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ANALYSES OF AN INFRARED THERMOGRAPHY EXPERIMENT FOR ESTIMATING THE THERMAL CONDUCTIVITY OF POLYMERIC MATERIALS

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Abstract. *The objective of this work is to propose a simple experimental setup to estimate the thermal conductivity of polymeric materials by using an infrared camera. In order to verify the influence of external conditions in the recorded temperature fields, an acrylic sample was analyzed under different conditions. Some factors were experimentally investigated, such as emissivity of the surface, convective heat transfer coefficient, and the camera positioning. Since the thermal conductivity was known, the convective heat transfer coefficient was the estimated parameter and Biot numbers for some different conditions were calculated. It was observed that the convective heat transfer coefficient is the factor that more influence in the temperature field recorded by the camera. Overall, it was noted that the experimental conditions cannot be represented by the classical lumped formulation, and it is necessary to employ a better approach.*

Keywords: *Infrared thermography, Thermal conductivity, Polymer, Experimental investigation.*

1. INTRODUCTION

Polymeric materials have been widely used in various fields of engineering because of a convenient combination of properties such as low density, together with the ease of processing. However, applications of polymers may also be limited by some of its properties, like low thermal and electrical conductivities. Over the last decades, fabrication and properties of polymeric nanocomposites have been continuously investigated, since it has been shown that some of polymer properties may be significantly enhanced by the addition of nanofillers (Njuguna *et al.*, 2008; Park *et al.*, 2012). Hence, the field of application for polymers is continuously increasing, and many works concerning theoretical and experimental investigation of properties of polymer-based materials have been published lately in the literature.

There are various experimental techniques that can be employed in order to assess the thermal properties of materials. These different techniques may be responsible for some differences among reported results. The thermal conductivity may be estimated, for example, by the guarded heat flow meter method (Moreira *et al.*, 2011; Nayak *et al.*, 2010), by the transient short hot wire technique (Xie *et al.*, 2006, Toberer *et al.*, 2012), and by infrared thermography, which is most commonly used for determining the thermal diffusivity of materials (Philippi *et al.*, 1995; Miettinen *et al.*, 2008; Laskar *et al.*, 2008). An infrared camera allows the recording of full temperature fields with non-contact measurements and it is considered a powerful tool in many industrial and scientific applications.

In this context, the objective of this work is to analyze a simple experimental setup to estimate the thermal conductivity of polymeric materials using infrared thermography, which was proposed in (Moreira *et al.*, 2012). An acrylic sample with known thermal conductivity was tested, and the recorded temperature fields under different experimental conditions were analyzed. Since the thermal conductivity was known, the convective heat transfer coefficient was the estimated parameter and Biot numbers for some different conditions were calculated. Overall, it was noted that the experimental conditions cannot be represented by the classical lumped formulation, and it is necessary to employ a better approach.

2. MATERIALS AND METHODS

The samples used in the experiment were uniform acrylic bars with a rectangular shape. The manufactured specimens were characterized by dimensions: 135x12x5 mm^3. The material was previously tested and according to results obtained using commercial equipment (LaserComp Fox-50), the thermal conductivity ranged from 0.174 W m^{-1} K^{-1} to 0.220 W m^{-1} K^{-1} (Moreira, 2011). In the current experiment, the samples were covered by a black paint, in order to magnify and standardize the emissivity of the surface, and consequently, minimizing reflectivity and absorptivity. For this purpose, three different spray paints were used. One of them had graphite powder in its composition (Grafit 33, the Kontakt-Chemie) and emissivity equal to 0.97 (Knupp, 2010). The other two paints had unknown emissivity and

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they provided different surface finishes, i.e., gloss and matte level. Figure 1 shows the specimens coated with both paints.

The experimental setup used in the characterization of polymeric materials is shown in Figure 2. The tested specimens were placed in a holder made of insulating material. In this arrangement, a thermal plate was used as the heat source at the end of sample. Moreover, to minimize the contact resistance between the sample and the thermal plate and provide a uniform temperature at bar basis, a thermal paste was used. A constant air flow was generated on the front surface of the sample by two different coolers, with the aim of standardizing the convective heat transfer coefficient in the different tests. All images of sample were recorded using an infrared camera (Flir A325G) with resolution of 320 x 240 pixels. It should be mentioned that, the temperature fields were selected in the steady state regime. The infrared camera and the specimen were isolated by a chamber made of insulating material in order to minimize the influence of the environment such as radiation and air currents.

Figure 1. Samples painted with graphite powder (a) and with the ink conventional spray with bright finish (b).

