http://dx.doi.org/10.21611/qirt.2014.129

Thermal Non destructive Control of an Aircraft Trellis Welding

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Abstract

The welding together metal parts occupies an important place in the world of construction of ships, trains, planes, and so many other things that cannot be built without the use of welding. In the field of aerospace welding is widely used especially for mounting lattice fuselage. These trellis are usually made by using aluminum or aluminum alloy tubes welded together and of which the weld must be controlled. In this work, we investigate the effect of the thermophysical nature of solder, used to connect two trellis elements, on the distribution of the surface temperature of the structure. This distribution is able to tell us if there is a thermophysical consistency between the tube and the used solder. The finite element method is used to simulate the thermal response of the surface temperature of the welded structure following an excitation by a thermal heat flux step. The simulations results are presented on the one hand in the form of thermographic images to show the contrast in temperature due to the presence of the weld zone and on the other hand in the form of the spatial variation of the temperature along the longitudinal surface of the pipe to better quantify the contrast induced by the welding temperature.

Keywords: thermographical images, finite element, surface temperature, trellis tube, welding

1. Introduction

The non-destructive thermal control by infrared thermography allows the study of temperature variation in materials, and permit to detect the presence of the non-homogeneity in a given structures, without damaging them. This technique is often used in several areas of the industry (automotive, petroleum, shipbuilding, aerospace, etc.)…

Presence of inhomogeneities in a material affects the heat propagation and causes a local temperature variation [1] [2]. The only precondition for detection is that defects in the object under examination lead to a sufficient variation of thermal properties compared to the studied material [3]. If we take the case of a weld, the thermographical image of the welded structure can reveal the difference between the thermophysical properties of the structure to be welded and that the metal or alloy used to make this weld [4]. The greater this difference, the greater the temperature contrast of the obtained thermographical image is important which can weaken the structure integrity.

The purpose of this study is to show, after applying a heat pulse, the temperature variation on the surface of a weld according to the thermophysical nature of the metal or metal alloy used to make this welding by help of a numerical method combined to an infrared thermographycal analysis. Aluminum tubes studied in this work are analogus to those used in the mounting of lattice planes [5].

2. Description of the structure

In this study a welded pipe, having a length l=1000mm, an external diameter d=100mm and a thickness e_p=10mm is considered (Fig 1. a)). The pipe consists of two identical parts assembled by welding of circular form and a triangular section with a width e_s (Fig 1. a) and the longitudinal section of the welded tube Fig 1. b).

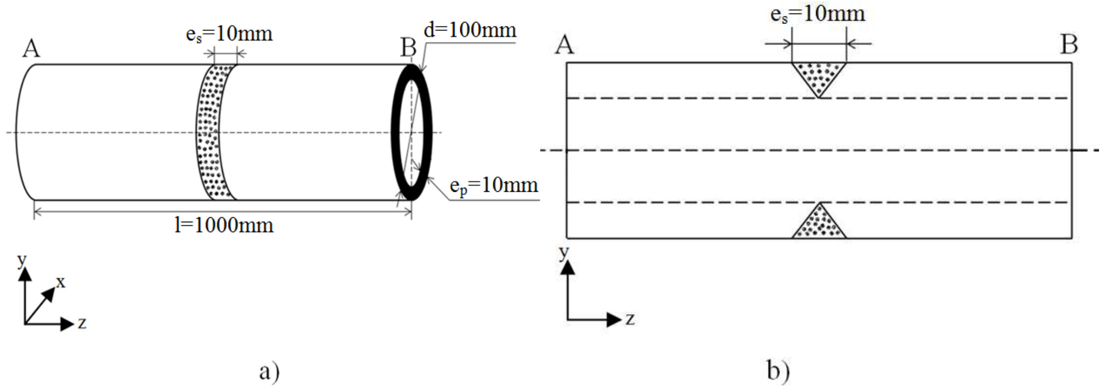

Fig. 1.a *Studied structure,* ***Fig. 2.b*** *Longitudinal section of the welded tube*

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3. Numerical modeling

In this study we treat a system of three dimensions heat transfer which means that the analytical solution is no longer valid and in this case we call for a numerical solution based on the numerical method of the finite elements *[6,7].* The equation of the three-dimensional heat is given by *[8]*

$$a\nabla^2 T = \frac{dT}{dt} \tag{1}$$

The report: $a = \frac{k}{\rho C_p}$ is called thermal diffusivity

Where:
k :the thermal conductivity,
ρ : the material density
C_p : the heat capacity.

