International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.3 Issue No.5, pp : 514-517 1 May 2014

Study of Finite Element Modeling of Pulsed Thermography

Ahmed ELHASSNAOUI, Abderrahim SAIFI, Asseya ELAMIRI, Smail SAHNOUN*
Laboratory of Electronics, Instrumentation and Signal
Processing, Faculty of Sciences, B.P 20. 24000 El Jadida,
Morocco.
* Corresponding author: ssahnoun@gmail.com

Abstract-- The modeling of pulsed thermography by finite element method has been the subject of numerous studies in the literature. In this paper, we studied the influence of the choice of shape function, of the mesh density and the time step on the calculation of the thermal response in such an modeling. For this, we performed numerical simulations in the case of a aluminum sample containing a round flat bottom hole, heated by a heat pulse of short duration. Results analysis showed the choice influence of the shape function and the mesh quality on the thermal contrast evolution as function of time. The study showed that the time step has no significant influence on the calculation of the thermal response.
Keywords: **Pulsed thermography, finite element modeling, shape function, mesh quality.**

1. Introduction

Pulsed thermography (PT) is a nondestructive evaluation method, which has been qualitatively and quantitatively applied to different categories of materials to detect a variety of defects, such as corrosion and delamination in composites and metals, etc.. [1]. PT was used to extract defect information such as size and depth [2-3].

To apply the pulsed thermography, the tested material needs to stimulate its surface by a heat pulse and analyze the process of self-cooling [4-5].

The finite element method is a numerical technique used to obtain approximate solutions to complex problems in physics and is widely used for modeling infrared thermography [6-7]. But the choice influence of shape function, mesh quality and time step on the thermal response has not been studied.

In this work, we study the effect of the choice of these parameters in the case of a sample of aluminum that contains a cylindrical defect and heated by a short duration pulse.

2. 3D finite element modeling of pulsed thermography.

To study the modeling of pulsed thermography by 3D finite elements, we consider an aluminum sample with square shape and edge equals to 100mm. The sample contains a round flat bottom hole with diameter equal to 40 mm and located at a depth equal to 3 mm (Figure 1). The thermal properties of the used material are as follows [7]:

- The specific heat: 490 J/kg.K,
- The thermal conductivity: 47.5 W/m.K,
- The material density: 7870 kg/m^3.

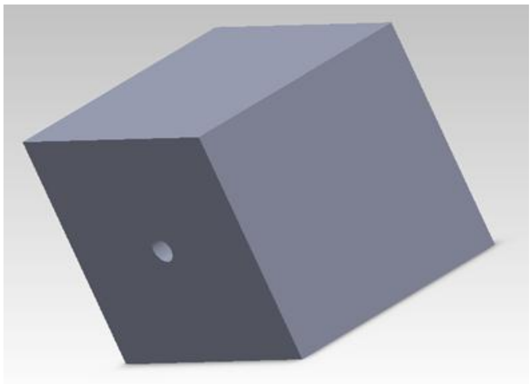

Fig. 1. Aluminum sample with round flat bottom hole.

We apply a heat flux equal to 1000W/m^2, for a time duration of 6 ms, to the surface above the defect and we calculate the temperature distribution in this surface as a function of time using a calculation software based on finite elements. The opposite face to the heated surface and the internal of the defect are maintained at a flux equal to 0, whereas the other cube surfaces are thermally insulated.

3. Effect of the shape function on the thermal response.

To study the effect of the shape function on the value of calculated temperature above the defect, we repossess the simulation described previously with different shape functions. We limit ourselves to finite elements of Lagrange (Linear, Quadratic, Cubic, Quartic). The considered mesh is tetrahedral, the mesh quality is normal (Figure 2) and the time step is equal to 0.001s.

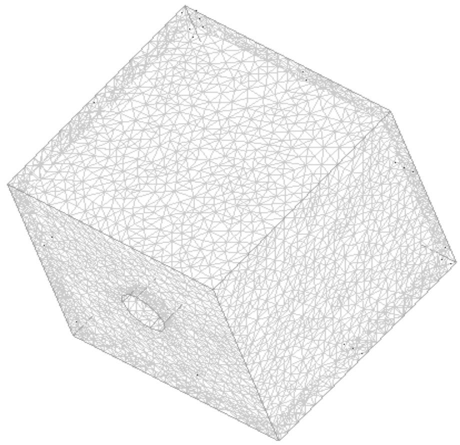

Fig. 2. Tetrahedral mesh with a normal density.

