A thermomechanical MT2.0 test for PMMA

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Abstract. The present work aims at designing a thermomechanical test with two spatial heterogeneities: one for the stresses and one for the temperatures. Such tests are used to identify parameters of a linear thermo-viscoelastic material model using the Virtual Fields Method. The temperature gradient in the sample is generated by means of an inductor placed behind the sample, allowing to cover a significant range of temperatures, from room temperature up to 80°C. The inductor is used in combination with a standard mechanical tensile machine, in order to generate the sought thermomechanical fields. The procedure is applied to samples made of polymethyl (methacrylate) (PMMA) for validation of the experimental protocol. Its main purpose is to provide an enriched thermomechanical database for fast identification of the thermomechanical behaviour of the material instead of having to conduct a high number of tests at different uniform temperatures.

Introduction

The emergence of optical techniques for kinematic and temperature measurements fields opens up the way for the development of advanced inverse methods adapted to the identification of parameters of material constitutive models with a reduced number of tests [1]. In the Virtual Fields Method (VFM), the stress can be computed from heterogeneous data (*i.e.*, strain and temperature measurements) and using the principle of virtual work, the constitutive parameters can be identified [2].
The VFM has been successfully applied to the identification of elastic, viscoplastic and viscoelastic constitutive models using kinematic (strain and strain rates) heterogeneous fields in [3,4,5]. More recently, the method was applied to calibrate the Johnson-Cook model using thermomechanical data from a Gleeble test system [6]. However, the position and range of the temperature gradient generated by such test systems are not user-defined, as these systems are not initially designed to generate heterogeneous temperature fields**.** The aims of this work are:

1. to design a thermomechanical test system in a controlled environment;
2. to use the experimental data to identify a constitutive material law with the VFM.

Material of interest and model

The poly(methyl methacrylate) material (PMMA) is selected because the stress has a high sensitivity to temperature and strain rate, even for small variations of these quantities, as shown in Fig. 1.

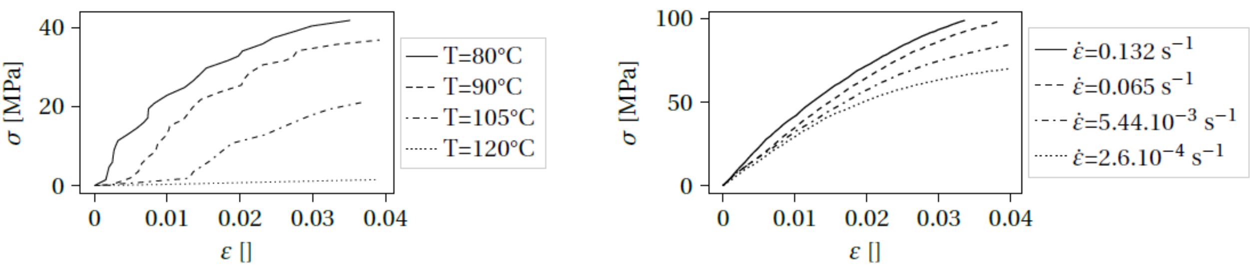

Fig. 1 – Sensitivity of the stress (a) to temperature [7] and (b) to strain rate [8] in PMMA

PMMA is considered as a viscoelastic, isotropic and thermo-rheologically simple material. The stress in the linear domain can be calculated using Eq. 1.

$$\sigma_{ij}(t,\varepsilon,T) = \int_0^t K(t-\tau,T)\dot{\varepsilon}_{kk}d\tau + 2\int_0^t G(t-\tau,T)\dot{e}_{ij}d\tau \qquad (1)$$

where $K(t-\tau,T)$ and $G(t-\tau,T)$ are the bulk and shear moduli respectively, $\dot{\varepsilon}_{kk}$ and $\dot{e}_{ij}$ are the volumetric and deviatoric strain rates respectively. The dot denotes the local time derivative with respect to τ.
The time and temperature dependency of the bulk and shear moduli is described using a generalized Maxwell model combined with time temperature equivalence. The model is expressed in terms of a Prony series in the plane stress framework [9,10,11].

Experimental set-up

The heterogeneous temperature fields are generated by means of an inductor heating a metallic bar. The system is placed behind the sample and generates a gradient from ambient temperature up to 80°C, as shown in Fig.2.a. The system is controlled such that a quasi-stationary temperature field is obtained (Fig.2.b).

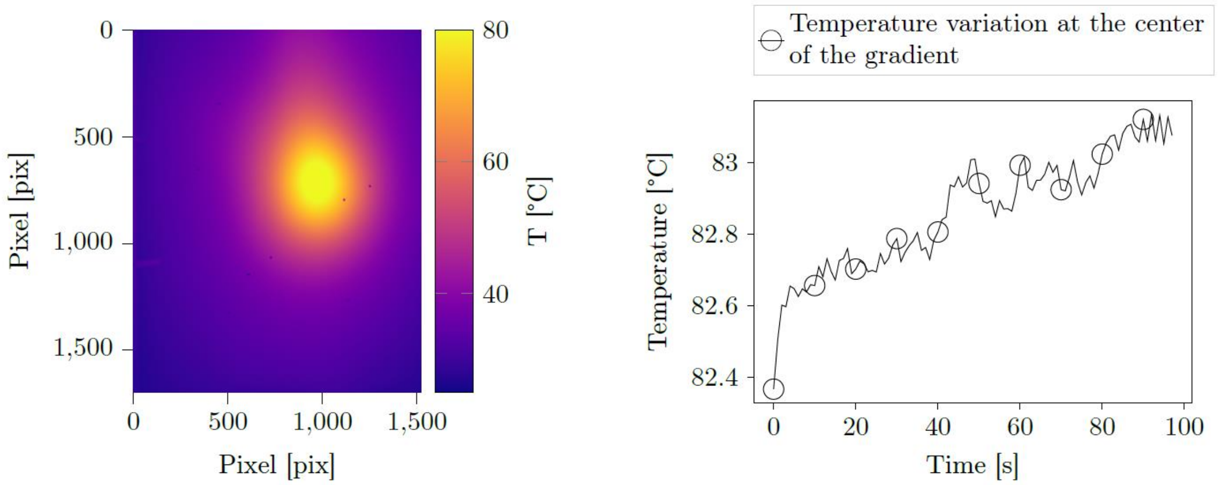

Fig. 2 – (a) Quasi-stationary temperature field generated, (b) Temperature time history measured at the centre of the hotspot.

The system developed to generate the heterogeneous temperature field is used combination with a standard mechanical tensile machine to generate the thermomechanical fields. Digital Image Correlation is used to obtain the displacement and strain fields. First, measurement performances are assessed using stationary images with and without heating of the specimen. Then, the test is conducted and temperature and strain fields are used by the VFM for the identification of the Prony series and time temperature equivalence parameters. This new procedure has a potential for fast viscoelastic characterization of polymer materials, replacing several isothermal tensile tests.

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