The analytical resolution is indeed impossible being given the geometry of the problem. The method consists in using an approximation by finite elements of the unknown functions T to discretize the variational form of the equation (1) and to transform it into system of algebraic equations of the form:

$$[A]T = F \tag{2}$$

With
A: the square matrix of dimension [N_h, N_h],
F: a vector of N_h components
T: the vector of the temperatures to be calculated.

We start by building the variation form of the equation (1). We carry out a spatial discretization which consists in calculating the elementary integrals by using the finite element and a temporal discretization.

There are many specialized software which make it possible to implement the method of resolution of problems by finite elements in a more or less simple and convivial way. They take care in particular of the grid of the studied object, of the automatic numbering of the elements and the nodes, of the calculation of a solution then of the chart of the results.

In this study, we used commercial software based on the finite element method and which makes it possible to calculate the evolution of temperature at any moment and in any point of material. The material is considered isotropic.

With the boundary conditions:
- A heat pulse is applied to the outer surface of the aluminum tube, with a flux density Q=600W/m².
- The inner surface of the tube subjected to convective cooling of the heat transfer coefficient h=10W/(m^2K) and external temperature T_{ext}=25°C.
- The other faces are assumed thermally insulated.

The initial temperature of the subdomains is 25°C.

4. Results of simulations

4.1. Effect of the thermal conductivity of the welding material

4.1.1. Thermophysical characteristics

The following table (Table 1) shows the thermophysical parameters used in this part.

Table 1. *The considered thermophysical parameters*

	Thermal conductivity k [W/m.K]	Density [Kg/m^3]	Heat capacity at constant pressure [J/Kg.K]
The aluminum tube	237	2700	900
The welding material	Kal x (1+αx10%)	2700	900

4.1.2. Digital resolution

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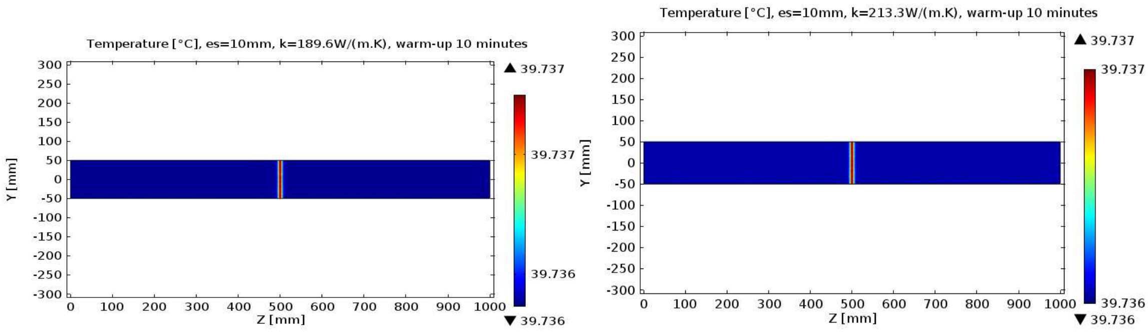
To illustrate the effect of the thermal conductivity of the welding material on the control surface temperature, we take a constant thickness of welding (e_s=10mm) and five values of thermal conductivity: 189.6W/(m.K), 213.3W/(m.K), 237W/(m.K), 260.7W/(m.K) and 284.4W/(m.K) representing respectively k_{al}×(1-20%), k_{al}×(1-10%), k_{al}, k_{al}×(1+10%) and k_{al}×(1+20%) where k_{al}=237W/(m.K) is the known aluminum thermal conductivity in bibliography. The calculated thermographical images, figures 2 and 3 and the temperature profile curves, figure 5, show that the more the thermal conductivity of welding material increases (respectively decreases), relative to that of aluminum, the more the external surface temperature decreases (respectively increases) and vice versa. However, the temperature variation value is very small and is about 0.001 for k = 189.6W/(m.K) and 720 and 0.0005 for k = 213.3W/(m.K). Then the detectability of the welded region becomes possible for a greater, or smaller, thermal conductivity of the welding material compared to the aluminum tube conductivity but it requires a sensitive camera to very small temperature variations.

