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Experimental investigation and modeling of non-monotonic creep behavior in polymers

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The deformation behavior of two unfilled engineering thermoplastics, ultra high molecular weight polyethylene (UHMWPE) and polycarbonate (PC), has been investigated in creep test conditions. It has been found that a loading history (prior to the creep test) comprising of loading to a maximum stress or strain value followed by partial unloading to arrive at the target stress value can greatly modify the strain-time behavior. Under such a test protocol, while the expected increase in strain during creep (constant tensile load) is observed, at relatively low creep stresses specimens have also demonstrated a monotonic decrease in strain. In an intermediate stress range, specimens have demonstrated time dependent behavior comprising of a transition from decreasing to increasing strain during creep in tension. This paper presents experimental results to delineate these findings and explore the effect of prior strain rate on the qualitative and quantitative changes in the output (strain-time) behavior. Furthermore, modification of the viscoplasticity theory based on overstress (VBO) model into a double element configuration is introduced. These changes confer upon the model the ability to yield non-monotonic behavior in creep, and supporting simulation results have been included. These changes, therefore, allow the model to simulate strain rate sensitivity, creep, relaxation, and recovery behavior, but more importantly address the issue of non-monotonic changes in creep and relaxation when a loading history involves some degree of unloading.

1. Introduction

It is undeniable that the market share of polymer based components in consumable and durable goods is increasing steadily. In evidence, data from an industry poll at the 2007 Society of Automotive Engineering World (SAE, 2007) listed advanced composites and polymers as the two materials expected to gain most favor in design and engineering use in the next 10 years. Aluminum and steel occupied the fourth and sixth position on the list. Whether it be in the replacement of existing metal parts or in the development of new design concepts, a comprehensive understanding of the deformation behavior and the ability to reliably simulate it in an effort to abridge product development cycles is imperative, and it is precisely at this juncture that numerical modeling plays a pivotal role in the adoption of polymeric materials. Due to the complex nature of loading histories to which parts will inevitably be subjected during their normal service life, material models with predictive capabilities narrowly limited to a specific test condition are naturally inadequate for the task at hand. Therefore, constitutive models that can respond to general stress states through the prescribed boundary conditions are preferred. The following paragraph gives a pertinent, though by no means exhaustive, account of the material models that have been

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