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EXPERIMENTAL ANALYSIS OF DIFFERENT PARAMETERS IN THE INCLUSION DETECTION BY THERMAL IMPEDANCE

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Abstract. *Breast cancer is the type of cancer that mostly affects women in Brazil, presenting 29.5% of new cases each year. New breast cancer detection methods are being developed to overcome the difficulties encountered in existing methods such as radiation emission and possible patient discomfort. This study aims to evaluate the influence of the depth of the inclusion in the detection using thermal impedance method. In addition to analyze the most suitable external heating location: localized or general in the surface. A silicone model filled with commercial gel was used to simulate the tissue and the adipose tissue. The heat flux and the superficial temperature were acquired in the model and it was possible to evaluate its thermal impedance. Besides that, RMSD damage metrics were calculated between the baseline (tests without inclusions, only with external heat generation) and the model with the inclusion of 10 mm to verify the inclusions. Thus, it was concluded that the thermal impedance method was able to identify the inclusion of 10 mm in all the depths tested when the localized external heatin was applied on the model.*

Keywords: *thermal impedance, inclusion detection, silicone model, external heating, depth of inclusion*

1. INTRODUCTION

Breast cancer is a disease caused by disordered multiplication of breast cells, which creates abnormal cells that multiply forming tumors. According to the National Cancer Institute, breast cancer is the most common type among women in the world, after the non-melanoma skin cancer, corresponding to about 25% of new cases each year, and, in Brazil, this percentage is 29.5% (INCA, 2017).

For breast cancer the reference exam for detection and diagnosis is the mammography. However, this technique has disadvantages as the discomfort caused to the patient and the difficulty for the detection of tumors in dense breasts, implying the necessity for research to develop new techniques that can help in the early detection of breast tumors (Menegaz et al., 2019).

Methods for detection of tumors based on properties of tissues has been developing over the years. Studies have addressed the screening from the identification of significant differences in electrical impedance values between healthy and malignant breast tissue (Zou e Guo, 2003).

In this work, it is proposed the development of the thermal impedance study on detecting inclusions, started on the work of Menegaz and Guimarães (2019). The thermal impedance method is based on the relationship between the heat flux imposed on the body and the consequent temperature variation caused by that heat flux. The application of thermal impedance in the detection of damages represents innovation and could increase the sensitivity of techniques based on thermal infrared images.

In this way, the main objective of this work is to develop an experimental analysis to evaluate the detection of inclusion in a silicone model using the thermal impedance method. Precisely, this work will observe the influence of external heating, partially or on the whole surface of the model, and the ability of the technique to detect inclusions at different depths.

2. THEORETICAL FUNDAMENTALS

This topic will present the theoretical fundamentals about the development of the experimental model and technique of thermal impedance.

2.1 Experimental model

In this work, a phantom sample is proposed for simulating a breast. In this case, it proposes a sample of simple geometry, composed of three different materials to mimics the skin, the lump, and the adipose tissue of a breast. According to Ismail et al. (2017), silicon is a material that has the properties closest to the desired tissues, better than agar and gelatin, usually employed. Besides, silicon is a soft material with a modulus of elasticity that can be related to adipose tissue samples, 6 ± 0.4 kPa, to the tumor, 6 ± 5 kPa, and easy to prepare.

2.2 Thermal impedance

Thermal impedance has been used to identify thermal properties, such as diffusivity and thermal conductivity, in addition to specific heat. The concept of impedance using only data from a surface was used in the work of Borges, Sousa and Guimarães (2008) to identify a transient three-dimensional thermal system. The basic principle is that the thermal impedance is the ratio between the temperature difference and the resulting heat flux, which can be given by the sum of the heat flows, or by the insulated heat flux.

