Constitutive Theory for Shape Memory Polymers

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Shape memory polymers are a class of materials that can be brought to a temporary shape while "remembering" its permanent shape. The material can stay in the temporary shape indefinitely, and can recover its permanent shape under certain thermal/mechanical processes. Compared to other shape memory materials, shape memory polymers possess advantages of large recoverable strains (400% reported, compared to 8% for shape memory alloys), low energy consumption for shape programming, light weight, low cost, excellent manufacturability, and bio-degradability. Due to these properties, shape memory polymers are finding various applications, especially in aerospace engineering and biomedical engineering.

A constitutive theory is developed for the shape memory polymers, for which the basic shape memory effect is due to glass transition. The theory is based on the framework of nonlinear thermoelasticity, and is capable of describing large shape changes of the material in arbitrarily prescribed temperature/loading paths.

It is well-known that polymeric materials typically undergo glass transition gradually in a temperature range. We thus introduce a frozen volume fraction function which gives the volume fraction of the material regions that are in the glassy phase for a given temperature. The thermal/mechanical properties of the material are assumed to be given by two constitutive equations for the rubbery and glassy phases, respectively. It is further assumed that when a material point undergoes the transition from the rubbery phase to the glassy phase with continuous temperature and stress, the strain must be continuous despite the change of the constitutive equation. This is achieved by taking a new reference configuration for the constitutive description of the material in the glassy phase. This new reference configuration, termed the frozen reference configuration, depends on the temperature and stress when the glass transition is taking place. The overall constitutive equation is obtained by integrating the constitutive equations for individual material points. The property of one way shape memory is captured in the constitutive equations through a net cooling history function that erases the dependence of the current rubbery state on past events. A comparison of the model predictions and the experimental data shows good agreement.