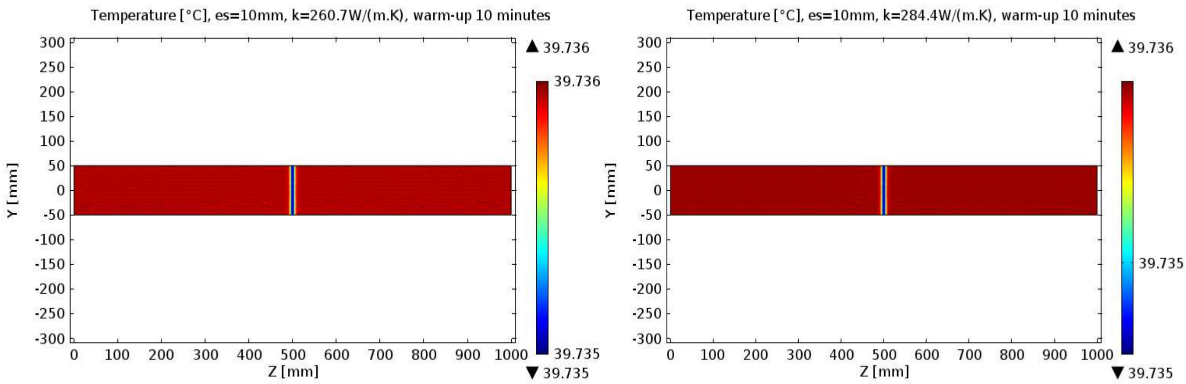


a) b)

Fig. 2. *Thermographical images of the of the external surface of the wlded tube for a warm-up of 10 min* ***a)*** *: k_{al}=189.6W/(m.K,),* ***b)****: k_{al}=213.3W/(m.K)*

Both thermographical images Figures 2 and 3 show that on the one hand when the conductivity of the weld metal is lower than that of metal to be welded, the welding area tends to take a greater temperature than the other areas of the tube and on the other hand, the greater the depth and width of the weld area are large the greater this variation is.

however, Figure 3 shows that, on the one hand when the conductivity of the weld metal is greater than that of metal to be welded, the welding area between the two parts of the tube is colder than the rest of the tube, and on the other hand, the larger the depth and width of the weld zone are, the more this temperature difference is large.



a) **b)**

Fig. 3. *Thermographical images of the of the external surface of the wlded tube for a warm-up of 10 min* ***a)*** *: k_{al}=260.7 W/(m.K,),* ***b)****: k_{al}=284.4W/(m.K)*

Figure 4 shows a weld having strictly the same thermophysical characteristics as the tube welding. We can note that there is no contrast in the thermographical image, the temperature is uniform throughout the structure surface which may be translated as an homogeneity of this structure.

