

The THz scanning for the measurement of the density change in strained foams

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Abstract. This paper is devoted to the development of the technique to estimate a distribution of the mechanical stress on the strained specimen based on the data about terahertz absorption. This hypothesis is based on the relation between density of the stressed body and absorption of THz radiation. Using the experimental setup developed by the NeTHIS the authors estimate the stress distribution near the holes with different diameters in stressed polymeric foams. The experimental results are in a good agreement with the numerical simulation of foams deformation process.

1. Introduction

The terahertz ($1 \text{ THz} = 10^{12} \text{ Hz}$) frequency region is located between the microwave region and the infrared (IR) light region. Previously, this phenomenon was merely studied by a small number of researchers, such as chemical spectroscopy, astronomy, and solid-state physics. Now the THz technology is strongly demand in a large variety of fields, ranging from basic sciences such as biochemical spectroscopy, astronomy, and condensed-matter physics to practical applications such as high-capacity communication, medicine, agriculture, and security [1, 2].

Since the THz frequency is located in the “wave” and “light” regions, the THz electromagnetic wave has both features and can be controlled with either electrical or optical components such as waveguide, antenna, mirror, and lens. In terms of THz photons, the corresponding photon energy, 1–100 meV is in the important energy region for a variety of materials and molecules. These features allow us to diversify applications of imaging and spectroscopy with this frequency band. For the measurements shown here THz waves are irradiated onto objects and the intensity distribution of THz reflection or transmission is imaged. Furthermore, simultaneous measurements with frequency spectra provide more explicit information about physical/chemical properties. The THz imaging and spectroscopy therefore can be used for nondestructive remote inspection. The THz wave is less harmful and does not cause much damage compared to X-ray imaging, because the photon energy is far lower. In addition to industrial and medical applications, THz technology is also of much interest in fundamental sciences.



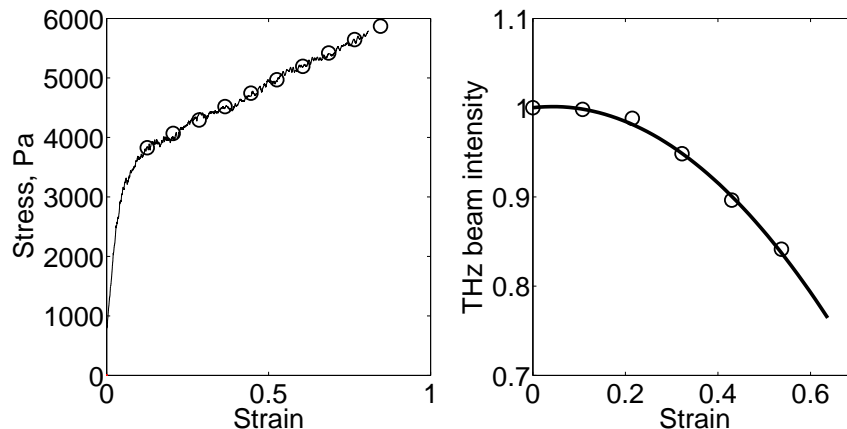


Figure 1. On the left—experimental stress–strain dependence of foam under investigation. On the right—dependence between absorption of THz beam and strain intensity of the foam.

In this paper, authors propose a technique in order to estimate a distribution of the mechanical stress on the strained object based on the data about terahertz absorption. This hypothesis is based on the relation between density of the stressed body and absorption of THz radiation. Using the experimental setup developed by NeTHIS the authors estimate the stress distribution near the holes with different diameters in stressed polymeric foams. The experimental results are in a good agreement with the numerical simulation of foams deformation process.

2. Theoretical aspects

Based on the phenomenon of the dependence between density and strain we can affirm that the dependence of the intensity of THz beam upon density of the material can be used for the calculation of the strain and stress fields. According [3], we can approve:

$$V/V_0 = \rho/\rho_0 = 1 - \theta, \quad (1)$$

$$\theta = \epsilon_{xx} + \epsilon_{yy} + \epsilon_{zz}, \quad (2)$$

where ϵ_{xx} , ϵ_{yy} , ϵ_{zz} —diagonal components of a strain tensor. Under uniaxial tension we can write $\epsilon_{xx} = \epsilon_{yy} = \epsilon_{zz}$.