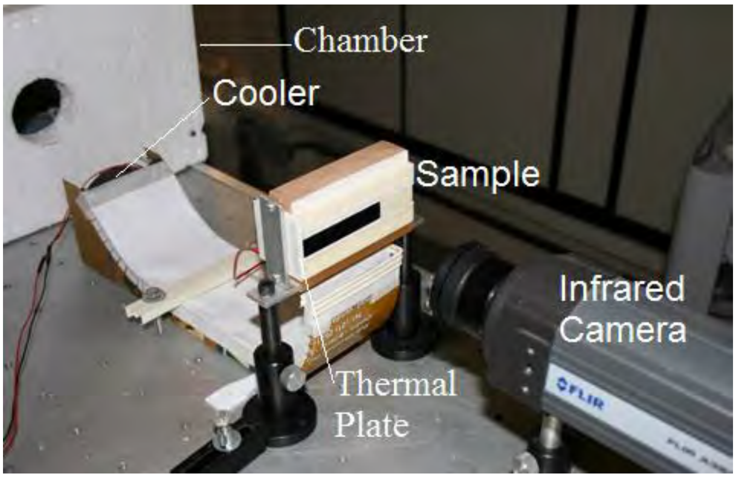

Figure 2. Experimental setup.

Some experimental parameters were varied in order to investigate the influence of external factors in the experimental data. These parameters were sample coating, camera position relative to the specimens and velocity airflow generated by both coolers. The main purpose was to analyze possible changes in the temperature field of the sample captured by infrared camera.

In the first approach, the infrared camera, initially positioned perpendicular to the sample surface, was rotated causing a displacement in the image of the specimen of 20 pixels. This procedure was repeated three times for different angles, resulting in four different configurations. The second test was performed considering two samples coated with different paints. In the last one, the velocity airflow incident on the sample surface was changed using two different coolers.

3. PROBLEM FORMULATION

The direct problem formulation stems from a multidimensional steady–state heat transfer problem which was partially lumped in the y and z directions, resulting in a fin approach (Ozisik, 1993). Figure 3 illustrates a sample in the experimental arrangement. The surface $x = a$ was considered to be at air temperature (T_∞).

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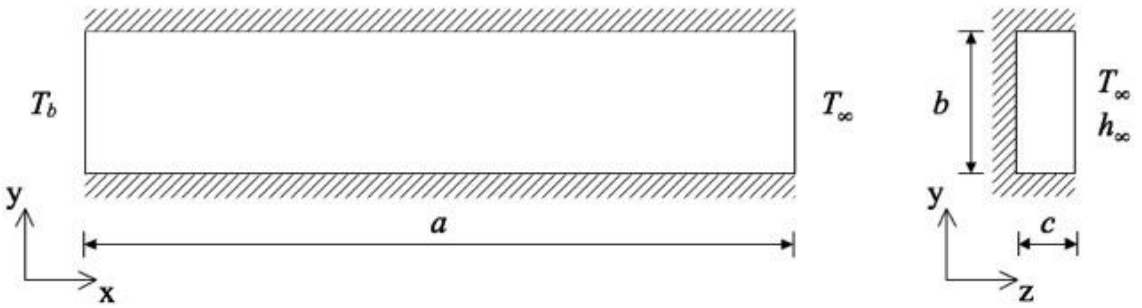

Figure 3. Schematic diagram of a sample in the experimental arrangement.

Defining the dimensionless variables

$$\xi = \frac{x}{a} \quad \text{and} \quad \theta = \frac{T - T_\infty}{T_b - T_\infty} \tag{1}$$

the heat conduction equation is written as:

$$\frac{d^2\theta}{d^2\xi} - m^2\theta = 0, \quad \text{for} \quad 0 < \xi < 1 \tag{2}$$

$$\theta = 1 \quad \text{at} \quad \xi = 0,$$

$$\theta = 0 \quad \text{at} \quad \xi = 1, \tag{3}$$

whose solution is

$$\theta(\xi) = \frac{Sinh[m(1-\xi)]}{Sinh[m]} \tag{4}$$

where

$$m = \sqrt{\frac{\mathrm{Bi}}{L_*^2}}, \quad \mathrm{Bi} = \frac{h_\infty c}{k} \quad \text{and} \quad L_* = \frac{c}{a}. \tag{5}$$

It is worth mentioning that this is the classical fin model, which is valid for Biot number (Bi) lower than 0.1, since the temperature gradient in the fin cross section is neglected. The parameter m in eq. (4) was fitted to experimental results and values obtained for distinct conditions were compared. Since the dimensions and thermal conductivity of the samples are known, the only unknown parameter is the convection heat transfer coefficient, which was calculated and compared for arrangements with different coolers.

4. RESULTS AND DISCUSSION

Figure 4 illustrates the temperature fields recorded by the camera when it was positioned perpendicularly to the sample, and then the image obtained after the rotation undergone by the infrared camera. The area analyzed was the one that presented the lowest temperature variation in the y direction. Dimensions of the selected region are the same in each image.

