Mechanical Properties of Highly Crosslinked UHMWPE Blended with Vitamin E

A. Rufner, D. Pletcher, T. Rowe, H. Brinkerhuff, M. Hawkins
Research Department, Zimmer, Inc., P.O. Box 708, Warsaw, IN 46581-0708, USA

INTRODUCTION:

Oxidative stability of highly crosslinked ultra-high molecular weight polyethylene (UHMWPE) has been achieved through post irradiation heat treatments. Recent studies have shown Vitamin E as an alternative method to stabilize UHMWPE without melt annealing.[1] Vitamin E is a well known oxidation stabilizer for commercial polyolefin materials, and is attractive for use in implant materials due to its biocompatibility. In this study, the effect of Vitamin E level and process conditions on mechanical properties was investigated using Design of Experiment (DOE) analysis.

MATERIALS AND METHODS:

For this study, GUR 1050 and GUR 1020 UHMWPE resins were blended with 0.2 wt%, 0.5 wt% and 1 wt% Vitamin E (d/l-α-tocopherol) prior to consolidation. Each of the material combinations were compression molded into a slab and cut into bars. The bars were preconditioned and e-beam irradiated according to a five factor DOE. The DOE contained the following factors: 1. material (GUR 1050 and GUR 1020) 2. Vitamin E concentration (0.2%, 0.5% and 1%) 3. preheat (warm and cold) 4. irradiation dose (90 kGy, 120 kGy, 150 kGy, 200 kGy and 250 kGy) 5. dose rate (75, 155 and 240 kGy-m/min). The responses for the DOE were Izod Impact and Dynamic Mechanical Analysis (DMA). Izod testing was performed using an Izod Charpy Impact test system. The Izod specimens were double-notched and tested according to ASTM D256. DMA testing was performed using a TA Instruments Model 2980. The storage modulus was determined at 200 MPa and a frequency of 1 Hz. The DOE was analyzed using Design Expert 6.0 Response Surface Analysis.

RESULTS AND DISCUSSION:

DOE's are structured, organized experiments for determining the relationship between factors that can affect a process. In this study, DOE analysis software was used to determine the factors that influence mechanical properties as well as create a model with high statistical correlation ($p<0.0001$). According to the DOE, factors that influence both Izod and DMA values were Vitamin E level and irradiation dose. Material resin impacted DMA whereas preheat temperature impacted Izod. Dose rate had no effect.

Overall, GUR 1050 had approximately 8% higher DMA values than GUR 1020. The DOE model was used to predict DMA values at various % Vitamin E levels. The predicted values (PV) as well as the individual measured values are depicted in Figure 1 (only the GUR 1050 is shown). This graph shows the actual values follow the predicted value trendlines. The curves show a leveling off effect at the higher levels of Vitamin E. The curves also indicate the storage modulus increases with increasing irradiation dose.

Overall, the cold preheat temperature had approximately 8% higher Izod values than the warm preheat. The values predicted by the DOE model as well as the individual values are depicted in Figure 2 (only the cold preheat temperature is represented). Actual values follow predicted value trendlines in this graph as well. The curves demonstrate the Izod values decreased with increasing dose and increased with higher concentrations of Vitamin E.

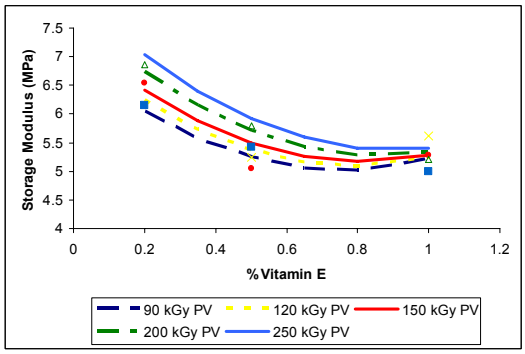

Figure 1: Predicted and Actual Storage Modulus of GUR 1050 UHMWPE at various irradiation dose levels as a function of %Vitamin E

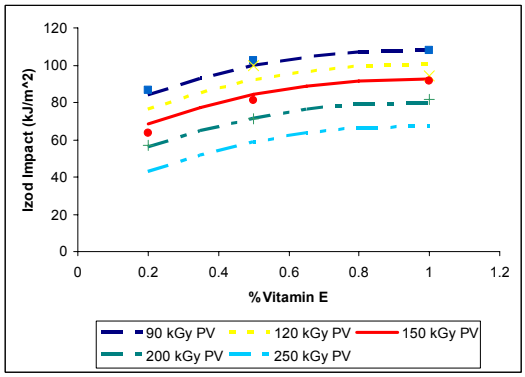

Figure 2: Predicted and Actual Izod Impact with a cold pre-heat condition at various irradiation dose levels as a function of % Vitamin E

CONCLUSION:

The presence of Vitamin E in UHMWPE does impact mechanical properties. The DOE analysis indicates Vitamin E level and irradiation dose are the significant factors. At higher %Vitamin E levels, the impact on mechanical properties level off. Future studies will include tensile properties.

References:[1]Oral, E., et. al. J Arthoplasty, 2006. 21(4): p. 580-591.