ANALYSIS OF THE SENSITIVITY OF VISCOELASTIC PARAMETERS AT THE STRAIN-RATE OF A THERMOPLASTIC

Younès Saadallah^{1,2}, Semcheddine Derfouf², Belhi Guerira²

¹University de Jijel, Algeria

²Laboratoire de Génie Mécanique, University of Biskra, Algeria

NOMENCLATURE

E	Elastic modulus, MPa
F	Fonction objective
N	number of measurement points
ε	Strain
$\dot{\varepsilon}$	Strain-rate, Min ⁻¹
σ	Stress, MPa
μ	Viscosity parameter, MPa. min ⁻¹
ex	experimental
mod	model

1. INTRODUCTION

Thermoplastic polymers exhibit strong time-dependent behavior at ambient temperatures. They have a viscoelastic behavior. It is an instantaneous elastic response added to another delayed elastic response.

The sensitivity of the mechanical behavior of thermoplastics to time is physically explained by their structure in macromolecular chains. Evidence of the influence of time on the behavior of thermoplastics is done by creep and relaxation tests. Another test makes it possible to observe the sensitivity of the behavior of the polymers at times: it is a series of tests with different strain rates.

The models used to describe viscoelastic behavior can be analog models. They are parallel or series combinations of springs and dampers. The simplest of them are the models of Maxwell and Kelvin-Voigt.

The present work concerns a study of the sensitivity of the viscoelastic parameters of a thermoplastic to the strain-rate at ambient temperature. The material of study, a polyamide 6 in this case, is supposed to behave according to the Kelvin-Voigt viscoelastic model. Tensile tests at different strain-rates are conducted. The model parameters are identified for each strain rate. The relationship of the identified parameters to the strain rate is established and discussed.

2. MODELING, EXPERIMENTATION AND IDENTIFICATION

2.1. VISCOELASTIC MODEL

The rheological model applied in this study is represented by the Kelvin-Voigt mechanism. This is a combination of a damper spring in parallel.

The stress generated in the mechanism is:

$$\sigma = E\varepsilon + \mu\dot{\varepsilon}$$

2.2. MATERIAL AND EXPERIMENTAL DEVICE

The material under study is a polyamide 6. The conditions under which the tests are carried out are summarized in a temperature of 300 K and a humidity of 20%.

The test machine is of the INSTRON 5969 brand with a capacity of 50 KN..

Tensile tests at different strain-rates are conducted. They are of the order of (6.10⁻⁹, 6.10⁻⁶, 6.10⁻⁵) min⁻¹.

2.3. IDENTIFICATION OF PARAMETERS

The identification is done by means of an inverse analysis. Thus, it is to formulate an objective function that minimizes the difference between the experimental results and those of the model. This functional is expressed by:

$$F = \sum_{i=1}^N \frac{1}{2} (\sigma_{ex}^i - \sigma_{mod}^i(E, \mu))^2$$

Minimization is performed by the technique of genetic algorithms.

3. RESULTS AND DISCUSSION

3.1. IDENTIFIED PARAMETERS

The table below shows the viscoelastic parameters identified. The two parameters depend considerably on the strain-rate. The higher the strain-rate, the larger the modulus E and the smaller the parameter μ . This is explained respectively by an increase in strength on the one hand and a decrease in viscosity on the other hand.

Strain – rate(min ⁻¹)	E (GPa)	μ (GPa. min)
6.10 ⁻⁹	1,55	100
6.10 ⁻⁶	2,00	5
6.10 ⁻⁵	2,25	0.15

3.2. CONFRONTATION TEST-MODEL

The figure below represents a test-model confrontation of the stress-strain relationship at different strain rates. A linear aspect is noticeable whatever the strain-rate. This is interpreted by the linear springs of the analog model.

3.3. SENSITIVITY OF PARAMETERS AT THE STRAIN-RATE

For a mathematical illustration of the sensitivity to the strain-rate of the viscoelastic parameters identified, we opted for an exponential regression in Excel. This gives the following functions:

$$K = 3259\dot{\varepsilon}^{0,04} \quad \mu = 11,5\dot{\varepsilon}^{-0,48}$$

The relationship between the parameters and the strain rates is therefore strongly non-linear as illustrated in the figures below.

4. CONCLUSION

The present work consists of a study of the sensitivity of the viscoelastic parameters to the strain rate of a polyamide. The behavior model is represented by a two-parameter analog mechanism. After identification of these parameters by inverse analysis, great importance was allocated to the study of their dependence on the strain-rate. It is found that the two parameters strongly depend on it and not linearly. Thus, an increase in the strain-rate causes the increase in the strength of the material and, on the other hand, the decrease in its viscosity. The dependency functions were determined from an exponential regression.

REFERENCES

- [1] J. D. Ferry, *Viscoelastic properties of polymers*: John Wiley & Sons, 1980.
- [2] B. Davoodi, A. Muliana, D. Tscharnuter, and G. Pinter, "Analyses of viscoelastic solid polymers undergoing degradation," *Mechanics of Time-Dependent Materials*, 19, 397-417, 2015.
- [3] C. R. Siviour and J. L. Jordan, "High Strain Rate Mechanics of Polymers: A Review," *Journal of Dynamic Behavior of Materials*, 2, 15-32, 2016.
- [4] D. A. Şerban, G. Weber, L. Marşavina, V. V. Silberschmidt, and W. Hufenbach, "Tensile properties of semi-crystalline thermoplastic polymers: Effects of temperature and strain rates," *Polymer Testing*, 32, 413-425, 2013.
- [5] C. W. Chung and M. L. Buist, "A novel nonlinear viscoelastic solid model," *Nonlinear Analysis: Real World Applications*, 13, 1480-1488, 2012.