The mesh properties are listed in Table 1:

Table 1: Properties of the considered mesh.

Number of vertex elements	16
Number of edge elements	186
Number of boundary elements	2560
Number of elements	14911
Minimum element quality	0.3498

Figures 3-a and 3-b show the variation of thermal contrast above the defective area versus time.

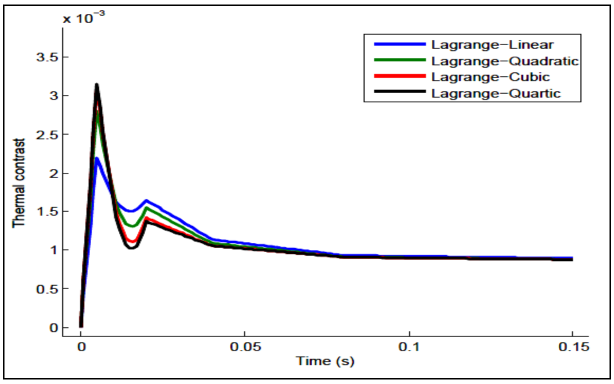

Fig. 3-a. Evolution of thermal contrast versus time for different shape functions, time interval = [0,0.15s].

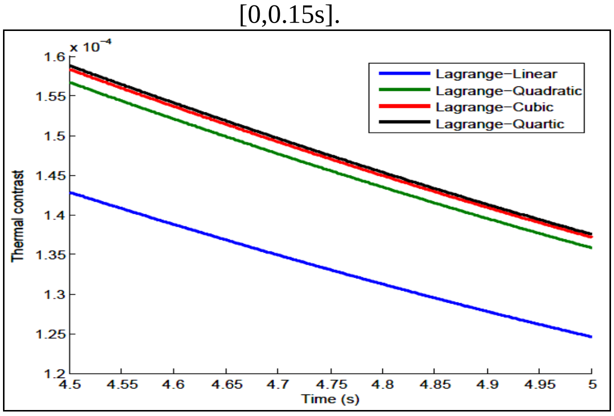

Fig. 3-b. Evolution of thermal contrast versus time for different shape functions, time interval = [4.5,5s].

We note that the choice of the shape function in the modeling of pulsed thermography influences the thermal response calculated by finite element. Indeed, the thermal contrast value obtained just after heating, at 0.006s, depends on the used shape function (Figure 3-a), this value will have an impact during cooling seen that the difference between the curves remains significant (Figure 3 -b). Figure 3-c represents the absolute difference between the calculated thermal contrast values in the case of a Lagrange-Linear interpolation and those calculated in the case of a Lagrange-Quartic function.

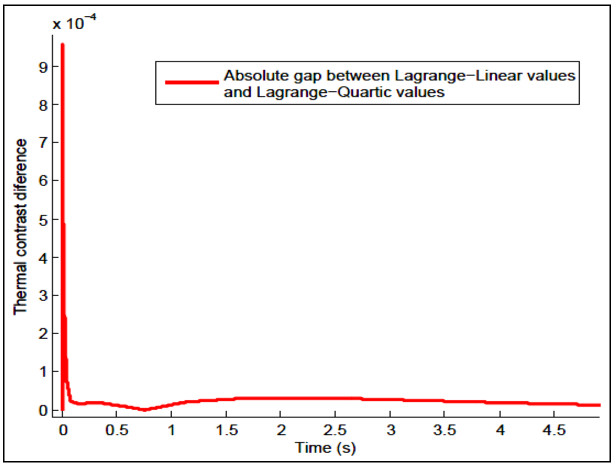

Fig. 3-c. Absolute gap between calculated thermal contrasts for two shape functions: Lagrange-Linear and Lagrange-Quartic.

We find that the maximum value of the absolute gap is located in the heating phase. We can conclude that the choice of the shape function is very important in modeling of pulsed thermography by the finite element method.

4. Effect of mesh quality.

We consider the shape function as Lagrange-Quadratic. To study the effect of mesh quality on thermal response in modeling of pulsed thermography by finite element method, we perform simulations as previously described with changing the quality for the tetrahedral mesh. The time step is equal to 0.001s. Table 2 shows the mesh properties for each considered quality.

Table 2: Mesh properties for each simulation.