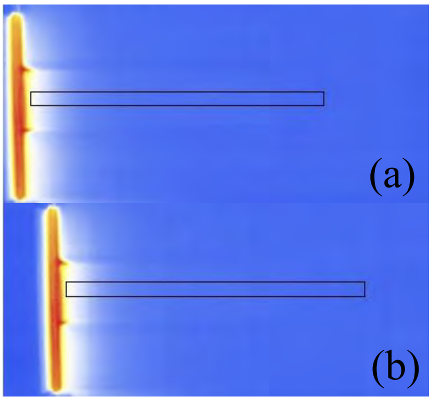

Figure 4. Temperature field recorded by the camera when the camera was positioned perpendicularly to the sample (a), and then the image obtained after the rotation undergone by the infrared camera (b).

The data analysis on temperature distribution along the *x* direction showed that there was no significant variation in the temperature distribution for different positions of the camera. Figure 6 illustrate the experimental curve and the model fitting for the first configuration. This comparison was made in all settings. It is possible to observe that the theoretical solution is in good agreement to experimental data close to the boundaries, while there is a slight dispersion at the central region, probably due to camera lens curvature.

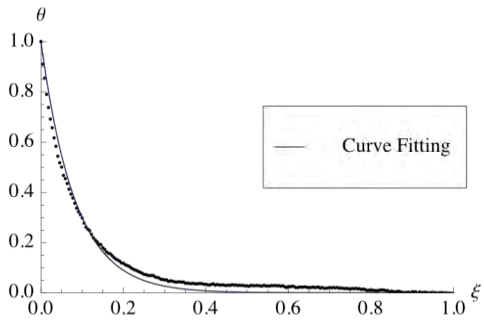

Figure 6. Experimental temperature distribution and model adjusting for the first configuration.

Figure 7 shows data relating to the temperature distribution along *x* direction for tests with different coolers. The procedure to obtain this distribution was the same as the previous test. In Figure 7 it can be seen that the temperature declines more quickly when the high velocity flow is used. This behavior was expected, because the increase in air flow velocity intensifies convective heat transfer. In the Figure 7 also illustrated the test realized without airflow. In this case, the heat exchange by convection was natural and the temperature decline was slower when compared to the test carried out in the presence of airflow. The Biot number presented a significant variation in the tests realized, showing the necessity of the presence of airflow. The Biot number was calculated for each arrangement. The average values found are reported in Table 1. According to Tab. 1, the increased velocity of the airflow increases the Biot number and calculated values for both configurations exceed the threshold for the classical fin model.

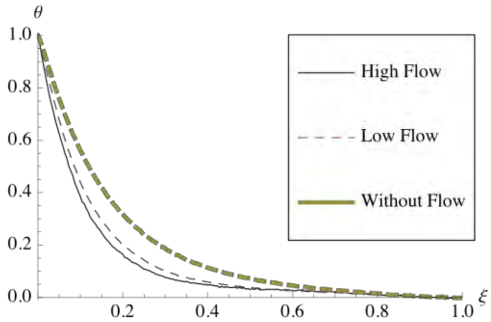

Figure 7. Temperature distribution along the *x* direction for different configurations tested: without airflow and with different coolers.

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Table 1. Biot number found for the configuration with airflow and without airflow.

Airflow	Biot Number
High	0.730
Low	0.362
No Airflow	0.179

The paint with graphite powder has already been used in other experiments involving thermography and presents the advantages of having emissivity near to 1 and known, and dry quickly after application. However, it was noted that samples coated with this paint are easily scratched and polished, such that, it is difficult to manipulate the samples after application of this paint. A polished surface has its reflectivity maximized, which may generate false results. Besides, this paint is not marketed in Brazil and it is another disadvantage.

The great advantage of conventional ink is that it is easily found in commerce. The shiny paint coating also increases the reflectivity and needs to be sandpapered after its application causing a non-uniformity of the paint layer to the painted surface. Figure 9 illustrates the comparison between the paint with graphite powder, the paint with polished graphite powder and the matte ink. As one can see, there is an accentuated dispersion in the central region of the sample painted with ink containing graphite particles. This dispersion increased when the surface was polished. Thus, the matte ink coverage is more appropriate for this type of experiment. Figure 9 also shows the comparison between the theoretical model and experimental data for this case. Again, theoretical and experimental curves fit well.

