Time Dependent Uniaxial Modeling of Adiprene-L100 at Large Deformations

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Introduction: Polymers have proven to have an enormous and intriguing range of desirable features. This is basically due to the arrangement of their building monomeric units, the various types of chains and the conformations and configurations that these chains can undergo. The many attractive characteristics of polymers extend to their mechanical behavior and have forced the choice of polymeric materials over traditional materials for numerous types of structures such as binder-constituent in explosives, load-bearing components, jet engines modules, among others. As the uses of polymers increase, a thorough understanding of the mechanical behavior of these materials becomes vital. Considerable progress has been made in developing mathematical models for the small strain regime under a specific narrow spectrum of strain rates and temperatures. Much less progress has been made for multi-axial finite deformation behavior under a wide range of strain rates and temperatures from a continuum point of view.

Viscoelastic model: A phenomenological one-dimensional constitutive model characterizing the complex and highly nonlinear finite mechanical behavior of viscoelastic polymers is developed in this work. This simple differential form model is based on a combination of linear and nonlinear springs with dashpots, incorporating typical polymeric behavior such as shear thinning and nonlinear dependence on deformation and loading rate. The constitutive material parameters for both the models are determined through a rigorous curve fitting technique. The constants once determined are then utilized to predict the behavior of Adiprene-L100 under strain rate jump compression, and multiple step stress relaxation loadings. The new constitutive model shows very good agreement with the experimental data for Adiprene-L100 for the various finite loading paths considered here and provides a flexible framework for three-dimensional generalizations.

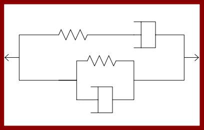

Figure 1. Rheological Schematic of the Modified Standard Solid Model

The governing equations for the above model is as follows:

$$\frac{E_1}{\eta_1}\sigma+\dot{\sigma}=E_1\dot{\varepsilon}+\frac{E_1}{\eta_1}c_2\varepsilon^{(n_2+1)}+\frac{\eta_2}{\eta_1}E_1\dot{\varepsilon}+c_2(n_2+1)\varepsilon^{n_2}\dot{\varepsilon}$$

where the viscosity term is given by

$$\eta(\dot{\varepsilon},T)=\eta_\infty+\frac{\eta_o-\eta_\infty}{\left(1+(a\dot{\varepsilon})^2-\left(\frac{\dot{\varepsilon}}{10^5}\right)^d\right)^b}\left(\frac{T_r-T}{T_r-T_{vf}}\right)^m$$

and the spring E2 is a non linear spring given by

$$E_2=c_2\varepsilon^{n_2}$$

Experimental Procedures: Experiments included room temperature and high & low temperature compression testing of the polymer at low and high strain rates.

Room temperature quasi static monotonic and relaxation compression experiments were performed on the specimen at different strain rates using the MTS servo-hydraulic testing machine. The machine is capable of testing and recording stresses and strains at very small rate of deformations. Typical specimen sizes were 1 in. length and 0.8 in. diameter.

High temperature compression tests were performed using the same machine but a slightly different setup including a thermocouple to monitor the temperature during the testing. A variable transformer was hooked up to a heating tape to increase the temperature of the specimens. Ceramic bars were used to compress the specimen in order to save the transducers from getting damaged.

Figure 2. The quasi static experiments testing system (MTS)

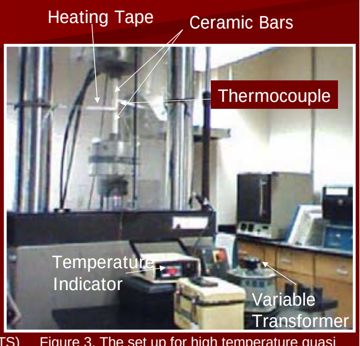

Figure 3. The set up for high temperature quasi static testing

High strain rate compression testing was performed using the conventional Split Hopkinson pressure bar apparatus. Strain rates as high as 10^5 /s can be achieved using the apparatus. For this specimen, strain rate of 5000 /s was achieved. Recording the data is done using the Nicolet 440 oscilloscope which can record data at intervals of 100 nanoseconds. The schematic of the configuration is shown below. Specimen dimension was diameter 0.42 in. and thickness 0.13 in.