Thus, it is possible to establish an equivalence among thermal, electrical and mechanical systems. The thermal impedance can be expressed as shown in Eq. (1) (Menegaz and Guimarães, 2019).

$$Z_t = \frac{\Delta V(\omega)}{I(\omega)} = \frac{\Delta T(\omega)}{q_0(\omega)} = \frac{T_{y=0}(\omega) - T_a(\omega)}{q_0(\omega)} \quad (1)$$

Where the parameter $q_0(\omega)$ is the thermal excitation represented by the heat flux imposed on the surface, $\Delta T(\omega)$ is the response to this flux measured at the surface temperature of the sample (system), the variable ω represents the domain of the frequency function obtained by the applying the Fourier transform to the time signals of $\Delta T(t)$ and $q(t)$ is measured by the heat and temperature sensors. In the equation $T_{y=0}(\omega)$ is the initial temperature and $T_a(\omega)$ are the temperatures along the time, causing the impedance condition to be given as a temperature difference by the heat flux.

Since the thermal system is a function of the thermal properties, perfusion, and metabolism, the thermal impedance must also assume different values if the medium has inclusions with thermal properties or if its internal heat generation is different from its surroundings.

Menegaz and Guimarães (2019) and Menegaz et al. (2019) showed that the use of the impedance concept (thermal or electromechanical) associated with damage metrics could detect inclusions inserted in a homogeneous medium. Equation (2) defines the damage metric.

$$RMSD = \sqrt{\sum_{i=1}^n \left\{ \frac{[Re(Z_{1,i}) - Re(Z_{2,i})]^2}{n} \right\}} \quad (2)$$

The term RMSD represents the damage metric; $Re(Z_{1,i})$ is the electromagnetic interference (EMI) measured under the damaged condition; $Re(Z_{2,i})$ is its counterpart, corresponding to the healthy condition (baseline condition) at the i -th frequency interval; and n is the total number of frequency points considered in the measurement.

A reliable threshold level is determined based on the information obtained for the healthy condition of the structure, using the calculated value of damage metrics. The threshold was determined according to Eq. (3).

$$PZT_{Threshold} = \mu_{X_{max}} + 3\sigma_{X_{max}} \quad (3)$$

3. MATERIAL AND METHODS

Figure 1 illustrates the experimental apparatus made for the development of this technique. The model was made of silicon rubber (Redelease®) and mimicked the skin. The inclusion was made of acrylonitrile butadiene styrene (ABS) and the adipose tissue was composed of a commercial gel. ABS has rigidity higher than silicon, and the gel allows inclusion to move within the model.

The model consists of three parts, cited above. The part that represents the skin is similar to a box made of silicone, with dimensions of 107 mm x 155 mm x 40 mm and a thickness of 2 mm, with an upper surface to close the box, that has the same dimensions, but with 10 mm of thickness, as shown in Fig. 1(A).

The inclusion of ABS that simulates the tumor was printed by a 3D printer (Cliever®) and had a diameter of 10 mm and a rod of 300 mm. Thus, it is easy to move the inclusion inside the experimental model allowing variation of depth of inclusion. The inclusion contains an electrical resistance in the center so that the internal heat is generated (Fig. 1 (B)).

Figure 1(C) shows details of the assembly. A hole in the middle of the sample allows the movement of the rod with the inclusion fixed on.

The internal heat generated by the inclusions simulate the temperature of the tumor, which is larger than the surrounding tissues, due to its large vascularization and the accelerated metabolism. A simulation of the heat generation was performed with a resistance of 4 k Ω , with a current of 0.02 A and a voltage of 40 V. This value of heat generation is based in the metabolic activities of a slow growing tumor (doubling times < 250 days) (Gonzalez – Hernandez et al., 2019).

Two electric resistances were used to the external heating — a square and a circular. The square resistance covered all upper surface of the sample, while the circular (80 mm of diameter) was positioned just above the inclusion in the center of the top surface of the model. Both resistance were used to periodic heating. Four periods were used and divided into two stages of heating and cooling. Heating was performed with a voltage of 10 V and a current of 0.5 A during 60 s. After that, the heating was off and the cooling stage of 60 s was run. The heat flux and the surface temperature were measured with a sensor of heat flux and temperature (HFS-3 (Omega®)) positioned in the upper face of the model.

The initial condition of the reference test without the inclusion, called baseline, was the temperature at which the sample, without generating internal heat, and the air-conditioned environment reached equilibrium, approximately after 2 h. The initial condition for the tests with inclusions was the steady state condition achieved by the sample after internal heat generation after 2 h. For each configuration of the model, ten tests were performed, in which temperature and heat flux measurements were taken every second during the experiment.