To illustrate the possibilities of the technique we choose typical polymeric foam and investigate its mechanical properties and absorption ability. The figure 1 (left) presents a stress-strain curve under uniaxial compression of the foam. The figure 1 (right) presents a relative absorption of THz beam versus strain under uniaxial compression. A combination of the equation (2) with the approximation of the relative absorption-strain plot (figure 1, right) gives us a relation between absorption of THz beam and intensity stress tensor (figure 1, right)

$$\rho/\rho_0 = C_1 - K(1 - I)^{1/2}, \quad (3)$$

$$\sigma_i = A(1 - I)^{1/2} + C_2, \quad (4)$$

where σ_i —intensity of stress tensor, I —relative absorption of THz beam, C_1 and C_2 —constants of the approximation, A and K —corresponding combination of elastic materials constants.

The two last equations show a relation between density and intensity of THz beam, intensity of stress. The use of the last two equations we can calculate strain, stress and density fields based on a field of the absorption of THz radiation.

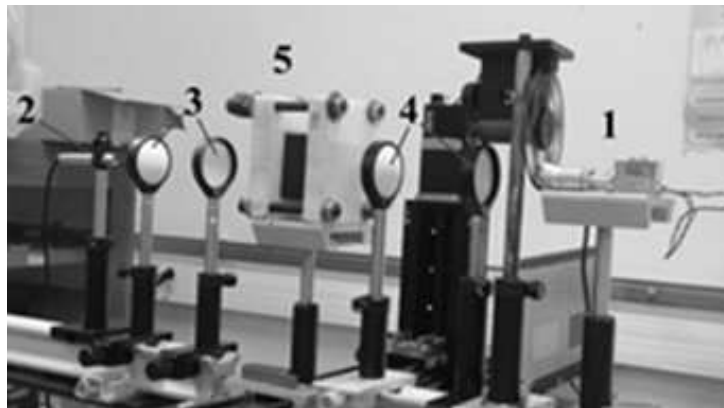


Figure 2. NeTHIS provided THz imaging system.

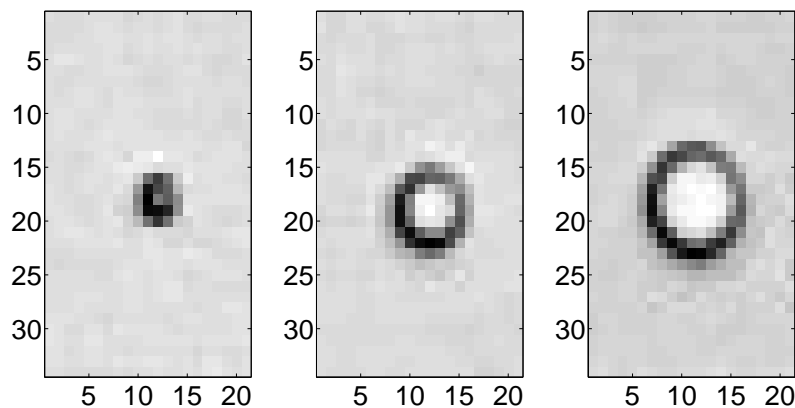


Figure 3. THz images of specimen with different holes: 10, 15 and 20 mm from left to right, respectively.

3. Experimental conditions

The experimental setup developed by NeTHIS is presented in figure 2.

The experimental setup includes: 1—terahertz source, 2—terahertz detector, 3 and 4—Teflon lenses, 5—specimen under investigation. The specimen consists of two parts: foam under investigation (black detail between two white plates) and loading device (two white plates). The specimen was sited between two unyielding Teflon plates and compressed by four screws. This method of deformation allow us to measure the strain only. To receive the stress-strain curve (figure 1.a) authors used electro-mechanical machine SHIMADZY AG-Xplus.

Three types of specimens were investigated. Actually, all of them have the same shape—quadratic surface 120 mm × 120 mm and 40 mm thick. Every specimen has unique hole with diameters 10, 15 or 20 mm. THz scanning allows us to plot images shown in figure 3.