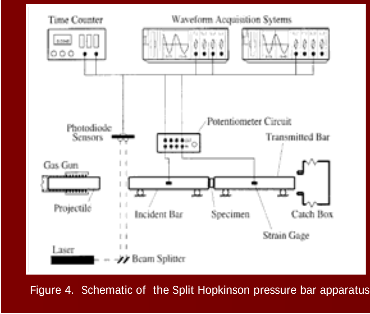

Figure 4. Schematic of the Split Hopkinson pressure bar apparatus

Figure 5. The Split Hopkinson Pressure Bar Set Up @ UMBC

Results and Plots:

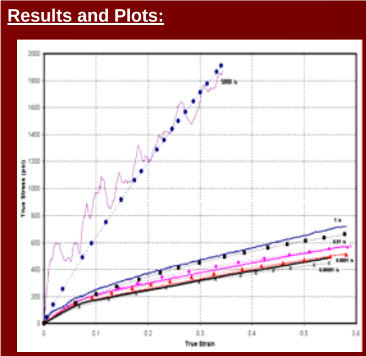

Figure 6. True stress-strain for uniaxial loadings with modified standard model correlations at different strain rates.

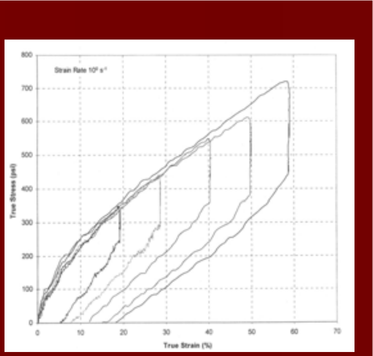

Figure 7. Stress relaxation experiments at 1 /s strain rate for different levels of strain.

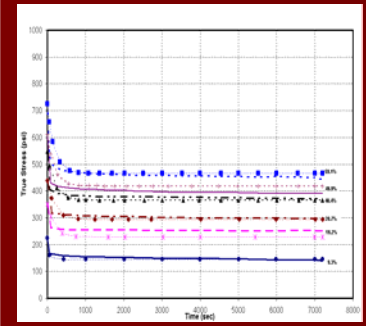

Figure 8. True stress-time for relaxation loadings with modified standard model correlations at different strain levels.

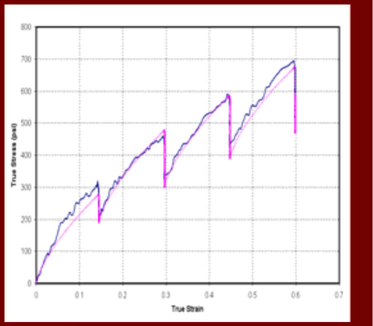

Figure 9. Multiple stress relaxation experiments at 1 /s strain rate with 2 hour relaxations different levels of strain

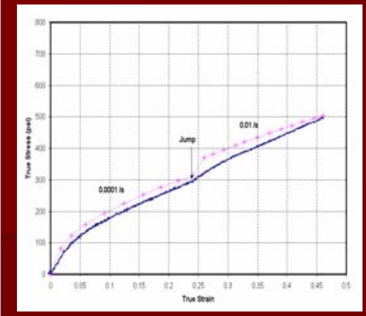

Figure 10. True stress-strain for uniaxial jump experiment with modified standard model predictions.

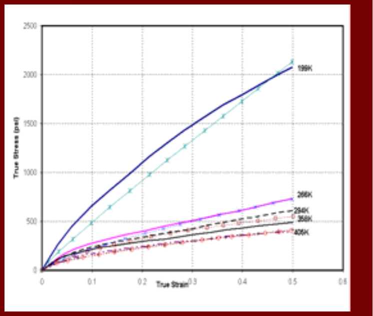

Figure 11. True Stress-Strain experiments at 0.01 /s strain rate at different temperatures

Conclusions: The compressive uniaxial behavior of the polymer Adiprene-L100 was modeled for quasi static and dynamic operating conditions as well as for stress relaxation experiments using modified standard solid model developed. Different temperature modeling was also performed on the polymer by modifying the viscosity term to incorporate temperature effects and showed that the model results are in fairly good agreement with the experimental data. This modified model has a physical foundation on the infinitesimal linear theory with a semi-empirical modification based on experimental observations. This, in turn, implies that the parameters of the model have a clear physical insight. In synthesis, the differential model developed in this work presents a simple and flexible framework to model nonlinear viscoelastic systems under finite deformation for a wide range of one-dimensional loadings. This model can act as a starting point for further generalizations to three dimensional cases, scope of which is beyond the purpose of this study.