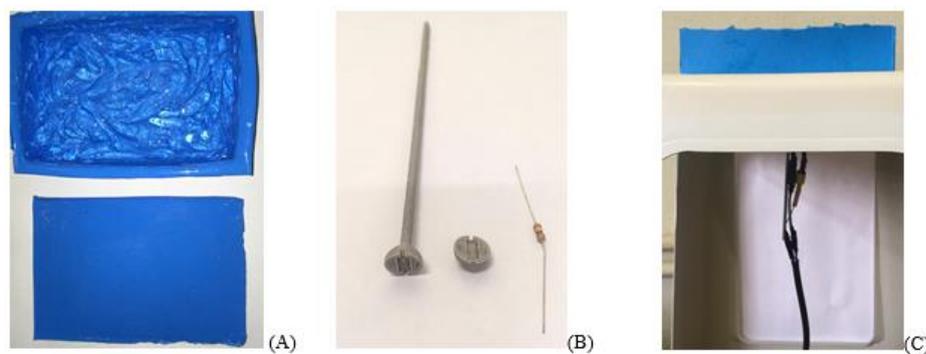


Figure 1. (A) Silicone model with gel inside, representing, respectively, the skin and adipose tissue; (B) Image of the inclusion of 10 mm divided in half and the resistance of 4 k Ω to be placed inside; (C) Final Assembly of the experiment.

The RMSD was then calculated to identify the difference between the model with and without inclusion.

Four configurations were made for each type of external heating (whole area heat and partially heated). One is the baseline that does not take into account the inclusion and internal heat generation but external heating. The other three tests use external and internal heating with the inclusion in three different positions: 2mm, 20mm, and 40mm distant from the top surface, called P1, P2, and P3, respectively.

4. RESULTS

Figure 2 and Figure 3 show the heat flux evolution for all configurations, with the two types of heating. Related temperature evolutions are shown in Figs. 4 and 5.

The values of heat flux and temperature difference then used to calculate the thermal impedance, shown in Figure 6 and 7. The different configurations are described in the figures.

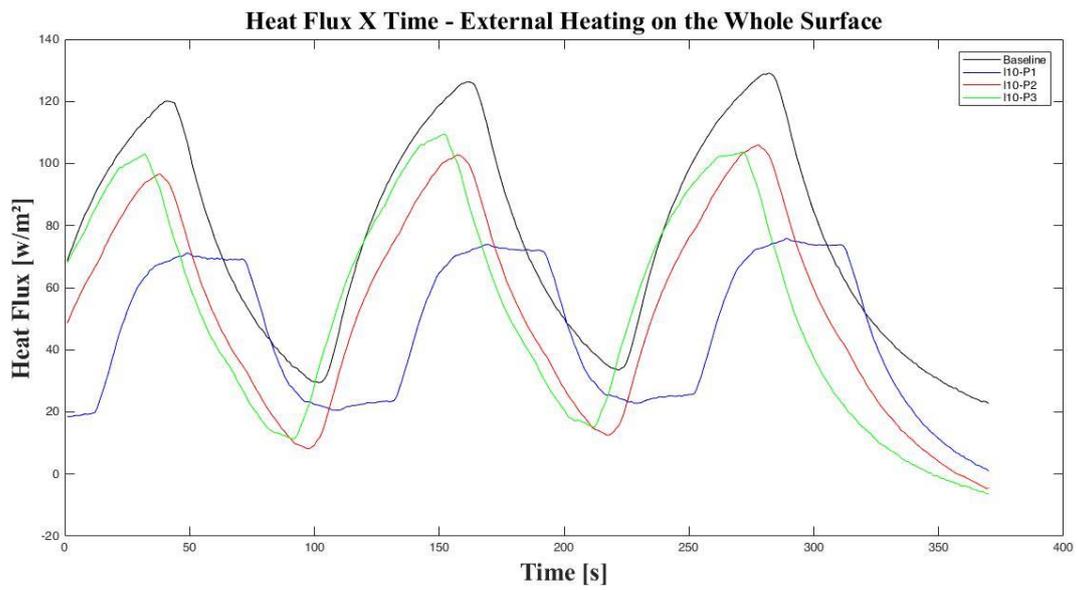


Figure 2. Heat flux evolution at the whole top surface.

