International Journal of Academic Research (ISSN: 2075-4124)
January 2015, pp: 260-266

Simulation of Viscoelastic Materials by ABAQOUS

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Abstract:

The present article aims to simulate the behavior of viscoelastic materials. First, we define required parameters such as shear module and loss factor in order to predict the behavior of viscoelastic materials. Then, the measurement of each above variable will be explained by test. To employ the result from test, related theories should be explained in brief. Finally, resultant variables are used to simulate in ABAQOUS software.

Keywords: Simulation, of Viscoelastic Materials, ABAQOUS, vibration level

Introduction

Noise and vibrations are an environmental issue we are always intended to reduce or eliminate them. In cars, the most common method is adding passive dissipative materials to the body in order to reduce noise and vibration level. Anyway, prediction of noise and vibration is important. One of accepted and effective way to reduce vibrational energy is using viscoelastic materials as constrained layer. Loss factor of viscoelastic materials and also the stiffness of constrictive layer attached to the structure is very effective to reduce vibrational energy. Thus, when the main structure is vibrated largely, viscoelastic layer is subjected to a huge transformation and its kinetic energy will be converted to thermal. Several ways have been presented to show the behavior of viscoelastic materials in the context of vibration absorbent layers since 1950. One of the ways to simulate the behavior of viscoelastic materials is modeling shear modules by a series of small damping oscillators. According to the same idea, two scientists performed transient and steady state analysis of sandwich panel. The intersection of all recent studies is that parameters in the selected model are accurately known or estimated. There are two basic information in linear viscoelastic, especially in dynamic behavior of semi-elastics: real and imaginary part of shear module. These variables are severely depended on temperature and frequency. Nashif found some information about how to use one-end involved beam for extracting mixed and frequency-depended shear module for different temperatures of a viscoelastic material. The results can be found in Standard ASTM756-98. The results of these standards have been used in the article.

Viscoelasticity as Reduced Fractions

Rubber with nitrile (Acrylic nitrile butadiene) base is one of the most common rubbers. The rubber studied in this example contain 35% of Black Carbon. Rubber has been stock to the steel plate. In the process of sticking them, temperature and pressure must be high enough, rubber must be also already attached to the steel by a thin layer of glue.

Rubber with nitrile base is basically a viscoelastic and quite incompressible material. Viscoelastic behavior is observed when shear module of material is a function of frequency as figure1. Poisson's coefficient of this material has been achieved with high accuracy of 0.4993. It has been assumed in this model that strains are little and linear. Thin layer of rubber has been constrained by metal plates which are good thermal conductors. The assumption of being isothermal is also valid for the rubber. Elastic behavior (in isothermal and isotropic conditions) has been modeled by linear viscoelastic model. However, using classic model of viscoelastic materials in which internal variables are first grade according to the variations law, many internal variables and consequently many parameters are needed to describe viscoelastic behavior. The number of required parameters are significantly reduced by using reduced fractions. Linear reduced fractions is appropriately consistent with empirical results for a wide range of frequencies and polymers. But this consistency is in single-axis state.

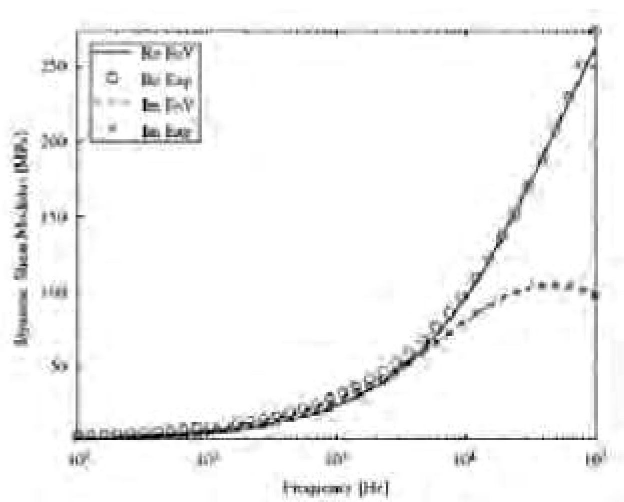

Figure1. Simple transformations of materials

Shear stress equation τ can be written as two Couple equations:

$$\tau(t) = G_{.} * \gamma(t) - (G_{.} - G_{\infty})\gamma^{V}$$

$$D^{\alpha} + \frac{1}{\tau_{*}^{\alpha}}\gamma^{V} = \frac{1}{\tau_{*}^{\alpha}}\gamma, \qquad \gamma^{V} = \cdot$$

