# INFRARED THERMOGRAPHY FOR ESTIMATING THE THERMAL INTENSIFICATION OF POLYMERIC NANOCOMPOSITES

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***Abstract.*** *The thermal conductivity augmentation in polymeric nanocomposites constituted of thermoset polymers filled with metal oxides nanoparticles is investigated in this work. A simple experimental setup was assembled and the steady state temperature fields were recorded by an infrared camera. The problem is handled with a lumped formulation and the theoretical solution is adjusted to the experimental data in order to estimate the thermal intensification of the epoxy resin by the addition of alumina nanoparticles. The obtained results were compared with previous data directly acquired from a guarded heat flow meter equipment and it seems that the thermal intensification estimates from both methods are in agreement.*

***Keywords:*** *Thermal conductivity, Nanoparticle, Polymer, Heat conduction, Steady State.*

## 1. INTRODUCTION

The development of new materials is often related to the design of novel compounds resulting from the combination of materials with different physical or chemical properties. Over the last two 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). In particular, the addition of metal oxides nanoparticles to a polymeric matrix may result in a composite with higher thermal conductivity than the polymer while maintaining electrical insulating properties, which is interesting for some applications like electronic packaging (Fu *et al.*, 2010) and as thermal interface materials (Sim *et al.*, 2005).

Although there are many works concerning the investigation on thermal properties of polymeric nanocomposites, changes in macroscopical properties of polymers caused by particle loading are not fully known and cannot be accurately predicted. Besides, there are various experimental techniques that can be employed in order to assess the thermal properties of materials and 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), 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 main objective of this work is to assess the thermal intensification of polymeric nanocomposites using infrared thermography and compare the obtained results with previous data obtained at different temperatures from a direct thermal conductivity meter. The steady state temperature fields of different samples were recorded by an infrared camera and the solution to a partially lumped heat conduction equation was fitted to the experimental results in order to estimate the unknown parameters.

## 2. MATERIALS AND METHODS

### 2.1 Materials and manufacturing

The samples were composed of an epoxy matrix filled with different amounts of alumina ($Al_2O_3$) nanoparticles, varying from 0% to 10% in volume fraction ($\phi$). The epoxy resin (ER) RR515, from SILAEX, is based on a diglycidyl ether bisphenol A and was polymerized by the addition of an aliphatic amine hardener in a proportion of 1:4 by weight. The dispersed phase was composed of 200 nm $\alpha$-$Al_2O_3$ spherical nanoparticles, provided by NanoAmor. Tables **??** and **??** show the thermophysical properties of the polymers and nanoparticles, respectively. More details about the nanocomposites manufacturing may be seen in (Moreira *et al.*, 2012). The employed specimens were bars with uniform rectangular cross section and dimensions 135 mm × 12 mm × 5 mm. According to previous results, the thermal conductivity of the samples ranged from 0.20 W m$^{-1}$ K$^{-1}$ (for neat epoxy samples) to 0.38 W m$^{-1}$ K$^{-1}$ (for 10% alumina loaded nanocomposites).

### 2.2 Experimental setup

The samples were allocated in a heat insulating holder and subjected to a uniform base temperature. One of the sample's surfaces exchanged heat with air and its temperature fields were recorded by the infrared camera Flir A325G, while the other ones were assumed to be isolated. The experimental setup may be seen in Fig. 1. The specimens were covered by a black paint, in order to magnify and standardize the emissivity of the surface facing the infrared camera. A Peltier element was used as the heat source and some images were recorded when the steady state regime was reached, which could be verified by the temperature profile remaining constant.

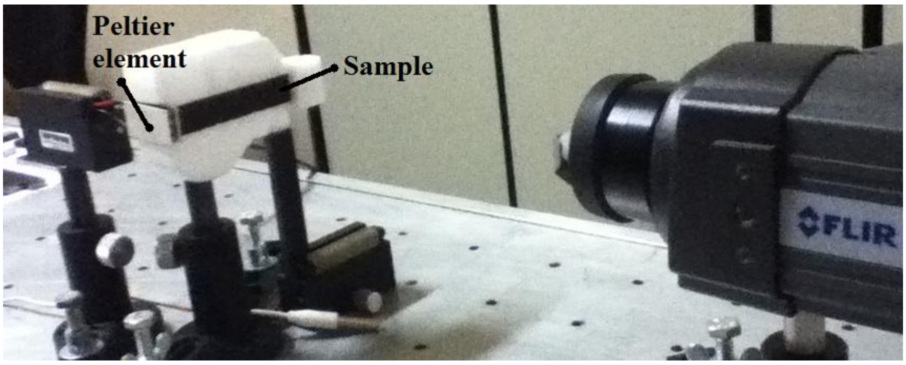


Figure 1. Experimental setup.