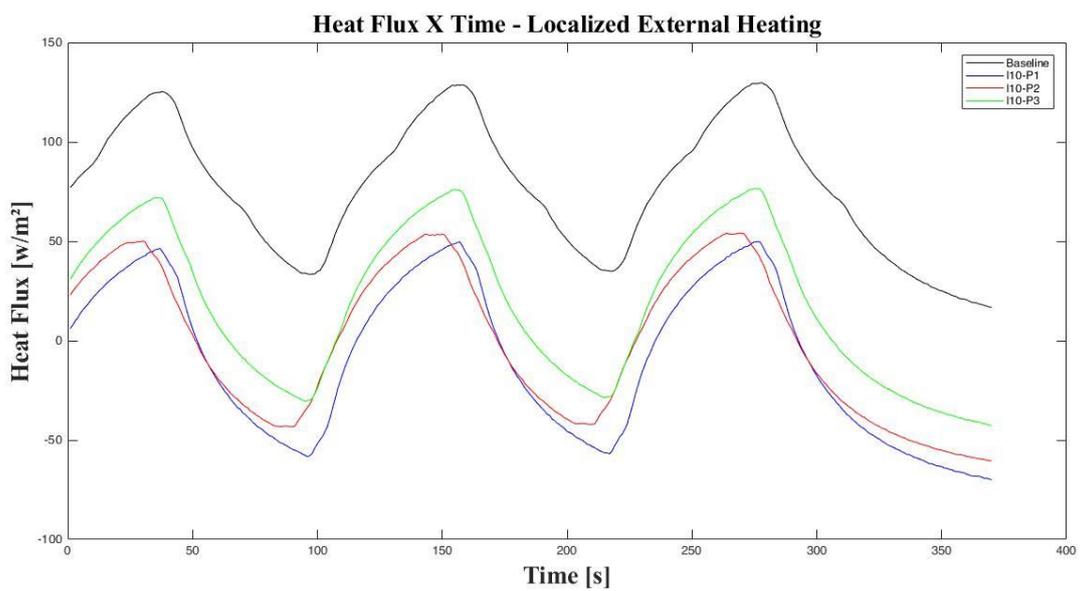


Figure 3. Heat flux evolution at localized an area at the top surface.

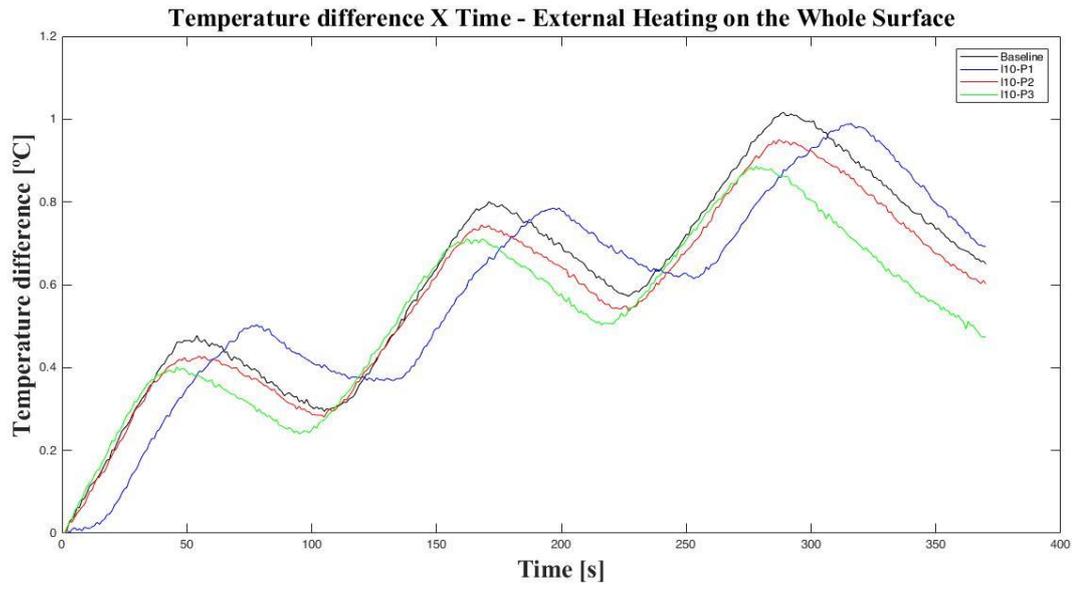


Figure 4. Temperature evolution at the whole top surface.

