Impact Strength Correlates with Fatigue Strength of Irradiated Vitamin E/UHMWPE Blends

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Introduction Ultrahigh molecular weight polyethylene (UHMWPE) is the preferred material of bearing surfaces of joint implants. Radiation cross-linked UHMWPEs have increased wear resistance [1] and their use has decreased peri-prosthetic bone loss [2]. The newest generation of cross-linked UHMWPEs includes radiation cross-linked antioxidant blends of UHMWPE for increased protection against oxidation [3]. The fatigue resistance of cross-linked UHMWPEs is a critical characteristic of joint implants as they are subjected to dynamic loading throughout their lifetime. In irradiated vitamin E blends, cross-linking is reduced and at high concentrations there is significant chain scissioning, which may additionally affect their toughness. The effects of the presence of vitamin E during irradiation and of cross-linking on fatigue resistance and impact toughness have not been investigated.A correlation between impact toughness and fatigue resistance may also be useful in evaluating the fatigue response of new cross-linked UHMWPE formulations such as surface cross-linked UHMWPEs with spatial gradients in their properties [4], which cannot be evaluated by the standard fatigue crack propagation resistance tests developed for uniform materials. The specific goals of this study were to determine and correlate the fatigue crack propagation resistance and IZOD impact strength of irradiated vitamin E blends of UHMWPE.

Methods Blends of vitamin E and UHMWPE (GUR1050) were prepared at 0, 0.1, 0.2, 0.5, 1 and 2 wt% vitamin E. The blends were consolidated into cylindrical pucks (dia. 10 cm, thickness 6.5 to 10 mm) and irradiated at ~3 MeV to 65, 100, 150, 200 and 300 kGy. Differential scanning calorimetry from -20°C to 180°C at 10°C/min was used and crystallinity was calculated by taking the ratio of the enthalpy of melting from 20°C to 160°C to that of 100% crystalline polyethylene; 291 J/g.Cross-link density was measured by swelling cubes (~3 × 3 × 3 mm) of the samples in xylene at 130°C [4]. Fatigue Crack Propagation Resistance testing was conducted according to ASTM E647 at 40°C with compact tension specimens of type A1 (n≥3) with R=0.1 (load ratio). A stress factor range at crack inception was reported ($MPam^{1/2}$) and is referred to as fatigue resistance. Double notching and testing of the IZOD impact samples (n=5) was performed according to ASTM F-648. The impact strength is reported (kJ/m^2).

Results The fatigue crack propagation and IZOD impact strength measurements showed a strong positive correlation, R^2=0.87 (Fig 1).

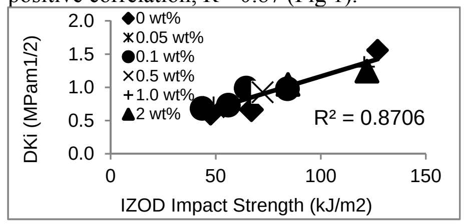

Figure 1. The correlation between the fatigue crack propagation resistance (ΔK) and the IZOD impact toughness of irradiated vit E blends.

This supported the use of impact testing as a screening tool for the fatigue strength of new cross-linked UHMWPE formulations. Impact testing is desirable over fatigue crack propagation, and may eliminate error from crack initiation, optical measurements, and the collection of data to calculate the stress factor range in the Paris Regime. The impact method also enables testing for spatially irradiated samples by calculating a composite measure of their toughness. The strong negative correlations were evident between crosslink density and both fatigue crack propagation and IZOD with coefficients R^2=0.77 and 0.89, respectively (Figs 2a and 2b).

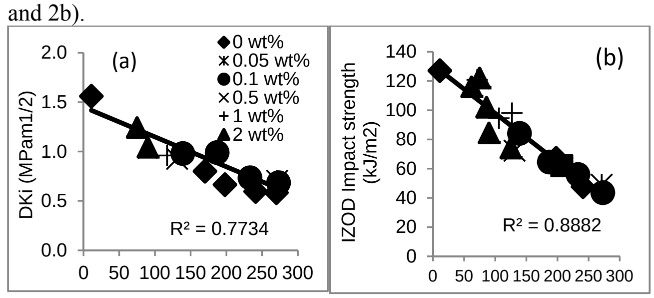

Figure 2. The dependence on cross-link density of fatigue crack propagation resistance (a) and the IZOD impact toughness (b) of irradiated vitamin E blends.

Cross-link density increased with radiation dose but there was no change in the crystallinity with increasing radiation dose. Fatigue crack propagation resistance and IZOD impact strength did not show dependence on crystallinity (R^2=0.14 and 0.12, respectively). The negative correlation between both properties (impact strength and fatigue strength) and cross-link density (Fig 2a) as well as the lack of their dependence on crystallinity showed that the decrease in these properties was mostly due to changes in the amorphous region and decreased plastic deformation. The results should be corroborated by a new correlation in cases where the crystalline morphology of the polymer is altered independently.

Conclusions This study showed that IZOD impact testing could be used as a screening tool to rank the fatigue strength of irradiated vitamin E blends with similar crystalline content.

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