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# Reconstruction of a triangular geometry defects in inaccessible face by a model of active thermography

A. ELHASSNAOUI[a], A. EL BALLOUTI[b], S. SAHNOUN[a,*]
[a] *Laboratory of Electronics, Instrumentation and Signal Processing, Faculty of Sciences, B.P 20. 24000 El Jadida, Morocco*
[b]*National School of Applied Sciences, ENSAJ, El Jadida, Morocco*

In infrared thermography radiations from a heated material are processed in thermogram. This application of thermoelectric technology is used in the study of thermal properties of materials. In this work, we proposed a model to estimate the thickness of the samples that have rear faces partially or completely inaccessible. We have improved the benchmark formula presented by S. Lugin / U.Netzelmann [1] known as "the echo defect shape (EDS)" by reducing the reconstruction error. The proposed model takes into account the effect of the opening angle in the reconstruction of a defect that has a triangular geometry.

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## 1. Introduction

In thermal non-destructive testing the temperature is used as a parameter to reveal the internal structure of materials. In active thermography materials are exposed to a short heat pulse. Then with the study of their responses, it flushes the presence of defects. This non-contact technique is the most popular techniques of non-destructive thermal testing, thanks to its speed (pacing mode pulse that does not exceed a few seconds), ease of implementation, and the relative simplicity of digital thermograms. [1-9].

The aim of reconstruction is to improve the quality of sensors in the detection and classification of defects and inhomogeneities. These sensors allow obtaining quantitative information, such as wall thickness, the dimensions of the voids or materials thermal diffusivity.

Based on the heat equation in one dimension, back wall reconstructions of specimens were realized by S. Lugin and all [1], R. Richter and all [10]. In this context, we present a method for reconstructing the rear face, supposedly inaccessible, of black PVC samples with defect geometry. Defect has a triangular shape with an opening angle. We show the effect of the latter on the reconstruction of the triangular shape defect geometry, then, we present a correction of the Echo Defect Shape (EDS) model developed by R. Richter [10], by proposing a new model called Angle Effect Model (AEM) that will reconstruct a triangular geometry defect taking into account the effect of the opening angle value.

## 2. Angle effect (AE) on the 2D reconstruction of triangular shape of a geometry defect

### 2.1 Calculation of Trel(t) by the finite element method

Consider two samples with the same dimensions (x = 0,15 m, y = 0,02 m and z = 0,15 m). Each one has an inaccessible defect in the rear face. The defect has a triangular shape with an opening angle, the values of the opening angle is 90 ° and 120 ° (Figs. 1 and 2).

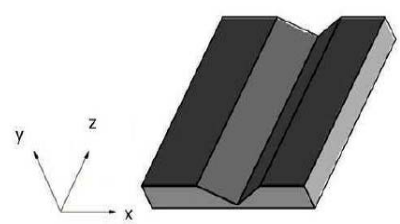


*Fig. 1. PVC specimen in 3D. The defect was imitated by a triangular notch shape [10].*

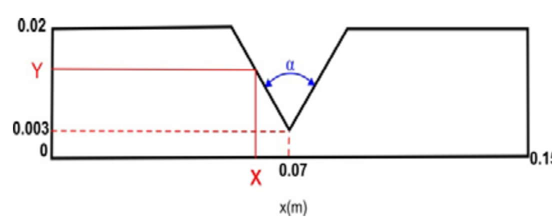


*Fig. 2. Profile of the sample PVC. The wall thickness varied from 0.02 m to 0.003 m.*

The material of our samples is the black hard-PVC, with an absorption coefficient of 0.96 without any surface treatment (Table 1).

*Table 1. Black hard-PVC thermal properties.*

| The material coefficients | |
|---|---|
| Density | 1413± 4 kg/m$^3$ |
| Thermal diffusivity | (1.45 ± 0.1).10$^{-7}$ m$^2$/s |
| Specific heat capacity | 1015 ± 40 J/(kgK) |
| Thermal conductivity | 0.208 ± 0.02 W/ (mK) |
| Emission coefficient | 0.963 ± 0.001 |
| Heat transfer coefficient | 9 W/(m$^2$ K) |

We apply a pulse heating (with time duration Δt = 170 ms) on the accessible face y = 0 m and we calculate the temperature distribution in this face with the finite element method, using a numerical software. The obtained data, as a function of time t, allows reconstruction of geometry defect shape.

In each point x (Fig. 2), we calculate the relative temperature Trel (t) by the following relation [1]:

$$T_{rel}(t) = \frac{T(t) - T_{defect-free}(t)}{T_{defect-free}(t)} \qquad (1)$$

Where

- T (t) is the temperature at the x point at the time t,
- $T_{defect\text{-}free}$ (t) is the temperature of the defect-free zone at the time t.

### 2.1 Results and discussion

In Fig. 3, we plot the evolution of the thickness values $y_{fem}$ as a function of $T_{rel}$, 60s after the flash, for the angle value α= 90 ° and α= 120 °.

