Revisiting the behaviour of elastomers with energy balances: energy stored, intrinsic dissipation, the physical meaning of the hysteresis loop…

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Most of phenomena involved in deformation of rubber depend on temperature and have distinguishable thermal and calorimetric signatures. However, since the pioneer investigations being those conducted by Gough and Joule in the 19th century, studies were dedicated more to mechanical response, and the thermal aspects of the deformation of rubber were not really explored experimentally. Therefore, revisiting the rubber deformation using experimental thermomechanics should offer new perspectives to better understand damage and deformation mechanisms. In the present study, temperature variations are measured during the mechanical tests by means of infrared thermography. The heat sources produced or absorbed by the material due to deformation processes are deduced from the temperature variations by using the heat diffusion equation. The calorimetric signatures of the most important effects in rubber deformation have been characterized in case of homogeneous and heterogeneous (at the crack tip) mechanical fields. Moreover, complete energy balances carried out during cyclic deformation show that viscosity is not systematically the preponderant contribution to the hysteresis loop: the mechanical energy brought to the material is not entirely dissipated into heat but can be predominantly used by the material to change its microstructure. This can be quantified by defining a ratio in terms of energy. This presentation gathers several results [1-9] obtained with several academic and industrial partners who are warmly acknowledged.

Key-words: IR thermography, rubber, quantitative calorimetry, energy balance, energy storage, intrinsic dissipation

References

[1] Energy storage due to strain-induced crystallization in natural rubber: the physical origin of the mechanical hysteresis. JB Le Cam. *Polymer* 2017; 127: 166-173

[2] Strain-induced crystallization in rubber: A new measurement technique. JB Le Cam. *Strain* 2018; e12256, 54 , issue 1

[3] Thermomechanical analysis of the singular behavior of rubber: entropic elasticity, reinforcement by fillers, strain-induced crystallization and the Mullins effect. J.-B. Le Cam, J.R. Samaca Martinez, X. Balandraud, E. Toussaint, J. Caillard. *Experimental Mechanics* 2015; 55: 771-782

[4] Heat and strain measurements at the crack tip of filled rubber under cyclic loadings using full-field techniques. J.R. Samaca Martinez, X. Balandraud, E. Toussaint, J.-B. Le Cam, D. Berghezan. *Mechanics of Materials* 2015; 81: 62-71

[5] Thermomechanical analysis of the crack tip zone in stretched crystallizable natural rubber by using infrared thermography and digital image correlation. J.R. Samaca Martinez, X. Balandraud, E. Toussaint, J.-B. Le Cam, D. Berghezan. *Polymer* 2014; 55: 6345-6353

[6] New elements concerning the Mullins effect: a thermomechanical analysis. J.R. Samaca Martinez, J.-B. Le Cam, X. Balandraud, E. Toussaint, J. Caillard. European Polymer Journal 2014; 55: 98-107
[7] Mechanisms of deformation in crystallizable natural rubber. Part 1: Thermal characterization. J.R. Samaca Martinez, J.-B. Le Cam, X. Balandraud, E. Toussaint, J. Caillard. *Polymer* 2013; 54:2717-2726
[8] Mechanisms of deformation in crystallizable natural rubber. Part 2: Quantitative calorimetric analysis. J.R. Samaca Martinez, J.-B. Le Cam, X. Balandraud, E. Toussaint, J. Caillard. *Polymer* 2013; 54:2727-2736
[9] Filler effects on the thermomechanical response of stretched rubbers. J.R. Samaca Martinez, J.-B Le Cam, X Balandraud, E Toussaint, J Caillard. *Polymer Testing* 2013; 32:835-841