감마선 멸균처리가 초고분자량 폴리에틸렌의 크리프와 마모에 미치는 영향

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Effect of Gamma-Irradiation Sterilization on the Creep and Wear of Ultra-High Molecular Weight Polyethylene

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ABSTRACT

The influence of gamma-irradiation sterilization on the creep and wear performance of ultra-high molecular weight polyethylene (UHMWPE) was investigated by conducting the dynamic compressive creep tests and pin-on-disc sliding wear tests. The changes of microstructure property, relative crystallinity, oxidation index, percent crosslinking, were also measured and the relationship between these and creep and wear results was discussed.

INTRODUCTION

Ultra-high molecular weight polyethylene (UHMWPE) is the viscoelastic polymeric material used for the concave bearing surface of hip and knee prosthetic joint implants. All prostheses components should be sterilized before implantation into the body. Gamma irradiation using a Cobalt 60 source has been the industry standard in conventional polyethylene component sterilization. Gamma irradiation sterilization causes chain scission and oxidation in UHMWPE.

The resulting oxidized chains can increase density, crystallinity, and fluid absorption [1], but results in reduced elongation and subsequent embrittlement in UHMWPE component [2,3] altering the performance of UHMWPE, especially, its resistance to abrasive and fatigue wear. However, there are several studies reporting wear resistance improvement after gamma-irradiation [4,5]. This phenomenon was interpreted by the increase of crosslinking in the molecular structure of UHMWPE.

In the present study, the effect of gamma-irradiation sterilization on the creep and wear of UHMWPE were characterized and its result was analyzed by evaluating the typical microstructural properties of the level of crystallinity, oxidation, and crosslinking in gamma-irradiated UHMWPE.

MATERIALS AND METHODS

Ram-extruded, un-irradiated, GUR 4150HP UHMWPE rod stock was machined to rectangular block specimens for the creep tests (n=6 per group), and to right angle circular cylinder specimens for the wear tests (n=3 per group) and for the microstructural property measurements. Half of block and cylinder specimens (GI) were sterilized by gamma irradiation with a total dosage of 2.5 Mrad at a rate of 0.9 Mrad per hour in air.

A custom-built creep testing machine [6] was used for conducting the dynamic compressive creep tests with maximum pressure of 8 MPa and minimum pressure of 0.8 MPa at a frequency of 1 Hz for a total duration of $1x10^4$ minutes (a total of $6x10^5$ loading cycles). All tests were conducted in bovine serum of 37℃ ± 0.3℃

After creep testing, the applied load was completely removed. The creep deformed specimen was allowed to recover in an ambient environment. The amount of creep strain, rate of creep strain, percentage of creep recovery, and rate of creep stain recovery were compared between two irradiation conditions.

Pin-on-disc wear tests were conducted with the right angle cylinder polyethylene pins and a rotating orthopaedic grade stainless steel disc in bovine serum at room temperature under a nominal contact pressure of 4 MPa. The amount of wear was determined by weight loss of each specimen, which was corrected for the weight gain obtained from a soak control test.

Relative crystallinity was measured for a non-irradiated and a gamma-irradiated specimen using differential scanning calorimetry. The heat of fusion was obtained from the plot of heat flow as a function of temperature. The relative crystallinity was calculated by the heat of fusion for perfectly crystallized polyethylene of 289.74 J/g [7].

The degree of oxidation of 100-μm slice was estimated by comparison of the maximum absorbance of the peak centered near 1715 cm^{-1} in FTIR spectra after normalization to the 720 cm^{-1} peak [8] at the surface and interior locations.

Degree of crosslinking of specimen was measured on the same 100-μm slices of each cylinder specimen as those for the oxidation measurements. The percent crosslinking (insoluble gel content) in each sample was determined by using hot xylene extraction procedure modified from ASTM D2765-90 [9].

RESULTS AND DISCUSSION

Comparison of non-irradiated specimens with gamma-irradiated specimens shows no significant difference in creep strain, rate of creep strain, or rate of creep strain recovery, but non-irradiated specimens show a significant higher percentage of creep recovery ($p=0.023$) than gamma-irradiated specimens.

After a total sliding distance of 62.5 km the mean wear of gamma-irradiated specimens was significantly less (36%, $p<0.05$) than that of non-irradiated specimens (Fig. 1).

The results of microstructural property changes in the non-irradiated and gamma-irradiated specimens are given in Table 1. There was a slight increase in the relative crystallinity, but oxidation index and percent crosslinking were significantly increased ($p<0.05$) by gamma-irradiation. Increased level of crosslinking improves the wear resistance. Relative crystallinity and oxidation index from the surface of specimen were higher than those from the interior of specimen, while percent crooslinking from the surface of specimen was lower than that from interior of specimen.

Table 1. Microstructural properties

Test Spec.	Crystallinity		Oxidation		Crosslinking	
	surface	interior	surface	interior	surface	interior
GI	51.93	51.73	0.06	0.04	91.05	93.11
NI	47.79		0.02		70.57	

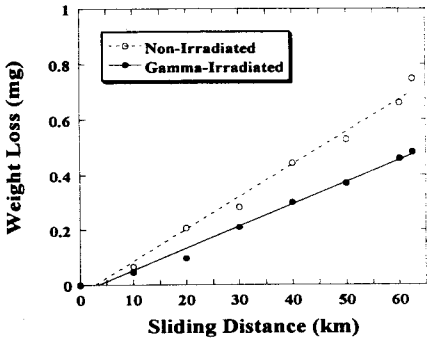

Fig. 1. Variation of wear

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