization method to compare the LMN and power law deformation functions for determination of the J-R curve for UHMWPE.

Methods: As-received UHMWPE (ram-extruded GUR 4150) was examined. J-R curves were previously obtained by the multiple specimen method following ASTM D6068-96 (5). Three point bend tests were performed on SENB specimens in ambient air, n = 9/group (5). Specimen dimensions were 20x40x180mm (BxWxL) with a rate-controlled razor sharpened central prenotch. A crack growth correction as suggested by ESIS was implemented (6). J-R curves were then obtained using the normalization method from load-displacement data of the specimen with the maximum crack extension (Δa). This method involves separation of load (P) into a geometry G(a/W) and a deformation function $H(v_{pl}/W)$ to obtain instantaneous crack length (2). $P = G(a/W)H(v_{pl}/W)$, where v_{pl} is the plastic deformation. A power law function with 2 constants and an LMN function (3 constants) were examined for the deformation function. Both functions use a forced blunting assumption to obtain calibration points. The effects of the selected crack tip constraint factor and the selected blunting region range on the predicted J-R curves were also evaluated.

Results / Discussion: The deformation function based on a power law resulted in a J-R curve that was in good agreement with that obtained by the multiple specimen method (Figure 1). The LMN function did not predict the J-R curve as well, particularly for smaller Δa. The best-fit power law based J-R curve was obtained using a crack tip constraint factor CF = 1, whereas CF = 0.5 was required to obtain the best-fit LMN function based J-R curve. For both deformation functions, a lower value of CF (higher levels of crack tip blunting) resulted in a more conservative J-R curve (e.g., Figure 2). It was also found that the selected blunting region range influenced the J-R curve (data not shown). Our results for SENB specimens indicate that power law fitting yields a more accurate J-R curve for UHMWPE. Bernal et al (3) and Mohrain et al (4) also obtained better fitting J-R curves using a power law deformation function for PP and HDPE.

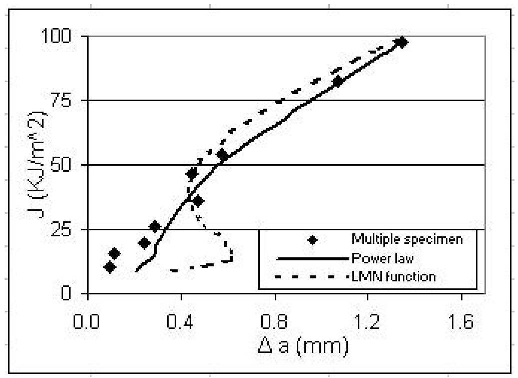

Figure 1: Comparison of J-R curve obtained by multiple specimen and single specimen methods.

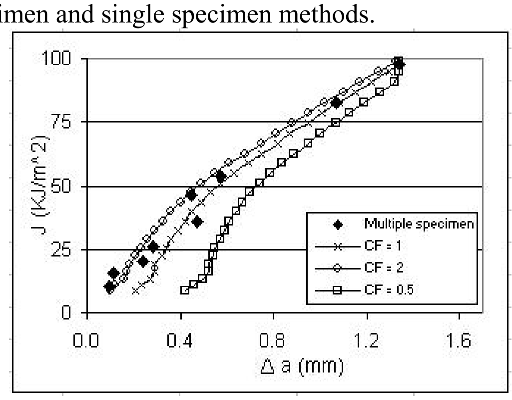

Figure 2: Influence of crack-tip constraint factor (CF) on the J-R curve obtained using the power law function.

Conclusions: The single specimen technique based on normalization was demonstrated to predict the J-R curve well for an as-received UHMWPE. Power law fitting yielded a better prediction than an LMN function. Preliminary tests for several crosslinked formulations of UHMWPE also demonstrate good prediction of the J-R curve with the single specimen approach using a power law function. Though potentially useful, the normalization method should be used with caution as the J-R curve is sensitive to the crack-tip constraint factor and to the range of the blunting region used for calibration.

References: 1). Chung WN. ASTM STP 1114. 1991; 320-339; 2). Landes JD. J Test Eval. 2003;31:126-132; 3). Bernal C. Macromol Symp. 1999;147:235-248; 4). Mohrain C. J Matl Sci. 2001;36:1487-1499; 5). Dapp EK. MS Thesis, CWRU 1999; 6).ESIS P2-91D.

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