Mesh quality	Extremely coarse	Extra coarse	Coarser	Coarse	Normal	Fine	Finer
Number of vertex elements	16	16	16	16	16	16	16
Number of edge elements	60	88	112	140	186	240	336
Number of boundary elements	224	390	872	1276	2560	4184	8676
Number of elements	399	865	2478	4838	14911	30344	91725
Minimum element quality	0.1706	0.1862	0.2317	0.267	0.3498	0.3193	0.3623

IJSET
International Journal of Scientific Engineering and Technology (ISSN : 2277-1581)
Volume No.3 Issue No.5, pp : 514-517 1 May 2014

Figures 4-a and 4-b show variation of thermal contrast versus time for each mesh quality.

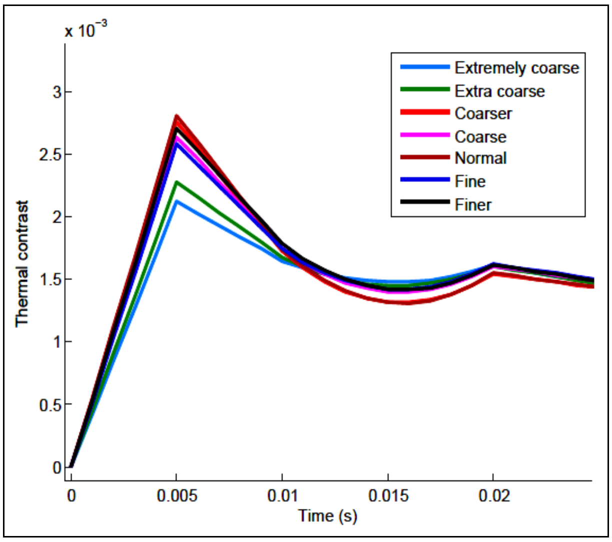

Fig. 4-a. Evolution of thermal contrast versus time for different mesh quality, time interval =[0,0.025s].

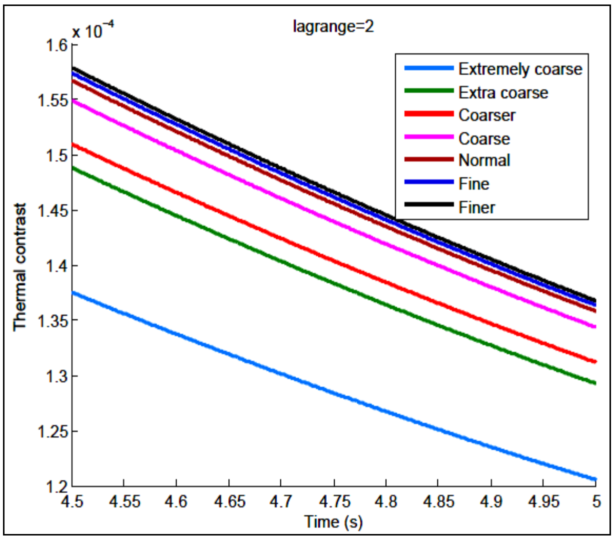

Fig. 4-b. Evolution of thermal contrast versus time for different mesh quality, time interval =[4.5,5s].

Figures 4-a and 4-b show the influence of mesh quality on the calculation of the thermal response. The maximum value of the thermal contrast just after heating, at t=0.006s, corresponds to a mesh with normal density. Theoretically, a finer density gives a closer value, but in practice of the finite element method, it should be noted that the higher the density is fine, most errors related to the calculation are important. We recommend to use a mesh with normal density in modeling of pulsed thermography.

Figure 4-c represents the absolute gap between the calculated thermal contrasts in the case of a normal mesh density and those calculated in the case of a fine mesh density.

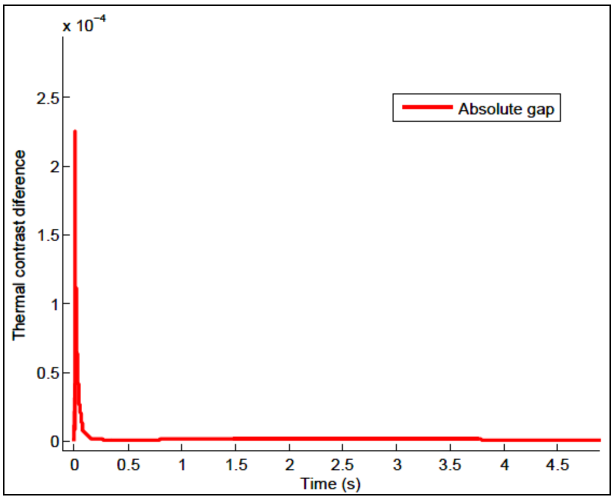

Fig. 4-c. Absolute gap between the calculated thermal contrasts in the case of a normal mesh density and those calculated in the case of a fine mesh density.

