Analysis of Mechanical Properties of Polymer Matrix Composites

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Abstract. Polymer materials have obvious viscoelastic properties. Viscoelastic mechanics mainly studies the relationship between deformation and external force, load time, load rate and other factors under the influence of external factors, as well as the stress field, strain field and relevant laws in the object. The deformation of viscoelastic materials is strongly dependent on time and temperature. The viscoelasticity of the material will change with the temperature. If there is no obvious creep at room temperature, there will be significant deformation and flow at higher temperature, and even the phenomenon of material failure will be different. If the temperature changes too much, it will change the mechanical properties of the material.

1. Introduction
Polymer materials have obvious viscoelastic properties. Viscoelastic mechanics mainly studies the relationship between deformation and external force, load time, load rate and other factors under the influence of external factors, as well as the stress field, strain field and relevant laws in the object [1, 2]. The deformation of viscoelastic materials is strongly dependent on time and temperature. The viscoelasticity of the material will change with the temperature. If there is no obvious creep at room temperature, there will be significant deformation and flow at higher temperature, and even the phenomenon of material failure will be different. If the temperature changes too much, it will change the mechanical properties of the material.

The term viscoelasticity comes from the model theory, that is, this property can be expressed by a typical model composed of elastic elements and viscous elements in series or in parallel, such as Maxwell model, Kelvin Voigt model, standard linear solid model. Viscoelastic mechanics is to establish the constitutive relationship of stress and deformation components on the premise of fully reflecting the viscous characteristics of materials, so as to solve the problem of stress and deformation analysis. It should be noted that the fundamental difference between plastic theory and viscoelastic theory is that plastic theory has nothing to do with the time of loading and unloading. Viscoelastic materials have two different mechanisms of deformation: elasticity and viscosity, which comprehensively reflect the characteristics of elastic solid and viscous fluid [3-5]. The deformation process of viscoelastic materials changes with time, which embodies the following four main characteristics:

1. Creep: under constant loading, the deformation will increase gradually;
2. Stress relaxation: under constant strain, the stress will gradually decrease;
(3) Hysteresis: the strain of the material lags behind the stress, resulting in a hysteresis loop formed by the stress-strain curve in the process of loading or unloading. The area under the hysteresis loop represents the energy loss in the process of loading and unloading;

(4) Sensitive to strain rate: some physical quantities reflecting the mechanical properties of materials, such as young’s modulus, shear modulus, Poisson’s ratio, etc., are generally related to strain rate.

At present, the common numerical methods for the micromechanical calculation of fiber-reinforced polymer matrix composites are the finite element method and the boundary element method. Direct solution in time domain is also a common research method. Generally, incremental superposition method is used to analyze stress and deformation, that is, the total time is divided into several intervals during calculation, assuming that the internal stress in each time interval remains unchanged, and the creep deformation generated in this period of time is used as initial strain and load to solve displacement increment according to elastic problem at the next moment, and then The total displacement is obtained by gradual superposition [6, 7]. Although the finite element method and boundary element method are widely used in the study of micromechanics of fiber-reinforced polymer matrix composites, there are still many difficulties in the process of numerical calculation. On the one hand, because the system is time-varying, it needs to mesh the time and space at the same time. On the other hand, the Laplace transformation is a common method in numerical calculation, but inverse transformation is difficult, especially for numerical calculation method, only numerical inverse transformation can be adopted, and finding effective inverse transformation technology has become a special research topic.

2. Solution method
Viscoelastic model consists of two basic elements: ideal elastic element and viscous element. They are combined according to certain rules to form a typical basic model of viscoelastic materials. The constitutive relation of ideal elastic element is

\[ \sigma = E \varepsilon \]  

The constitutive relation of viscous element is

\[ \sigma = F \dot{\varepsilon} \]  

The basic model of viscoelastic material is a combination of two simple cases described by the above two models. The differential constitutive relation can be expressed as follows:

\[ \sigma + p_i \dot{\sigma} = q_i \dot{\varepsilon} \]  

Under the action of constant stress, the strain of Maxwell model is a process of infinite increase, which is a typical fluid characteristic. Kelvin solid model is a parallel connection of spring element and glue pot element. Its differential constitutive relation is

\[ \sigma = q_0 \varepsilon + q_1 \dot{\varepsilon} \]  

The strain of Kelvin model increases monotonically, but not infinitely, but tends to a certain limit. The standard linear solid model is a series of elastic elements and Kelvin elements. The stress-strain relationship of this model is as follows

\[ \sigma + p_i \dot{\sigma} = q_0 \varepsilon + q_1 \dot{\varepsilon} \quad (q_1 > p_i q_0) \]  

The creep behavior of the standard linear solid model is similar to that of Kelvin model, and it is also a monotonic increasing process, and tends to limit value process. The difference is that, like Maxwell model, it has a transient elastic response, that is, when the constant stress acts, the model will produce an initial strain. There are two ways to construct more general linear viscoelastic model: Kelvin chain and generalized Maxwell model. Kelvin chain is composed of any number of different Kelvin elements in series, sometimes including spring element and viscous element in series. Kelvin chain and generalized Maxwell model have the same form of constitutive equation:
\[
\sum_{k}^m p_k \frac{d^k \sigma}{dt^k} = \sum_{k}^n q_k \frac{d^k \varepsilon}{dt^k}
\]

Eq. (6) can also be abbreviated as:

\[
P \sigma = Q \varepsilon
\]

where

\[
P = \sum_{k}^m p_k \frac{d^k}{dt^k}; \quad Q = \sum_{k}^n q_k \frac{d^k}{dt^k}
\]

The constitutive relations of the differential forms of the above viscoelastic models are simple and intuitive. The research of this paper is based on differential constitutive relation. According to Boltzmann superposition principle and genetic integral method, integral constitutive relation can also be established. Compared with the differential constitutive relation, the classification eigenrelation can directly reflect the basic experimental feature memory feature of materials. There are two forms of integral constitutive relation, one is creep constitutive relation:

\[
\varepsilon(t) = \sigma_0 J(t) + \int_{0}^{t} J(t-t') \frac{d \sigma}{dt'} dt'
\]

The other is relaxation constitutive relation:

\[
\sigma(t) = \varepsilon_0 Y(t) + \int_{0}^{t} Y(t-t') \frac{d \varepsilon}{dt'} dt'
\]

3. Numerical example

In this study, the boundaries instability for the viscoelastic beam are determined. The viscoelastic material is considered to be as polymethyl methacrylate at room temperature. Fig. 1 plots the boundaries of principal instability under various static forces. Increasing the static force reduces the natural frequency and increases the loss factor. Therefore, the region of principal instability shifts away from the axis at low frequencies as the static force is increased.

![Figure 1. Influence of the static force.](image)
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