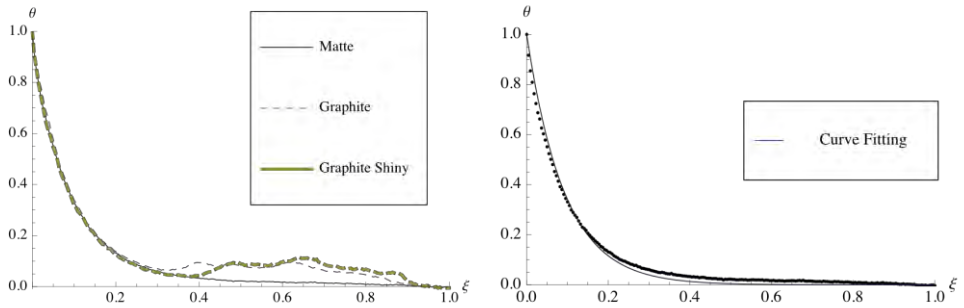

Figure 9. Comparison between the paint with graphite powder, the paint with polished graphite powder and the matte ink (left) and between the theoretical model and experimental data obtained on the sample painted with conventional matte cover (right).

5. CONCLUSIONS

In this paper, we analyzed a simple experimental setup to estimate the thermal conductivity of polymeric materials by using an infrared camera. In order to control external parameters and study their influence on the results were carried out some tests, such as emissivity of the surface, the external radiation, convective heat transfer coefficient, and the camera positioning. The emissivity of the paint used to coat the sample should be as large as possible to decrease its reflectivity, therefore it is necessary that the paint has a matte finish. The airflow is needed to ensure that the coefficient of heat transfer by convection is constant, requiring the presence of a steady airflow at the sample surface. However, this should not have very high speed it would invalidate the application of the theoretical model used. Finally, the position of the infrared camera does not significantly alter the experimental results of thermal conductivity.

Results presented in this work are preliminary, and the tests should be performed again to check the repeatability of the results presented in this article. Further investigation shall be carried out, in order to verify the variation of convection heat transfer coefficient under various conditions. Besides, the theoretical model should be modified to allow its use in cases with higher Biot number.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Knupp, D.C., 2010. “Análise teórico-experimental de transferência de calor em nanocompósitos via transformação integral e termografia por infravermelho”.

Laskar, J.M., Bagavathiappan, S., Sardar, M., Jayakumar, T., Philip, J. and Raj, B., 2008. “Measurement of thermal diffusivity of solids using infrared thermography”. Materials Letters, Vol. 62, No. 17, pp. 2740–2742.

Miettinen, L., Kekalainen, P., Merikoski, J., Myllys, M. and Timonen, J., 2008. “In-plane thermal diffusivity measurement of thin samples using a transient fin model and infrared thermography”. International Journal of Thermophysics, Vol. 29, pp. 1422–1438.

Moreira, D.C., 2011. “Análise experimental de propriedades termomecânicas em nanocompósitos poliméricos”.

Moreira, D.C., Sphaier, L.A., Reis, J.M.L. and Nunes, L.C.S., 2011. “Experimental investigation of heat conduction in polyester-Al2O3 and polyester-CuO nanocomposites”. Experimental Thermal and Fluid Science, Vol. 35, pp. 1458–1462.

Moreira, D.C., Telles, M.C.O., Nunes, L.C.S., Sphaier, L.A., Reis J.M.L., 2012. “Infrared thermography for estimating the thermal intensification of polymeric nanocomposites”. In *Proceedings of the 14th Brazilian Congress of Thermal Sciences and Engineering - ENCIT2012*. Rio de Janeiro, Brazil.

Nayak, R., Dora P., T. and Satapathy, A., 2010. “A computational and experimental investigation on thermal conductivity of particle reinforced epoxy composites”. Computational Materials Science, Vol. 48, pp. 576–581.

Njuguna, J., Pielichowski, K. and Desai, S., 2008. “Nanofiller–reinforced polymer nanocomposites”. Polymers for Advanced Technologies, Vol. 19, pp. 947–959.

Ozisik, M.N., 1993. Heat Conduction. John Wiley & Sons, Inc., 2nd edition.

Park, W., Choi, K., Lafdi, K. and Yu, C., 2012. “Influence of nanomaterials in polymer composites on thermal conductivity”. Journal of Heat Transfer, Vol. 134, No. 041302, pp. 1–7.

Philippi, I., Batsale, J.C., Maillet, D. and Degiovanni, A., 1995. “Measurement of thermal diffusivities through processing of infrared images”. Review of scientific instruments, Vol. 66, No. 1, pp. 182–192.

Toberer, E.S., Baranowski, L.L., Dames, C., 2012. “Advances in Thermal Conductivity”. Annual Review of Materials Research, Vol. 42, pp. 179–209.

Xie, H., Gu, H., Fujii, M. and Zhang, X., 2006. “Short hot wire technique for measuring thermal conductivity and thermal diffusivity of various materials”. Measurement Science and Technology, Vol. 17, pp. 208–214.

8. RESPONSIBILITY NOTICE

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