Infrared based-surface calorimetry unravel many mysteries in the deformation of natural rubber

Jean Benoît Le Cam[1], Sylvain Charlès[1], Adel Tayeb[1]

[1]IPR – UMR UR CNRS 6251, Rennes University, F-35000 Rennes, France

[a] jean-benoit.lecam@univ-rennes.fr

Abstract.

Elastomers are materials with remarkable elastic properties that are unique among flexible materials. Moreover, the coupling between temperature and deformation is controlled by several deformation mechanisms. This coupling was partially demonstrated under strain by Gough [1] in the early 19th century, and its characterization was completed by Joule [2]. Other thermomechanical couplings also operate in natural rubber, particularly those governing strain-induced crystallization, which is a highly exothermic phenomenon. This phenomenon is generally studied by X-ray diffraction [3].

In both Gough's experiment on the origin of the thermoelasticity of natural rubber and the measurement of crystallinity by X-ray diffraction, strong assumptions are made about the deformation, typically the fact that the deformation mechanisms occur homogeneously under uniaxial tension.

In this presentation, infrared thermography and surface calorimetry are used to reveal new information about these tests [4,5,6,7]. The results obtained help to explain a number of difficulties encountered in understanding both Gough's results and X-ray diffraction measurements.

This information is essential for materials mechanics to improve characterization techniques [8] and thermomechanical models [9,10].

Literature references

[1] J. Gough, A description of a property of caoutchouc or india rubber (letter to Dr Holme written in 1802). Proc Lit and Phil Soc Manchester, 2nd, ser. 1, 288, 1805.
[2] J. P. Joule, On some thermodynamic properties of solids. Phil Mag 4th, 14:227, 1857.
[3] S. Trabelsi, Etude statique et dynamique de la cristallisation des élastomères sous tension. PhD Thesis, University of Paris 11, 2002.
[4] J.R. Samaca Martinez, J.-B. Le Cam, X. Balandraud, E. Toussaint, J. Caillard, Mechanisms of deformation in crystallizable natural rubber. Part 1: Thermal characterization. Polymer, 54:2717-2726, 2013.
[5] J.R. Samaca Martinez, J.-B. Le Cam, X. Balandraud, E. Toussaint, J. Caillard, Mechanisms of deformation in crystallizable natural rubber. Part 2: Quantitative calorimetric analysis. Polymer, 54:2727-2736, 2013.
[6] J.-B. Le Cam, A. Tayeb, S. Charlès. First evidence and characterization of strain-induced crystallization heterogeneity in natural rubber under homogeneous strain states. Polymer, 255: 125120, 2022.
[7] M. Baudoin, Impact de la taille des particules de caoutchouc du latex d'Hevea brasiliensis sur les propriétés aux interfaces fluides et en feuilles de caoutchouc sec. PhD Thesis, University of Rennes, 2024.
[8] V.N. Khiem, J.-B. Le Cam, S. Charlès, M. Itskov. Thermodynamics of strain-induced crystallization in filled natural rubber under uni- and biaxial loadings. Part I: complete energetic characterization and crystallinity evaluation. Journal of the Mechanics and Physics of Solids, 159, 104701, 2022.
[9] X. Balandraud, J.-B. Le Cam. Some specific features and consequences of the thermal response of rubber under cyclic mechanical loading. Archives of Applied Mechanics. 84: 773-788, 2014.
[10] V.N. Khiem, J.-B. Le Cam, S. Charlès, M. Itskov. Thermodynamics of strain-induced crystallization in filled natural rubber under uni- and biaxial loadings. Part II: Physically-based constitutive theory. Journal of the Mechanics and Physics of Solids, 159, 104702, 2022.