We note that the absolute gap is very important during heating phase that can influence the calculations in the cooling phase.

We can conclude that the mesh quality is an important factor in modeling of pulsed thermography by finite element method.

5. Effect of the time step.

In this part, we study the effect of time step on the value of calculated temperature above the defect. For this, we perform numerical simulations with variation of the time step value. The considered shape function is Lagrange-Quadratic and the mesh quality of the tetrahedral mesh is fixed at a normal density.

Figure 5 shows the variation of thermal contrast versus time for three values of time step 0.0005s, 0.001s and 0.0015s.

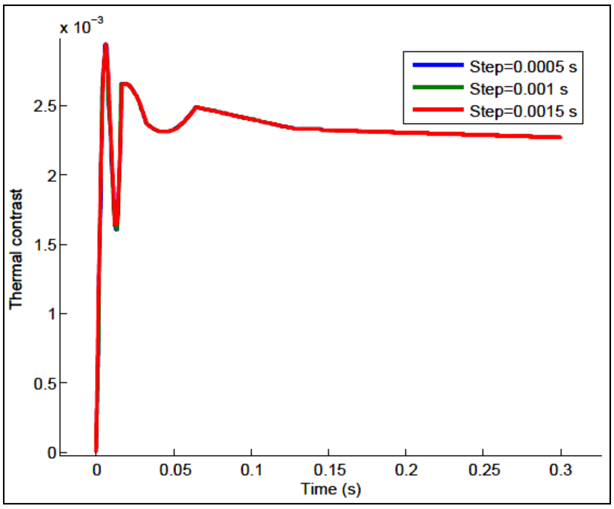

Fig. 5. Evolution of the thermal contrast as a function of time for different values of the time step, time interval =[0,0.3s].

The curves in Figure 5 are superimposed, so the variation of time step has no significant influence on the calculation of the thermal response in modeling of pulsed thermography by the finite element method.

6. Conclusion

We studied the influence of the shape function, the mesh quality and the time step on the calculation of the thermal response in modeling of pulsed thermography by finite elements. We found that shape function and mesh quality influence the value of the calculated thermal contrast.

We also showed that the variation in time step has no significant influence on the calculation of the thermal response in modeling of pulsed thermography by the finite element method.

References

i. *Maldague X. Nondestructive evaluation of materials by infrared thermography. New York: Springer; 1993.*

ii. *A. Elhassnaoui, A. Elballouti, S. Sahnoun, J. Optoelectron. Adv. Mater. 15, 5-6, 447 (2013).*

iii. *Sun JG. Analysis of pulsed thermography methods for defect depth predic- tion. J Heat Transfer 2006;128(4):329.*

iv. *H.D. Benitez, C. Ibarra-Castanedo, A.H. Bendada, X. Maldague, H. Loaiza, E. Caicedo, Definition of a new thermal contrast and pulse correction for defect quantification in pulsed thermography, Infrared Phys. Technol. 51 (2008) 160–167.*

v. *D.A. Gonzalez, C. Ibarra-Castanedo, J.M. Lopez-Higuera, X. Maldague, New algorithm based on the hough transform for the analysis of pulsed thermographic sequences, NDT E Int. 39 (2006) 617–621.*

vi. *Streza, M.; Dadarlat, D.; Fedala, Y.; Longuemart, S., "Depth estimation of surface cracks on metallic components by means of lock-in thermography," Review of Scientific Instruments , vol.84, no.7, pp.074902,074902-8, Jul 2013 doi: 10.1063/1.4813744*

vii. *Natarajan, S.; Habtemichael, Y.; Graham, S., "Thermal metrology techniques for UV LED light sources," Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), 2012 13th IEEE Intersociety Conference on , pp.314,324, May 30 2012-June 1 2012.*

viii. *D. Peng, R. Jones, Modelling of the lock-in thermography process through finite element method for estimating the rail squat defects, Engineering Failure Analysis, Volume 28, March 2013, Pages 275-288.*