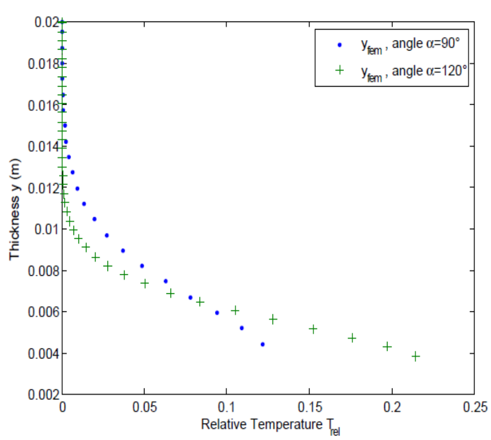


*Fig. 3. Variation of the thickness $y_{fem}$ as a function of $T_{rel}$ for α = 90 ° and α = 120°.*

It is noted that the thickness variation yfem according to the relative temperature Trel depends on the opening angle value α.

## 3. Determination of the thickness function as y = f (Trel, α)

### 3.1 The echo defect shape (EDS)

S. Lugin and U. Netzelmann [1] developed the EDS model who estimates the wall thickness $y_{EDS}$ from the relative temperature on the heated face by the relation:

$$y_{EDS} = [-\frac{kt}{\rho c}\ln(T_{rel}(t))]^{\frac{1}{2}} \qquad (2)$$

Where:

- $y_{EDS}$: the sample thickness in meters;
- t: the time elapsed after the delta pulse heating in seconds;
- k: thermal conductivity in watts per meter-Kelvin;
- ρ: density in kilograms per cubic meter;
- c: specific heat capacity in joules per kilogram-Kelvin.
- $T_{rel}$(t)The relative temperature is given by equation (1).

We calculated the thickness of the wall $y_{EDS}$ by S. Lugin and U. Netzelmann model. We applied the EDS model to the relative temperatures $T_{rel}$ obtained by the finite element method (Fig. 3). To compare the results of both models for angles α = 90 ° and α = 120 °, we have plotted in the Fig. 4 the $y_{EDS}$ values calculated by the EDS model, with the $y_{fem}$ values (Fig. 3) according to the relative temperature $T_{rel.}$

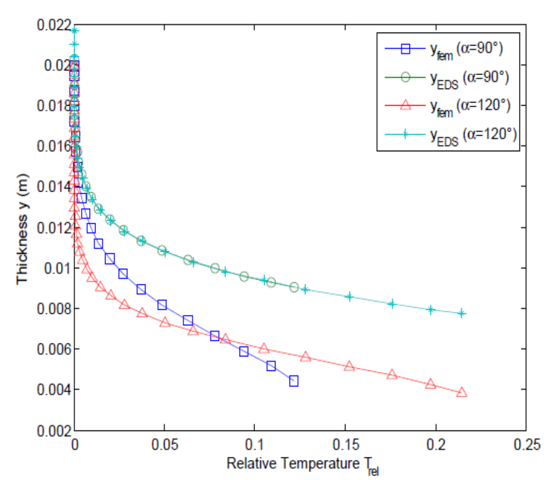


*Fig. 4. Comparison between $y_{fem}$ and $y_{EDS}$ for α = 90 ° and α = 120°.*

We note that the values of the inaccessible wall thickness $y_{EDS}$ provided by the EDS model don't change with the angle value α. The two curves are indistinguishable. For two defects having different aperture angles, the EDS model gives the same thickness, which will lead to errors in the reconstruction of the materials inaccessible faces. However, according to the results of Fig. 3, we note that the thickness values yfem depend on the value of the opening angle value α.

### 3.2 A new model for the reconstruction of a triangular geometry defects (Angle Effect Model AEM)

We propose the AEM model that takes into account the effect of the opening angle value α in the calculation of the inaccessible wall thickness y AEM from the value of the relative temperature Trel (t) at time t after heating. In this model we estimate the thickness of the inaccessible wall y AEM from the corresponding relative temperature Trel(t) according to the relation:

$$y_{AEM} = A(\alpha)[-\frac{kt}{\rho c}\ln(T_{rel}(t))]^{\frac{1}{2}} - B(\alpha)T_{rel}(t)^{E(\alpha)} \qquad (3)$$

Where:

- $y_{AEM}$: the sample thickness in meters;
- t: the time elapsed after the delta pulse heating in seconds;
- k: thermal conductivity in watts per meter-Kelvin;
- ρ: density in kilograms per cubic meter;
- c: specific heat capacity in joules per kilogram-Kelvin.
- $T_{rel}(t)$The relative temperature is given by equation (1).
- α: opening angle of triangular shape (rad).

The coefficients A(α), B(α) and E(α) are given by:

$$A(\alpha) = -0.35103\ \alpha + 1.5005 \qquad (4)$$

$$B(\alpha) = \frac{0.151}{\alpha^{7}}\ (\alpha \neq 0) \qquad (5)$$

$$E(\alpha) = 0.47165\ \alpha^{2} - 2.2827\ \alpha + 3.1166 \qquad (6)$$

The AEM model that takes into account the effect of the opening angle; because is a very important parameter in the reconstruction of inaccessible faces of materials.

To test our model, we reported on Fig. 5 $y_{fem}$ thicknesses and those obtained from Equation 3.

