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

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NOMENCLATURE

E Young's modulus, MPa
K viscoelastic parameter, MPa
F Fonction objective
N number of measurement points

ϵ Strain
 $\dot{\epsilon}$ Strain-rate, Min⁻¹
 σ Stress, MPa
 μ Viscosity parameter, MPa. Min⁻¹

e elastic
ve viscoelastic
ex experimental
mod model

1. INTRODUCTION

Thermoplastic polymers exhibit strong weather-dependent behavior at ambient temperatures. Subject to stresses below the threshold of plasticity, 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 mechanical constitutive law being managed by parameters which represent its properties, it is natural that these parameters also depend on the time. As the speed of strain increases, the resistance of the material increases. The models used to describe viscoelastic behavior can be classified into analog models, power law models, and fractional models. Models inspired by analog models 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 at the strain-rate at ambient temperature. The thermoplastic object of study, a polyamide 6 in this case, is supposed to behave according to the Kelvin-Voigt viscoelastic model with instant elasticity. Tensile tests at different rates of constant strain 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. RHEOLOGICAL MODEL

The rheological model applied in this study is represented by the Kelvin-Voigt mechanism with instant elasticity.

Kelvin-Voigt mode

The stress generated in the spring is identical to that of the combination in parallel damping spring.

$$\sigma = E\epsilon_e = K\epsilon_{ve} + \mu\dot{\epsilon}_{ve}$$

As the elastic strain velocity is zero, the overall strain rate is equal to the velocity of viscoelastic strain :

$$\dot{\epsilon} = \dot{\epsilon}_{ve}$$

The stress as a function of the total strain is written :

$$\sigma = \frac{E}{E+K} (K\epsilon + \mu\dot{\epsilon})$$

2.2. MATERIAL AND EXPERIMENTAL DEVICE

The material under study is a polyamide 6. It is a technical thermoplastic named TECAMID 6 sold in sheets of 07 mm thick. 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. It is equipped with a contactless video extensometer. This one allows to correct some problems like those related to the sliding of the edges of knife and the inertia of moving parts. The data is processed using a Bleuhill 3 control and acquisition system.

Tensile tests at different constant strain rates are conducted. The strain-rates correspond to the speeds of the traverse movement. They are of the order of (0.0000646, 0.000625, 0.00612, 0.0556) Min⁻¹.

2.3. IDENTIFICATION OF PARAMETERS

The equations of the model being formulated, the experimental results being obtained, it is necessary to identify the parameters of the model. 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 by involving all the parameters to be identified. This functional is expressed by:

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

N is the number of measurement points, σ_{ex}^i et σ_{mod}^i respectively represent the experimental constraints and simulated by the model. Minimization is performed by the technique of genetic algorithms.

3. RESULTS AND DISCUSSION

3.1. IDENTIFIED PARAMETERS

The table below shows all the viscoelastic parameters identified. It is noted that the instantaneous modulus of elasticity E is independent of the strain rate while the other two parameters depend considerably on it. The higher the strain-rate, the larger the module K 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)	K (GPa)	μ (GPa. Min)
0.0000646	2.976	7.312	23.881
0.000625	2.976	12.206	5.006
0.00612	2.976	18.636	0.738
0.0556	2.976	32.308	0.064

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. It should be mentioned that at higher solicitations, it is often necessary to predict non-linear behavior.

3.3. STUDY OF THE SENSITIVITY OF PARAMETERS AT THE STRAIN-RATE

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

$$K = 58881\dot{\epsilon}^{0.2163} \quad \mu = 6,6166\dot{\epsilon}^{-0.872}$$

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 taken into account is represented by a three-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 instantaneous modulus of elasticity is insensitive to the speed of strain while the other 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. The comparison of the experimental results with those obtained by the model revealed a very good coherence.

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