(1)

$$D^{\alpha}y(t) = \frac{١}{\Gamma(١-\alpha)}\frac{d}{dt}[\int_{٠}^{t}\frac{y(s)}{(t-s)^{\alpha}}ds] \quad (2)$$

Using Fourier transform, operator D is relation 3:

$$F[D^{\alpha}y(t)](\omega) = (i\omega)^{\alpha}F[y(t)](\omega) \quad (3)$$

Using equations 1 and 3, equation 4 will be obtained:

$$t(\omega) = G^{*}(\omega)\gamma(\omega)$$
$$G^{*} = (G_s(\omega) + iG_l(\omega)) = G_{٠} - \frac{G_{٠} - G_{\infty}}{١ + (t_{*}i\omega)^{\alpha}} \quad (4)$$

Using ASTM E756-98 standard, real and imaginary part of shear module can be obtained. Real and imaginary part of shear module is a function of temperature and frequency shown practically by a one-end involved beam in figure2. A non-contact electromagnetic stimulation has been placed at the free-end of beam. The how to perform the test is presented in ASTM E756-98. A piezoelectric crystal collect system response at the tangly end. Temperature is increased from -30 to 180 degrees within 10 degrees steps. When the sample temperature reached to steady state, all tests will be performed. The required time to achieve desired temperature at each step is about 30 minutes. The length of the beam used for each test is 15cm and it width 25.4mm.

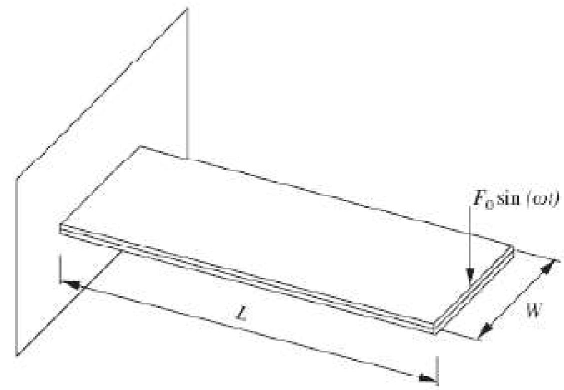

Figure2. The beam used for test

Shear module, obtained from test results, has two real and imaginary parts. To pass the curve4 through these results, real and imaginary parts have to be separated. Real and imaginary parts of curve4 are separated in equation5.

$$G_{٠} - \frac{\left(١ + cos\left(\frac{\pi\alpha}{٢}\right)\right)(G_{٠} - G_{\infty})(\omega t)^{\alpha}}{٢(١ + cos\left(\frac{\pi\alpha}{٢}\right).(\omega t)^{\alpha})} + \frac{sin\left(\frac{\pi\alpha}{٢}\right)(G_{٠} - G_{\infty})(\omega t)^{\alpha}}{٢(١ + cos\left(\frac{\pi\alpha}{٢}\right).(\omega t)^{\alpha})} * i \quad (5)$$

In order to achieve coefficients of the curve easily, it is necessary to define a variable like B instead of $\cos(\frac{\pi\alpha}{2})$ in real part of equation5, then equation6 is given:

$$G_{.\_}\frac{(١ + B)(G_{.} - G_{\infty})(\omega t)^{\alpha}}{٢(١ + B.(\omega t)^{\alpha})} \quad (6)$$

Figure1 shows the curve6 passing through the results from test. It is evident that passing the curve through a smaller frequency band will have more accurate results. The numbers of figure1 have been obtained in room temperature. To achieve the parameters of equation6, minimum squares method must be used to have the least error for passing the curve. To do so, MATLAB software was used. Finally, the following values were obtained.

$$G_{.} = ۴١۴Mpa,$$
$$G_{\infty} = ۴Mpa\ ,$$
$$t_{*} = ٣.٣١ * ١٠^{-۶}s,$$
$$\alpha = ٠.۶ \quad (7)$$

Viscoelastic materials and ABAQOUS

ABAQOUS software investigates viscoelastic materials' behavior in two main fields:

1- Time
2- Frequency

In time field, several transformations of these materials and ... are investigated, and in frequency field, the behavior of materials depending on the frequency.