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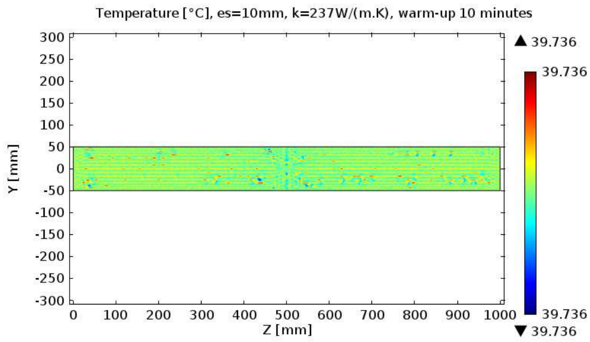

Fig. 4. *Thermographical images of the of the external surface of the wlded tube for a warm-up of 10 min, k_{al}=237 W/(m.K,)*

The above results are clearer on the curves of the spatial variation of the temperature along an AB axis passing through the pipe surface and the weld zone, Figure 5.

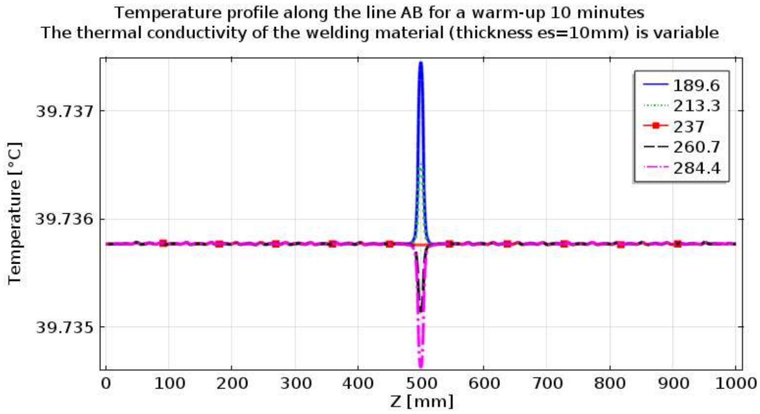

Fig. 5. *Temperature profile along the surface line AB for a warm-up 10min for 5 different values of conductivity k: 189.6 - 213.3 - 237 - 260.7 and 284.4 W/(m.K,)*

4.2 Effect of the heat capacity Cp of the welding material

4.2.1 Thermophysical characteristics

The following table (Table 2) shows the thermophysical parameters used in this part.

Table 2. *The considered thermophysical parameters*

	Thermal conductivity k [W/m.K]	Density [Kg/m^3]	Heat capacity at constant pressure [J/Kg.K]
The aluminum tube	237	2700	900
The welding material	237	2700	Cpal x (1+αx10%)

4.2.2 Digital resolution

To illustrate the effect of the thermal heat capacity of the welding material on the control surface temperature, , we take a constant thickness of welding (e_s=10mm) and five values of thermal heat capacity : 720J/(kg.K), 810J/(kg.K), 900J/(kg.K), 990J/(kg.K) and 1080J/(kg.K) representing respectively $C_{p\text{-}al}$×(1-20%), $C_{p\text{-}al}$×(1-10%), $C_{p\text{-}al}$, $C_{p\text{-}al}$×(1+10%), $C_{p\text{-}al}$×(1+20%) where $C_{p\text{-}al}$=900J/(kg.K) is the known aluminum heat capacity in bibliography. The calculated

thermographical images, figure 6 and 7 and the temperature profile curves figure 8 show that

the more the heat capacity of welding material increases (respectively decreases), relative to that of aluminum, the more the external surface temperature decreases (respectively increases) and vice versa. The detectability of the part of the welding material becomes easier for a greater (or smaller) heat capacity of the