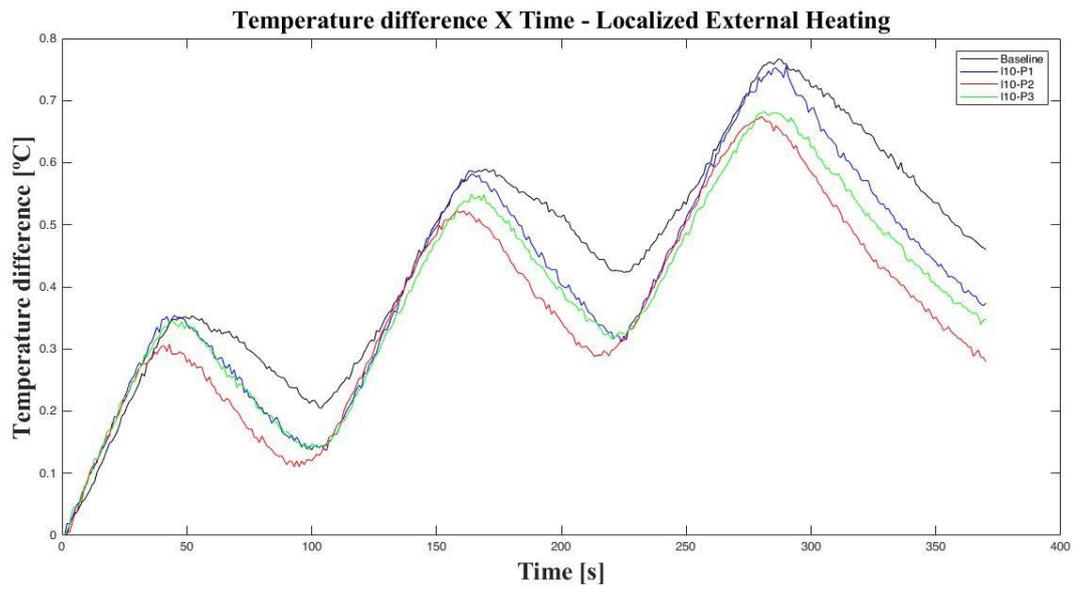


Figure 5. Difference temperature evolution at localized an area at the top surface.