Viscoelastic theory in ABAQOUS

Consider a shear test with small strain, this shear strain varies frequently by time.

$$\gamma(t) = \gamma_{.} exp\ (i\omega t) \quad (8)$$

It is assumed that this viscoelastic piece has been under oscillation for a long time, and reached to a steady state.

$$\tau(t) = (G_s(\omega) + iG_l(\omega))\gamma_{.} exp\ (i\omega t) \quad (9)$$

This module (mixed) can be dimensionless first by the help of equation1, and then Fourier transform.

$$g(t) = \frac{G_{R(t)}}{G_{\infty}} - ١ \quad (10)$$

$$G_s(\omega) = G_{\infty}\left(١ - \omega\Im g^{*}(\omega)\right)$$
$$G_l(\omega) = G_{\infty}(\omega\Re g^{*}(\omega)) \quad (11)$$

When there is a multi-axis stress in the model, ABAQOUS assumes that shear module and volume module are independent. The behavior of volume module is defined by two parts of storing volume module $K_s(w)$ and wasting volume module. A shear module similar to this model's module can be dimensionless by the help of Fourier transform $k^*(w)$ and time-dependent volume module $k_{R(t)}$.

$$K_s(\omega) = K_\infty\left(1 - \omega\Im k^*(\omega)\right)$$
$$K_l(\omega) = K_\infty(\omega\Re k^*(\omega)) \quad (12)$$

Defining viscoelastic materials' properties in ABAQOUS

There are 4 ways to define viscoelastic materials' properties in frequency field, including:

1- Determining the coefficients of Peron series
2- Results of creeping test
3- Results of releasing test
4- Determining the frequency-dependent coefficients

Determining the frequency-dependent coefficients is categorized into two parts of Formula and Tabular methods.

Relations of Formula method

The relations of this part is as follows;

$$g^* = g_1^* f^{-a}$$
$$k^* = k_1^* f^{-a} \quad (13)$$

Relations of Tabular method

The relations of this part is as follows;

$$\omega\Re g^*(\omega) = G_l/G_\infty \quad \omega\Im g^*(\omega) = 1 - G_s/G_\infty$$
$$\omega\Re k^*(\omega) = K_l/K_\infty \quad \omega\Im k^*(\omega) = 1 - K_s/K_\infty \quad (14)$$

Simulation of a real example in ABAQOUS software

In this section, we simulate the beam of figure2. In figure 2, steel plates are placed in up and down, each of them with thickness of 0.5mm. They are drawn in Part module of ABAQOUS software as Shell. There is viscoelastic material between two mentioned plates, which is made of NBR with thickness of 0.1mm. In Part module, this part is drawn as Solid.

In table1, the properties of elastic section for steel and viscoelastic layer are presented.

Table1. The properties of elastic part

Poison's coefficient	Yang module GPa	Density (kg/m^3)	
0.3	210	7800	Steel
0.4939	0.002757904	1250	Layer NBR

In Load module, we apply 1N load on the beam end, and close all freedom degrees at the other end.

Findings

In the following, the results from test are compared with software results. Figure3 indicates that the results are well consistent.

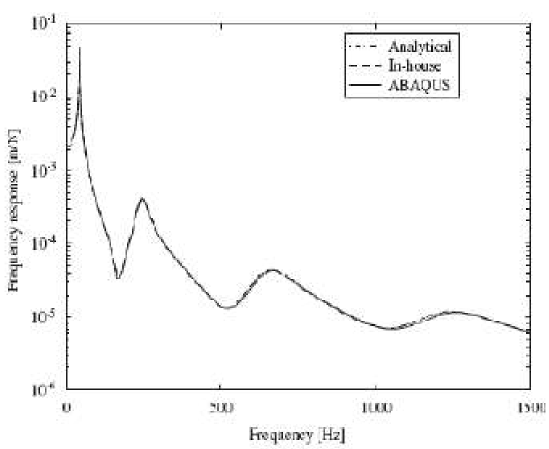

Figure3. Analytical solution results (dotted mode of answer for tangly support)

Conclusion

By the help of ABAQOUS software, we can simulate the behavior of viscoelastic materials, conditional to calculate storing shear module and wasting module of viscoelastic materials by the test. Table method is the best choice among them.

List of Symbols

G	instantaneous shear module
G_∞	final shear module
$G_{R(t)}$	time-dependent shear module
G_l	wasting shear module
G_s	storing shear module
$K_{R(t)}$	time-dependent volume module
K_l	wasting volume module
K_s	storing volume module
g^*_1	mixed number
k^*_1	mixed number
t_*	reversibility constant s
a	real value
b	real value
D	operator
E	elasticity module
F	Fourier transform

f frequency

G shear module

i

K volume module

M Resilience module

Greek Symbols

Shear internal module

Real part of shear module

Mixed part of shear module

α a number between zero and one

shear variable

v poison's variable

τ shear tress

ω angular velocity

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