Depth Dependent Oxidation and Wear Resistance of Gamma Irradiated UHMWPE as a Function of Aging Conditions

by

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ABSTRACT

The gamma irradiation of UHMWPE is commonly used as a sterilization technique for use in total hip replacements. A byproduct of this sterilization process is the formation of free radicals, molecules that are unstable and highly reactive. These free radicals can react together to form crosslinks between the polymer chains improving the wear resistance of the UHMWPE. Reaction of the free radicals with oxygen present in the material however can cause oxidative chain scission, a shortening of the molecular chains, which degrades the wear behavior of the UHMWPE.

This work examines the effects of the chain scission or oxidation as a function of depth and time on wear performance. Three representative artificial aging environments were chosen to separately investigate the effects of temperature and surface oxygen pressure. Wear, oxidation index and gel fraction measurements were made as a function of subsurface depth at specific aging times to quantify oxidation effects. Maximum wear rate is observed to be related to the maximum oxidation index and minimum gel fraction.

Two analytical models were developed to predict oxidation as a function of depth and time. The first, a homogeneous model, including a dose depth profile, treats UHMWPE as essentially amorphous with diffusion of oxygen and crosslinking in the material competing to produce an oxidation profile as a function of depth and time. This model predicts the basic shape and relative oxidation levels for each aging environment however it is not able to demonstrate oxidative changes after the oxygen front reaches a given depth, since at this point the model assumes all free radicals in the wake of the oxygen front have been consumed. The second, a heterogeneous semi-crystalline model,

treats UHMWPE as a material containing crystallite regions with amorphous polymer chains surrounding and connecting them. The heterogeneous model is able to accurately predict the subsurface depth of maximum oxidation and the relative extents of these maxima when temperature and surface oxidation pressure are varied. In addition, the results of the model indicate that the values of the crystallite free radical diffusion coefficient may be much smaller than those reported in the literature.