At the every image, you can see a black ring near hole. This effect associated to refraction, reflection and absorption of THz beam on the border on medium interface.

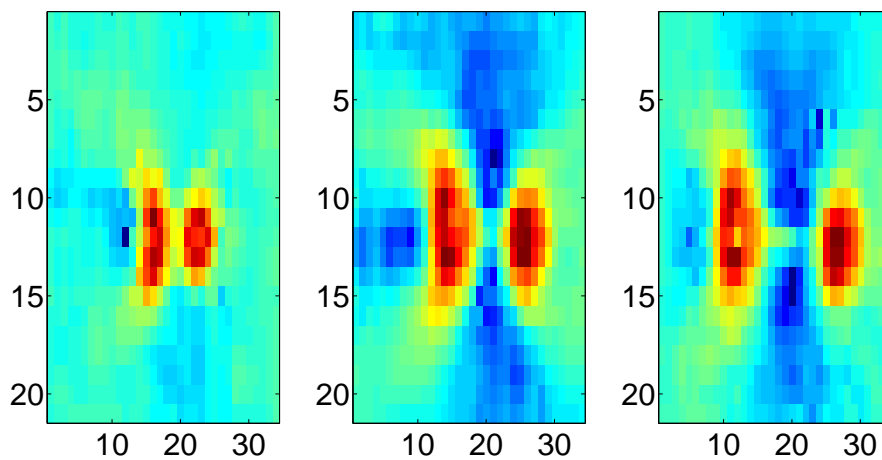


Figure 4. Stress field of the specimen which was calculated based on the results of THz beam absorption in holes 10, 15 and 20 mm (from left to right, respectively).

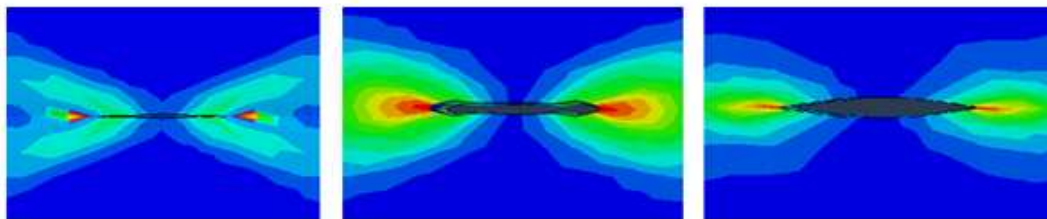


Figure 5. Numerical simulation of the stress field in the specimens with a hole of 10 mm (a), 15 mm (b), 20 mm (c) with deformation of 0.3.

4. Comparison of calculation and simulation

According to the aforementioned theory, we have tried to calculate the stress field of the strained specimens with the different stress concentrators based on THz image of the specimen. Every specimen was strained by 30%. Figure 4 presents the stress fields calculated with the use of the proposed method.

In order to check the experimental results, the numerical simulation of the stress field distribution near the holes was carried out with the use of the finite-element package ABAQUS. Simulation was performed based on the standard model “Low density foam”. Figure 5 presents the results of the numerical simulation.

As you can see according to calculation, the highest value of the stress is 1.1×10^4 . The result of simulation shows the same value (2×10^4). The area near high stress value approximately has the same range in calculation and simulation. According to the results of the calculation and numerical simulation, values of stress have the same order of magnitude. The qualitative similarity between modeling (figure 4) and calculation (figure 5) is obvious. We can assume that the difference in the stress values is associated with THz images resolution. The areas with the high stress values on the modeling pictures are very small. Therefore, we can not detect it using available equipment. More precise hardware allows us to make more accurate measurements and obtain more precise results.

5. Conclusion

As a result of this work, authors propose a new way of estimation of the stress distribution in porous non-metals bodies based on the absorption of THz beam. The results of the mechanical testing and numerical simulation show the good quantitative agreement and high efficiency of THz based experimental technique. The THz based methods can be considered as a promising way to obtain the quantitative information about stress-strain state of THz transparent bodies.

Acknowledgments

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