Surface calorimetry under large deformations of rubbers: a bi-dimensional heat source field reconstruction method in the Lagrangian configuration

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Abstract. The determination of heat source fields during mechanical loading provides local information on the material deformation processes such as viscous and damage phenomena, or microstructure changes. In this study, a methodology is developed to reconstruct heat source fields at the surface of a stretched rubber specimen from full kinematic and thermal fields and the bidimensional formulation of the heat diffusion equation. The main problem is to take into account the large deformations and thus to know the position of material points in the infrared images. In the present study, a methodology has been developed for compensating the movement of points in the infrared images. We present results obtained for the Lagrangian formulation of the heat diffusion equation.

Introduction

Infrared imaging and more especially surface calorimetry provides information of importance that is complementary to that obtained with conventional mechanical characterization [1]. In the particular case of materials capable of withstanding very large strains, typically elastomers, the points observed on their surface by the infrared camera undergo large displacements and a methodology for determining their displacement within the infrared images has to be developed [2].
In Section "Theoretical background", the Lagrangian formulation of the heat diffusion equation is presented. In Section "Experimental setup", the experiments carried out for applying and validating the displacement compensation methodology are precisely described. In Section "Results and Discussions ", the results obtained are discussed according to the capability of the methodology to capture local singularities in the heat source field, which involves metrological considerations. Concluding remarks close the paper.

Theoretical background

Considering that thermal conduction follows Fourier's law and that the material is incompressible, the heat diffusion equation has first been written in the Lagrangian configuration [3]. This formulation has then been simplified by applying several successive assumptions (i) the temperature is assumed to be homogeneous throughout the thickness of the specimen (ii) heat conduction is assumed to be isotropic (iii) external radiation is assumed to be constant over time. With these assumptions and by using the temperature variation instead of the temperature, the heat equation has finally been simplified.

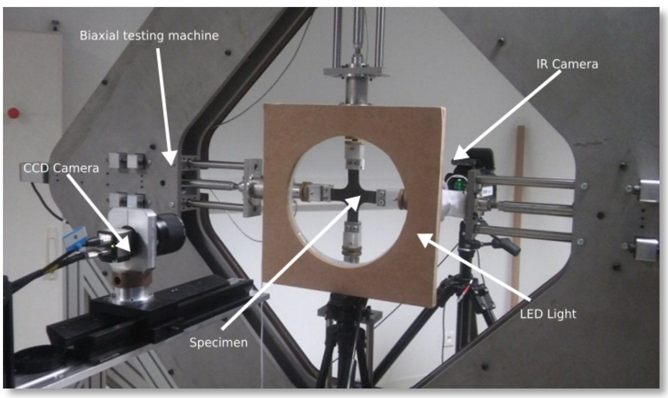

Fig. 1 - Experimental Setup.

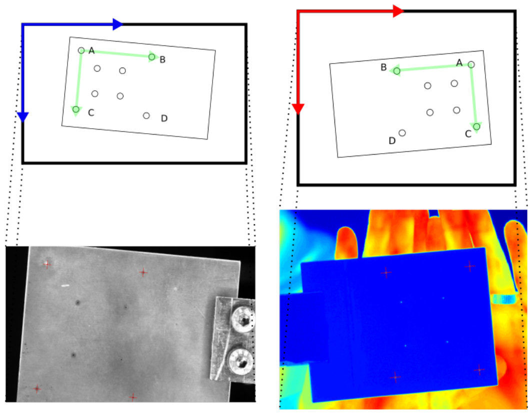

Fig. 2 - Calibration scheme

Experimental setup

The experimental setup is presented in Fig. 1. It consists of a biaxial tensile machine, a CCD camera in the visible domain, used to determine the displacement field using the digital image correlation (DIC) technique and a thermal camera to measure the temperature field at the specimen's surface. First of all, the visible and infrared images have to be put in the same basis. For that purpose, IR and visible images of a calibration pattern placed in place of the specimen are first stored and processed (see Fig. 2).

Results and Discussions

The methodology is first applied to a Gaussian-shaped temperature field, for which analytical calculations are possible, in order to determine the accuracy of the methodology proposed. Several filtering techniques have also been considered to reduce the noise of the IR images. It will be fully discussed in the presentation.

Concluding remarks

A method for compensating the displacement of material points within the infrared images has been developed. Its metrological features have been fully investigated in the framework of determining the heat source field from the lagrangian formulation of the bi-dimensionnal heat diffusion equation. This method is particularly suitable for materials with strong thermomechanical couplings and low thermal conductivity, such as elastomers [4], especially when crystallizing [5].

References

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