Predictive Model of an Elastomer for Dynamic Properties under Thermal Environment

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ABSTRACT

In this paper, the variability of dynamic stiffness in an elastomer due to thermal aging is estimated using a degradation model and uncertainty quantification method. A degradation model introduced for the thermal aging also describes the variation of the material properties along time. A finite element model describes the dynamic characteristics of the elastomer. The variability of the predicted degradation under the quantified uncertainties is estimated using the double-loop eigenvector dimension reduction (EDR) method. The proposed method is applied to a mount as a numerical example.

1. ELECTRONIC SUBMISSION

Elastomers are subjected to long term variation of its dynamic characteristics due to environment such as ozone, humidity, abrasion, chemicals and heat (Celina 2013). Among them, thermo-oxidative aging is a dominant factor in the degradation of mechanical properties in elastomers. The dynamic characteristics of elastomers are also heavily dependent upon frequency and operational temperature (Jung et al. 2011; Kwon and Lee 2015; Lee and Hwang 2011; Lee et al. 2016). In this paper, a variability analysis procedure for the thermal oxidative aging for elastomers is described.

2. DEGRADATION MODEL OF ELASTOMERS FOR THERMAL AGING

The thermo-oxidative degradation of mechanical properties is a common phenomenon in elastomers. Under the thermal aging condition, the modulus of elastomer generally becomes larger proportional to the exposed time to air at a constant temperature(Bauer et al. 2005). A linear degradation model can describe the change of the modulus E due to the thermal aging in time at a reference temperature T_0 as:

$$\mathrm{E}(t,\mathrm{T}) = E_0(1+\gamma\cdot t) \tag{1}$$

where t and γ are time and a proportional constant for the thermal aging, respectively. For arbitrary environmental temperatures, the shifted time can replace the time t in Eq. (1) by multiplying a shift factor S_T to the time. The Arrhenius relation relates the shift factor and temperature as:

$$\ln S_T = h_1\left(\frac{1}{T}-\frac{1}{T_0}\right) \tag{2}$$

where h_1 is a constant. Introducing the equivalent exposed time, the amount of degradation in different temperatures can be estimated by accumulating the shifted time as:

$$t_e(T_0,t) = \int_0^t S_T(T(t),T_0)dt \tag{3}$$

Here, t_e refers to the equivalent exposed time at the reference temperature. Thus, for a given operational temperature history as shown in Fig. 1, we can predict the amount of degradation in the storage modulus for elastomers using Eqs. (1-3).

The complex modulus has variability due to the uncertainties in the operational temperature, manufacturing variations and experimental errors as well described in Refs. (Jung et al. 2009; Jung et al. 2011; Lee et al. 2013). The degradation model also has uncertainties which should be treated as

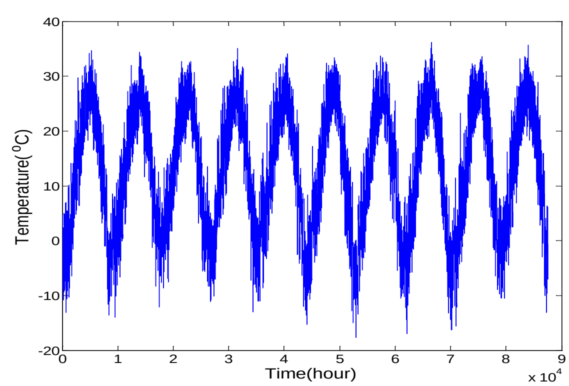


Figure 1. Temperature history for 10 years in Seoul

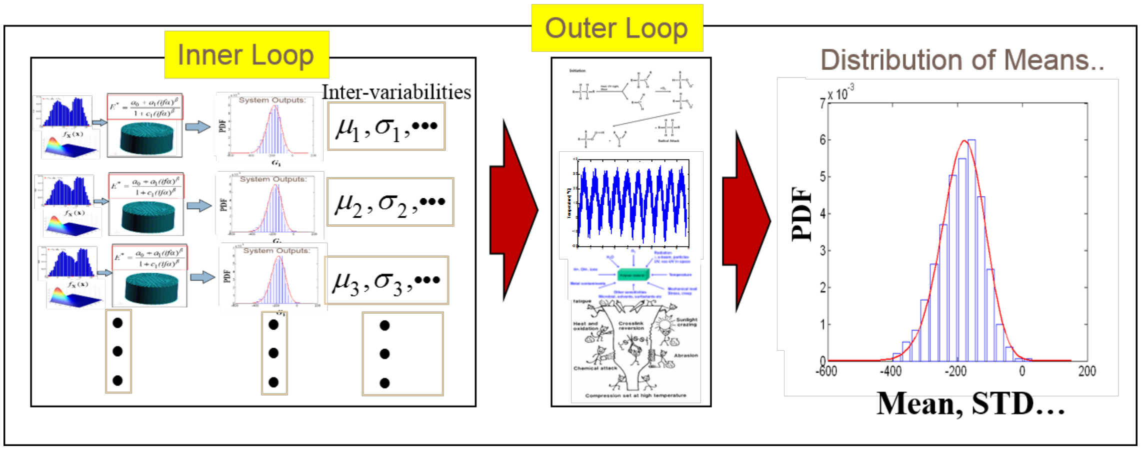


Figure 2. Double-loop variability estimation procedure

Table 1. Statistical properties of the degradation model parameters

Random Variable	Mean	Standard Deviation	Distribution Type
γ (1/week)	0.005	10% COV	Normal
h_1 ($^oK^{-1}$)	8.299E3	5% COV	Normal