### 2.3 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 2 illustrates a sample in the experimental arrangement. The surface $x = a$ was considered to be at air temperature ($T_\infty$).

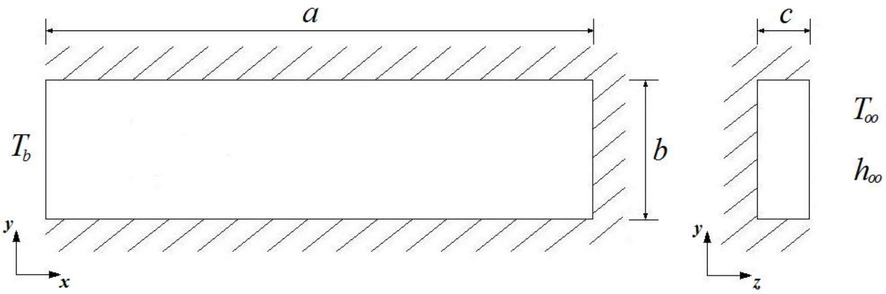


Figure 2. Schematic diagram of a sample in the experimental arrangement.

The dimensionless variables are defined:

$$\xi = \frac{x}{a} \qquad \text{and} \qquad \theta = \frac{\bar{T} - T_\infty}{\bar{T}_b - T_\infty}, \tag{1}$$

and the dimensionless formulation of the considered heat conduction problem is given as:

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

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

$$\theta = 0, \qquad \text{at} \qquad \xi = 1, \tag{4}$$

where

$$M = \text{Bi}\, L^*, \qquad \text{Bi} = \frac{h_\infty\, a}{k}, \qquad \text{and} \qquad L^* = \frac{a}{c}. \tag{5}$$

In order to assess the thermal conductivity augmentation ($k_{nc}/k_r$) of the nanocomposites, the parameter $M$ was fitted to the experimental results and the relation $M_{nc}/M_r$ was calculated. The recorded temperature distribution was previously averaged in the $y$ direction. The convective heat transfer coefficient ($h_\infty$) was assumed to be the same for all cases.

## 3. RESULTS AND DISCUSSION

Figure 3 presents an infrared image of the neat epoxy sample in steady-state regime. As one can observe, the temperature field observed at the sample surface varied from 40°C at the basis to 25°C, approximately.

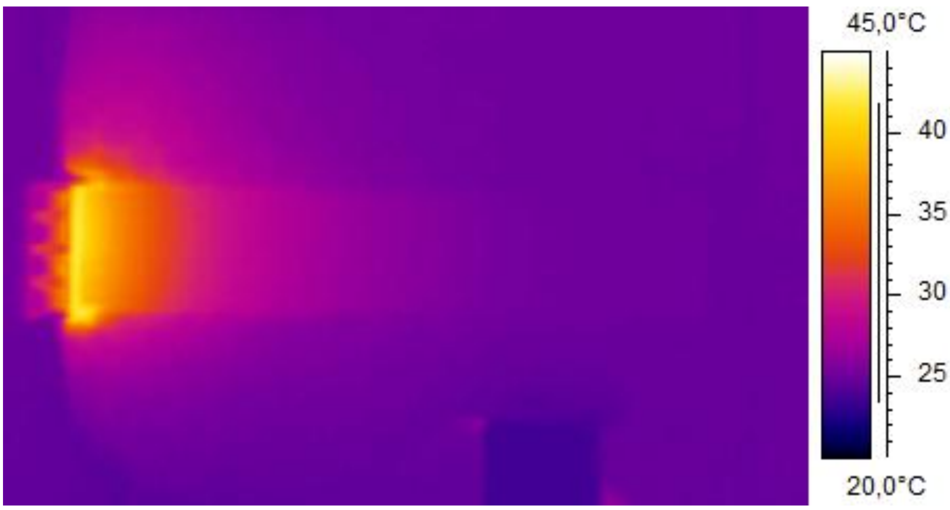


Figure 3. Infrared image of the neat epoxy sample during a test.

The temperature distribution in the $x$ direction of all of the measured samples are displayed in Fig. 4, as well as the curve fitting for the neat epoxy samples. It is possible to observe that the temperature decaying is smoother for higher loaded samples, which may be explained by the fact that the addition of alumina nanoparticles is responsible for an increase in the thermal conductivity of the epoxy resin. In addition, it should be mentioned that the curve fits well the experimental results for all the studied cases

Figure 5 shows the estimated thermal intensification of the nanocomposites ($k_{nc}/k_r$). The results are compared with previous results of thermal intensification, obtained from direct measurements of the thermal conductivity of the same nanocomposites by the guarded heat flow meter (GHFM) method (Moreira, 2011). The estimates obtained from the GHFM method were taken at different temperatures and it is possible to observe a variation of the thermal conductivity

