Proposition of a Terahertz thermometry system to measure temperature in the thickness of a solid polymer

Cyndie Poulin, Meriam Triki, Karim Bousmaki, Alexandre Duhant, Hervé Louche, Bertrand Wattrisse

Proposition of a Terahertz thermometry system to measure temperature in the thickness of a solid polymer

Cyndie Poulin(1), Meriam Triki(1), Karim Bousmaki(2), Alexandre Duhant(1), Hervé Louche(2) and Bertrand Wattrisse(2)

(1) T-Waves Technologies, Cap Omega, Rd Point B. Franklin, 34960 Montpellier Cedex 2, France

(2) LMGC, Université de Montpellier, CNRS, cc 048, place E. Bataillon, 34095 Montpellier Cedex, France

Abstract — In this work, we show the faisability of studying thermal gradient in the thickness direction of a polymer by 2D imaging THz set up. We will describe experimental procedure and data processing.

Key Words — Terahertz, absorption coefficient, IR thermography, POM material.

Introduction

Thermal fields obtained by Infrared Thermography are only measured on the sample surface. Due to this experimental limitation, it is sometimes possible to study thin samples in order to ensure that the surface temperatures remain close to the average temperature across the thickness. However, this assumption does not hold for thick samples, and/or for high convective heat losses and/or when material heterogeneities develop in the thickness during mechanical tests. As XR tomography enables 3D microstructure analysis, a challenge is now to obtain local and volume temperature measurements in heterogeneous situations. In 2013, Pradère *et al.* proposed to use the THz wavelength for temperature measurements at the surface using a thermoreflectance method [1, 2] based on a commercial THz pyrometer. Recently, they demonstrated the possibility to realize thermal tomography [3] with THz waves using an IR camera. In the present study, we would like to follow this subject of research. As a first step, we consider measurements of thermal transmittance on a planar polymer sample with THz waves using a THz sensor developed by T-Waves Technologies [4]. The main results obtained have been published in [5].

Experimental methodology

The study was conducted on a POM polymer material (Polyacethal-C [12]), was chosen for its good transparency in the THz wavelength. The experimental design, presented in Figure 2a, illustrates the parallelepiped POM sample (L_x x L_y x L_z =0.045 m x 0.07 m x 0.0116 m) in the THz setup and the device chosen to impose the thermal loading. 2D images, acquired by a point by point setup, were recorded by measuring the beam intensity attenuation in transmission of an object placed at the focal point of this setup. The sample is moved in the plane perpendicular to the beam direction. A permanent 3D heterogeneous thermal state was obtained by the circulation of a heat transfer fluid (here water) leading to a thermal gradient in the sample, mainly in the radial direction. The sample support solution was chosen in order to impose symmetric boundary conditions.

Five experiments were successively conducted at five different loading states: reference state (room temperature of T_a=23 °C) and four thermal loadings, corresponding to a water imposed temperature T_{water} of 30 °C, 40 °C, 50 °C and 60 °C. An infrared camera (FLIR SC6000) was focused on the entire front face in order to measure the surface temperature field at equilibrium. An example of the surface temperature along the y' radial direction (between points A and D) is given in the red discontinuous plot in Figure 2b, for a thermal loading corresponding to a water imposed temperature T_{water} of 60 °C. In the same figure, we have plotted the intensity of the transmitted THz beam, denoted I_T, through the sample along the AD line plotted in Figure 2(a), the transmitted THz increased as the distance from the hole increased and the temperature decreased.

The transmission coefficient Γ_{THz} across the sample thickness was calculated for each discrete point $M_i(x_i,y_i)$ located at position (x_i,y_i) on the front surface using the following ratio: $\Gamma_{THZ}(x_i,y_i)=I_T(x_i,y_i)/I_0$, where I_0 is the THz radiation emitted by the source and I_T is the one transmitted across the thickness. Figure 2a pools the data obtained for all imposed water temperatures (T_{water} = T_a, 30 °C, 40 °C, 50 °C and 60 °C) for all points M_i located on the AE profile. Although, they were obtained in different tests (associated with different experimental conditions), the responses of all points for all water temperatures were plotted on a master curve associated with the thermo-dependence of the THz absorption and/or reflection coefficients.

Discussion

To simulate the transmitted intensity, we consider the following equation which shows the linear dependence of absorption coefficient α with temperature: $\alpha(T)=a_\alpha+b_\alpha(T-T_0)$. The two parameters ($a_\alpha$ and b_α) of the thermal dependence can be identified using a simple analytical model of temperature dependence along the sample thickness. The evolution of the transmission coefficient in the radial direction y' is plotted in Figure 2b for all applied water temperatures. The difference between the "measurement" (dashed line) and the identified "model" (continuous line) is very small and the model enables us to capture variations in the THz transmission coefficient with a very limited number of parameters.