random process. Thus, the predicted material property of the elastomers become a distribution of distributions: i.e. the statistical moments of the thermally aged material properties for the elastomers are not deterministic values but described by statistical distributions. A double-loop uncertainty propagation analysis can provide the statistical properties for the distribution of distributions. In this study, the double-loop EDR method(Youn et al. 2008) is used to predict the degradation of elastomers under the thermo-oxidative degradation. In the inner loop of the double-loop EDR method, the variability due to temperature and material model parameter uncertainties. In the outer loop, the variability due to aging environment and aging-model uncertainties. Figure 2 shows the concept of the double-loop EDR method

3. NUMERICAL EXAMPLE

The described method that can estimate the variability of dynamic characteristics due to thermally aged material properties is applied to an elastomer made of a Styrene-Butadiene Rubber (SBR) as shown in Fig. 3. Finite elements was used to calculated the responses of the elastomer. To calculate the dynamic stiffness of the elastomer in vertical direction, frequency response analysis was carried out using commercial software MSC/NASTRAN with fixed displacements on the bottom surface and a unit force on the top surface.

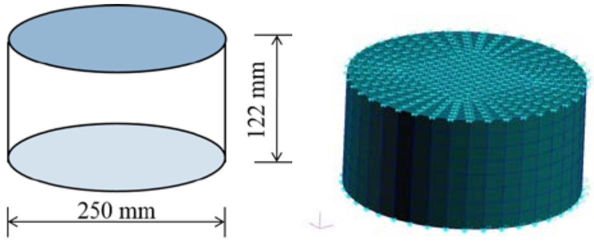
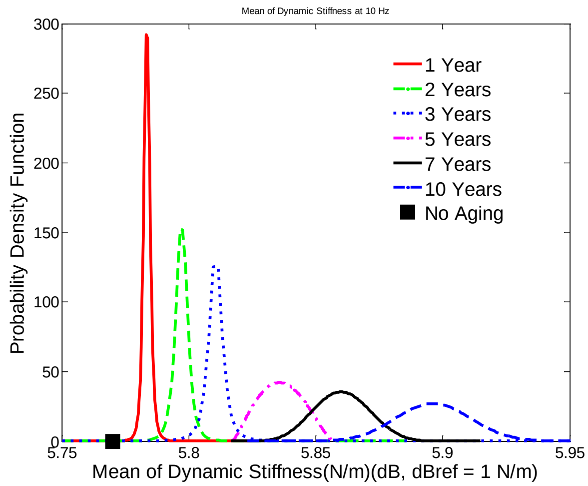


Figure 3. An elastomer and its finite element model

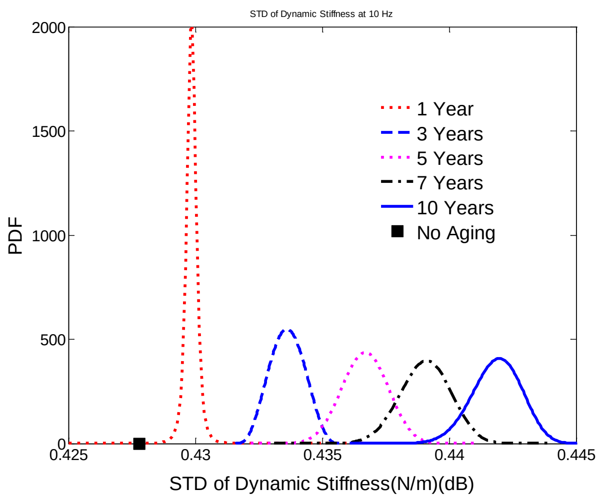
The uncertainties due to environmental temperature and uncertainties of the material properties for the SBR quantified in a previous work(Lee and Hwang 2011) was used to estimate the variability of the dynamic stiffness of the elastomer. This is the inner loop for the quantification of the variability. The outer loop of the variability estimation quantifies the variability due to thermal aging: i.e. the variation of the variability of the dynamic stiffness in terms of the distribution of the mean and standard deviation of the variability along environmental temperature history. Table 1 lists the assumed uncertainties of the degradation model parameters of Eqs. (1) ~ (2). The 10-year temperature history measured in Seoul as shown in Fig. 1 was selected as an environmental temperature history. Figure 4 shows the distributions of the mean and the standard deviation of the dynamic stiffness at 10 Hz along time. The estimated mean distributions well demonstrate the proposed prediction methodology for thermal aging.

4. CONCLUSION

In this paper, the variability of dynamic characteristics of an elastomer due to the thermal aging is estimated using the double-loop variability estimation method. The degradation model of the elastomer is introduced with the equivalent exposed time in order to consider the change of environmental temperature. The double-loop variability estimation method estimates this variation of the variability. The proposed estimation procedure for the thermal aging is



(a) Mean



(b) Standard deviation

Figure 5. Distribution of mean of the dynamic stiffness at 10 Hz according to thermal aging

applied to an elastomer in order to demonstrate the effectiveness of the method.

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