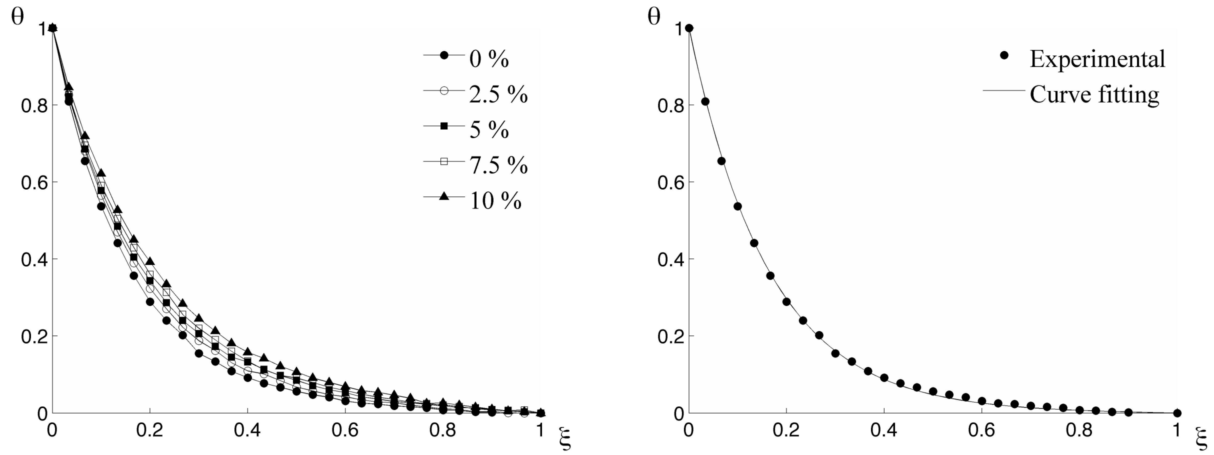


Figure 4. Dimensionless temperature distribution along the $x$ axis of all the measured samples (left) and curve fitting to the neat epoxy sample experimental data (right).

augmentation with temperature, especially at 75°C.

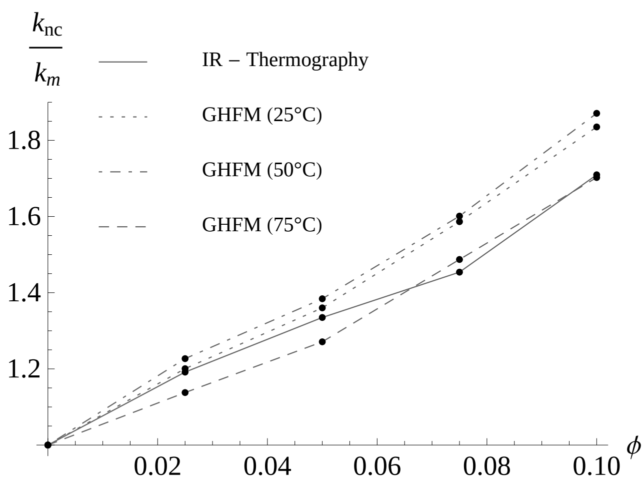


Figure 5. Comparison of the results for the thermal intensification on the epoxy resin estimated by the guarded heat flow meter and the infrared thermography methods.

According to Fig. 5, the thermal intensification estimated by the present method tends to previous data from the GHFM method at 25°C for lower loaded nanocomposites. However, for higher loaded specimens, the present data is closer to the intensification observed at 75°C. At this point, one should notice that the measured temperatures in all tests ranged from 25°C to 45°C, as was presented by Fig. 3. In this way, the estimated thermal intensification was expected to be closer to 25°C or 50° previous data, which are similar.

## 4. CONCLUSIONS

In this work, the thermal conductivity augmentation of epoxy-alumina nanocomposites was estimated using infrared thermography. The results showed that the addition of alumina nanoparticles enhances the thermal conductivity of the epoxy resin. The thermal intensification estimated in this study was compared with previous results obtained from the guarded heat flow meter method at three different temperatures and it has been demonstrated that the estimated results for lower loaded nanocomposites are close to the previous data. Although the temperatures in infrared thermography experiments ranged from 25°C to 45°C, the thermal intensification observed in samples containing 7.5% and 10% of nanoparticles were close to the results obtained at 75°C by the GHFM method and, as a consequence, was lower than expected compared to the GHFM data for 25°C and 50°C.

As a final comment, it should be mentioned that the thermal conductivity of the nanocomposites employed in this experiment is very low, and so is the absolute difference between this property for samples containing different amounts of nanoparticles. As a consequence, little variation in external parameters may be accounted as a difference in thermal intensification. Further investigation shall be carried out, in order to control such external parameters and study their influence in the results.

## 5. ACKNOWLEDGEMENTS

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