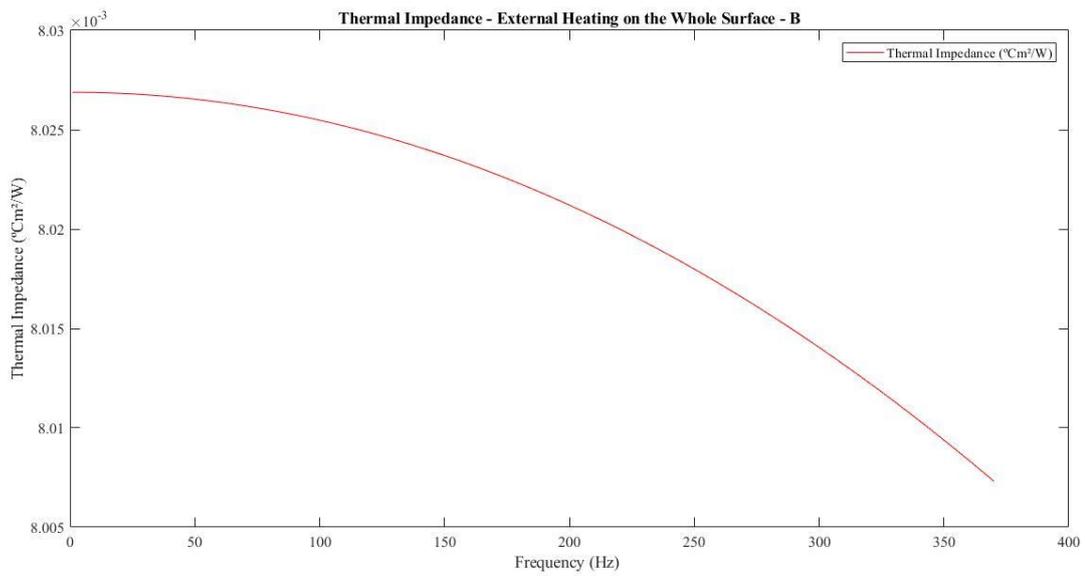


Figure 6. Baseline Impedance from the top surface with whole area heating.

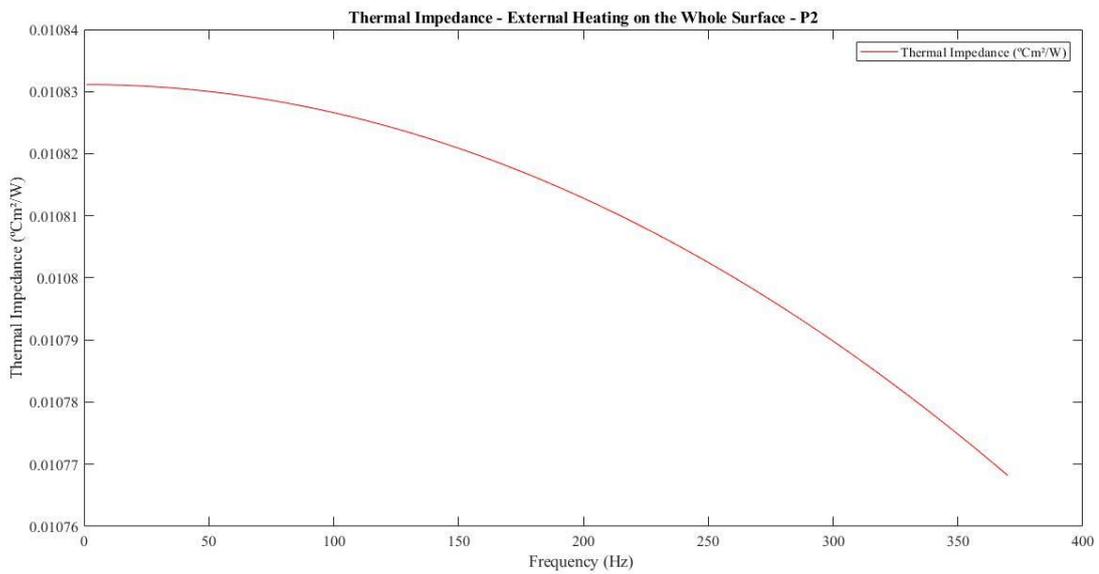


Figure 7. . Impedance considering inclusion at 10mm from the top surface and whole area heating.

The thermal impedance curves indicate whether or not there would be differences in the thermal behaviour of the model by the presence of an inclusion. The damage metrics shows if the inclusion could be detected. The threshold value was presented, guaranteeing 95% confidence in the probability of detection of the abnormal material. The results above the threshold indicate that the inclusion was detected. In cases where box plots intersect the threshold, the results were considered inconclusive.

4.1 External heating on the whole surface results

Based on Figure 8, inclusion can not be detected. On the other hand, Figure 9 shows that for using partially heat the inclusion was detected for the three positions.