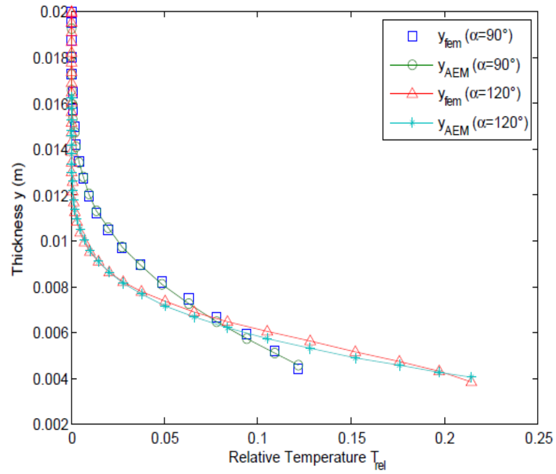


*Fig. 5. Variation of the thickness $y_{AEM}$ and $y_{fem}$ for α=90° and α = 120°.*

We note that the thickness values obtained by our model yAEM values are close to the values of yfem.We can confirm that AEM model allows the reconstruction of triangular geometry defects regardless of the opening angle value α. Indeed, for each value of the opening angle it provides the value of the thickness of the wall there, from the relative temperature Trel (t).

### 3.3 AEM model application in the reconstruction of inaccessible faces

We applied the AEM model in the reconstruction of inaccessible faces of two samples infected by an opening angle defect. Both samples are in black PVC having an absorption coefficient equal to 0.96 without surface treatment, thickness y = 0.02m and width x = 0.15m. The first sample has an opening angle α = 90 ° (Fig. 6) and the second has an opening angle α=120 ° (Fig. 7). They are heated in the input face y=0m during time Δt=170 ms.

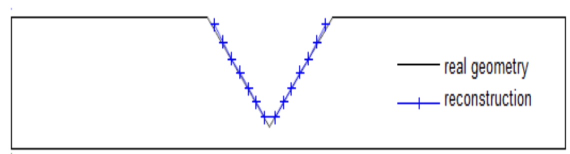


*Fig. 6. Reconstruction with Angle Effect Model AEM for α = 90 °.*
***Resulting error** = 0.0016 mm.*

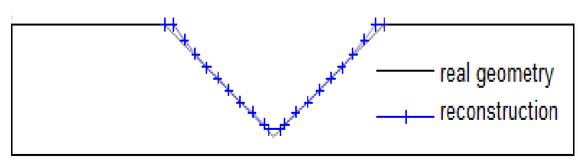


*Fig. 7. Reconstruction with Angle Effect Model AEM for α = 120 °.*
***Resulting error** = 0.0027 mm*

The results showed that we obtained a reconstruction with an error equal to 0.0016 mm in the case α=90° and an error of 0.0027 mm in the case of α=120 °. It should be noted that the AEM model improves the quality of the reconstruction of 700% in the case of α = 90 ° and 400% in the case of α = 120 ° relative to some model that exists in the literature. The EDS model [10] estimates a reconstruction with an error of 1.17 mm for α = 90 °, and an error of 1.02 mm for α = 120 °.

## 4. Conclusion

We reconstructed the inaccessible materials face infected by triangular defects geometry with an opening angle, from the calculation of the temperature which can be measured by the sensors. We have highlighted the effect of the opening angle value on this reconstruction. The value of the opening angle α is an important parameter in determining the thickness of the infected samples. We have shown that the change in the angle value α does not affect the thickness calculation y by the EDS model.

The AEM model that we proposed allows calculating the thickness y AEM as a function of the relative temperature taking into account the opening angle α value. This model allows a better reconstruction, with very low error, of the inaccessible face of auscultated sample.

## References

[1] S. Lugin, U. Netzelmann, NDT E Int. **40**, 220 (2007).
[2] J. C. Ramirez-Granados, G. Paez, M. Strojnik, Appl Opt. **51**, 3153 (2012).
[3] K. D. Cole, J. V. Beck, A. Haji-Sheikh, B. Litkouhi. Heat Conduction Using Green's Functions. CRC/Taylor and Francis, Boca Raton, 2nd edition, 2011.
[4] M. Weiser, M. R¨ ollig, R. Arndt, B. Erdmann. Heat and Mass Transfer, **46**, 1419 (2010).
[5] M. Krishnapillai, R. Jones, I. H. Marshall, M. Bannister, N. Rajic, Compos. Struct. **75**, 241 (2006).
[6] M. Pilla, M. Klein, X. Maldague, A. Salerno, in: D. Balageas, G. M. Busse, G. Carlomagno (Eds.), QIRT, 53 (2002).
[7] D. A. Gonzalez, C. Ibarra-Castanedo, J. M. Lopez-Higuera, X. Maldague, NDT E Int. **39**, 617 (2006).
[8] J. G. Sun, J. Heat Transfer **128**, 329 (2006).
[9] A. Stuart. Acta Numerica, **19**, 451 (2010).
[10] R. Richter, C. Maierhofer, M. Kreutzbruck, M. Schilling, NDT E Int. (2012).

*Corresponding author: ssahnoun@gmail.com