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Research paper

Effect of cyclic strain on the mechanical behavior of virgin ultra-high molecular weight polyethylene

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ABSTRACT

Ultra High Molecular Weight Polyethylene (UHMWPE) is a polymeric material employed in critical biomedical applications. Knowledge of its mechanical behavior is essential in order to obtain accurate prediction of stresses and deformations in real components, in particular when cyclic loading is considered. In the present research the effects of alternating and pulsating cyclic strain on the mechanical response of UHMWPE were studied by means of an experimental procedure based on tests carried out in strain control at different mean cyclic strain levels. During the tests the temperature increase due to hysteretic heating was controlled by means of a compressed air cooling apparatus specifically devised. By taking advantage of the possibility to control and stabilize temperature, cyclic steady-state mechanical response was investigated at room temperature and at 37 and 50 °C, comparing the effects of alternating and pulsating loading cycles. A transient thermal analysis using the finite element method (FEM) was also carried out to analyze temperature distribution within the specimen. UHMWPE exhibited cyclic softening as a result of a thermal contribution due to temperature increase and of a mechanical contribution related to the effects of applied load on the microstructure. The material exhibited different peak stress percent reductions for pulsating and alternating loading and during tensile and compressive loading phases. For pulsating tests significant cyclic mean stress relaxation was also observed. Based on the experimental procedure described the cyclic curve was determined as a function of temperature and fitted with a Ramberg–Osgood type constitutive equation, in which material parameters are temperature dependent. In this way the combined effects of temperature rises, such as those that might occur in biological environments or due to frictional heating, and mechanical loads could effectively be taken into account for constitutive modeling purposes of cyclic mechanical behavior of UHMWPE.

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1. Introduction

For many years medical grades of ultra-high molecular weight polyethylene (UHMWPE) have been the material of choice for bearing components in critical biomedical applications, such

as arthroplasties. The wear and fatigue damage to UHMWPE is a significant clinical problem that motivated a number of experimental total joint and numerical investigations to enhance understanding of the underlying mechanisms with the goal to increase component lifetimes.

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