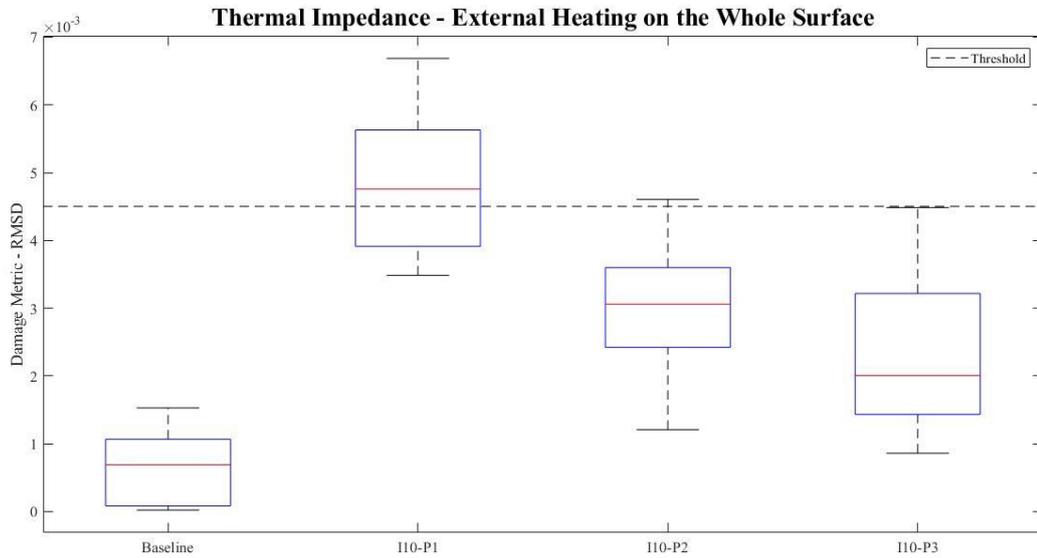


Figure 8. Damage metric considering whole surface heating for the three tests.

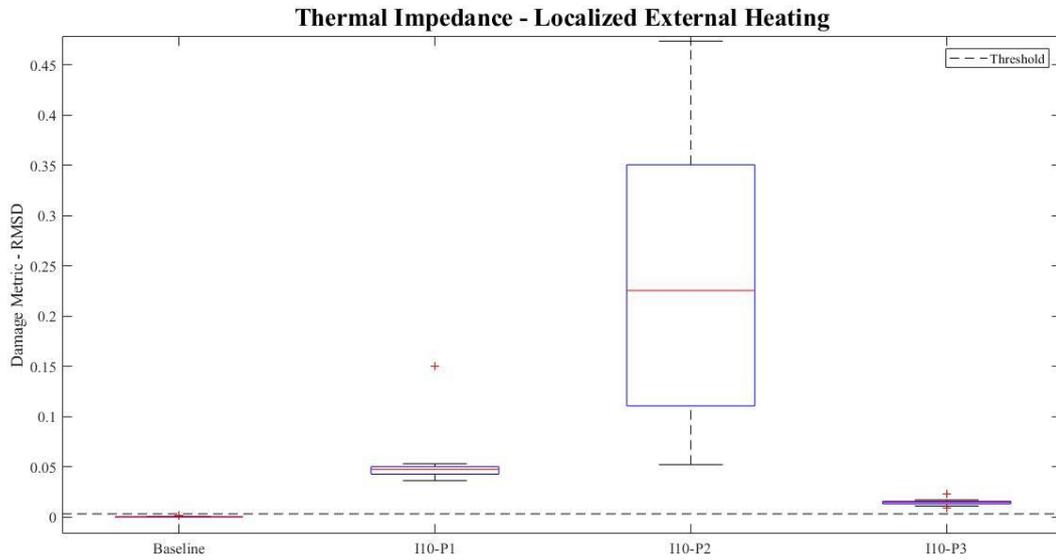


Figure 9. Damage metric considering partially heat for the three tests.

5. CONCLUSIONS

The detection of inclusions in a silicone model using the thermal impedance technique was evaluated. Two electric resistances were used to the external heating — a square and a circular. The square resistance covered all upper surface of the sample,

while the circular (80 mm of diameter) was positioned just above the inclusion in the center of the top surface of the model. Both resistance were used to periodic heating. Inclusion that mimics a tumor was inserted inside the silicone model in three different positions to analyze the ability of detection of the technique.

The results show that partially heat is better than whole heating to detect an inclusion. The higher sensitivity is the reason for that. Besides, for the tests evaluated, the inclusion was identified for all positions when the partial heat was used.

6. ACKNOWLEDGEMENTS

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