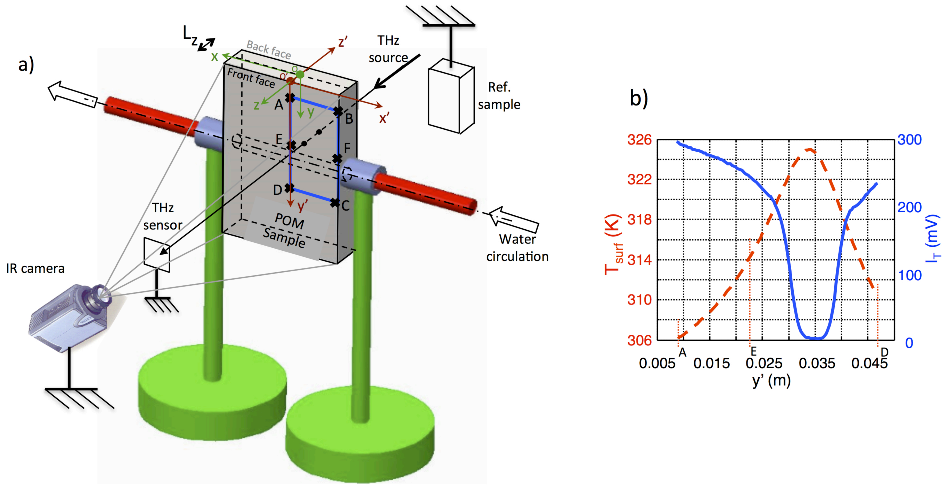

Figure 1: a) experimental setup used to impose a 3D thermal state in the POM sample. b) surface temperature along the y' radial direction (between points A and D) at T_{water} of 60 °C (red discontinuous line); intensity of the transmitted THz beam I_T, through the sample along the same AD line (blue continuous line).

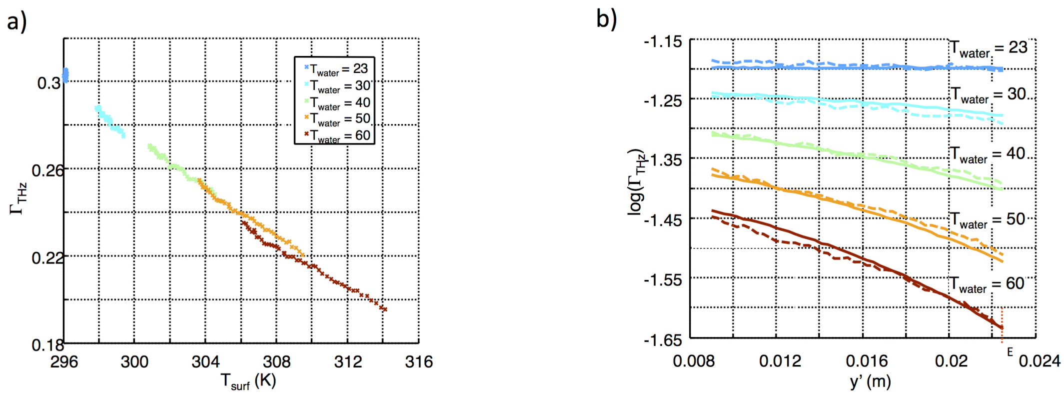

Figure 2: a) Transmission coefficient Γ_{THz} across the sample thickness calculated for each discrete point along the radial AD line, for the four imposed water temperature.

Conclusion

The analysis of THz and thermal measurements obtained on the sample profile, combined with the thermal model, enabled us to identify the thermo-dependence of the THz absorption coefficient. The mean temperature can then be determined along the THz direction once the thermodependence of the transmission coefficients are known and using the constant reflection coefficient. The present experimental device has a rotational stage on which the sample is placed which allows acquisition of a 2D image for each angle step, and in the future, we hope to be able to obtain 3D thermal measurements by THz tomography for a given material based on knowledge of the thermal dependence of the reflection and absorption coefficients.

References

[1] C. Pradere, J.P. Caumes, S. BenKhemis, G. Pernot, E. Palomo, S. Dilhaire, J.C. Batsale. Thermoreflectance temperature measurement with millimeter wave. *Review of Scientific Instruments*, 85:064904-1-064904-4, 2014.

[2] C. Pradère, J.P. Caumes, S. Benkhemis, E. Palomo, S. Dilhaire, D. Balageas, J.C. Batsale, Transient thermal tomography for temperature measurement by using terahertz photoreflectometry. *PhotoMechanics Conference*. Montpellier. May 27-30, pp 179-182, 2013

[3] M. Romano, A. Sommier, J.C. Batsale, C. Pradere, 3D transient temperature measurement in homogeneous solid material with THz waves. *SPIE Photonics Europe*; 04/2016

[4] M. Triki, A. Duhant, C. Poulin, B. Moulin, C. Archier, T. Antonini, F. Teppe, W. Knap. Real-time non-destructive imaging with THz waves. IEEE Conference Publications. DOI: 10.1109/MIKON.2016.7492135. *21st International Conference on Microwave, Radar and Wireless Communications (MIKON)*, May 9-11, pp 1-3 2016.

[5] C. Poulin, M. Triki, K. Bousmaki, A. Duhant, H. Louche and B. Wattrisse, Terahertz thermometry system to measure temperature in the thickness of a solid polymer, *QIRT Journal*, doi.org/10.1080/17686733.2017.1362791, 2017.