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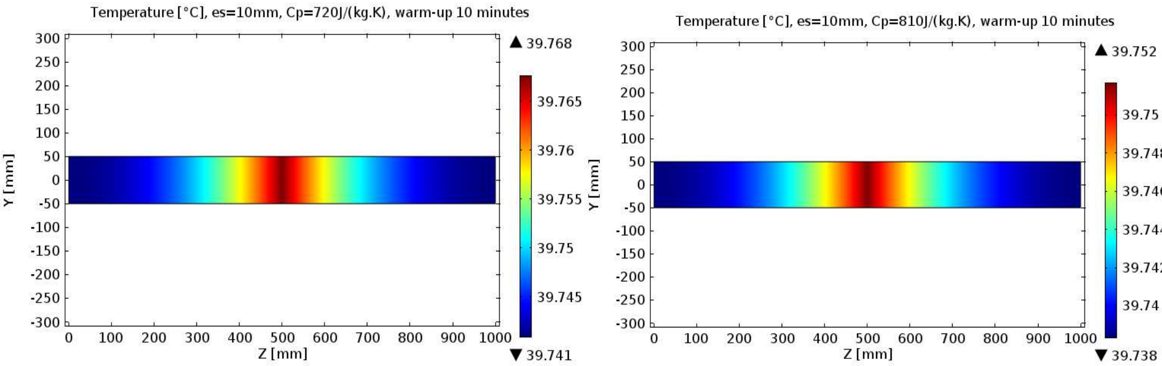
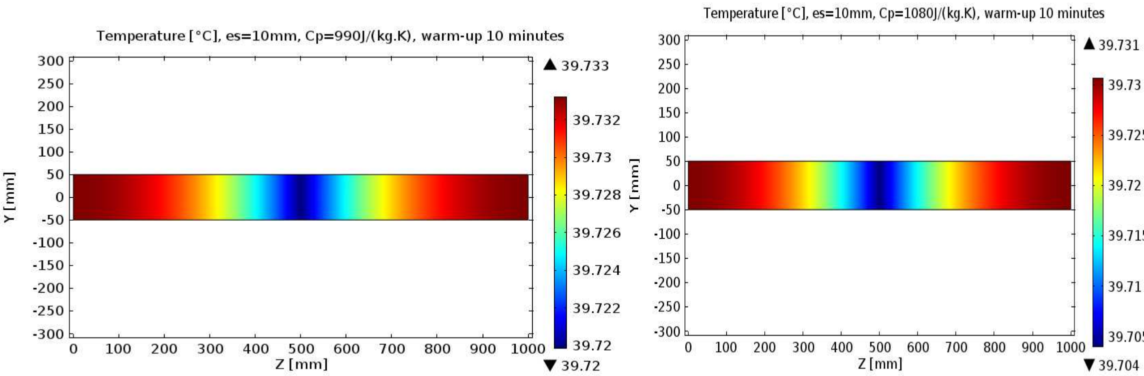
welding material compared to that of the aluminum tube. But this time the temperature variation value is about 0.02 degree for Cp = 720 and 0.01 degree for Cp = 810 J/(kg.K).



a) **b)**

Fig. 6. *Thermographical images of the of the external surface of the wlded tube for a warm-up of 10 min* ***a) :*** *(C_p=720J/(kg.K)),,* ***b):*** *(C_p=810J/(kg.K))*



a) **b)**

Fig. 7. T*thermographical images of the of the external surface of the wlded tube for a warm-up of 10 min* ***a)****:C_p=990J/(kg.K),* ***b):*** *(C_p=1080J/(kg.K))*

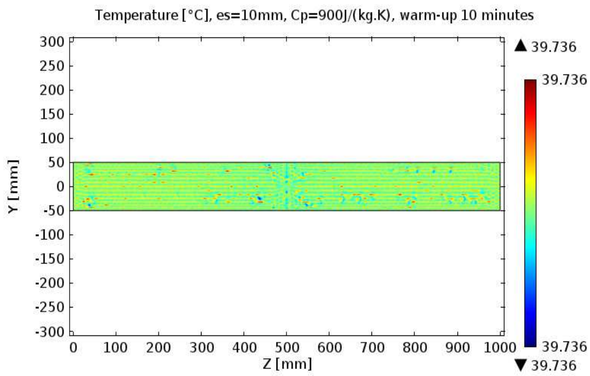


Fig. 8. *Thermographical images of the of the external surface of the wlded tube for a warm-up of 10 min a) : $C_{p\text{-}al}$=900J/(kg.K)*

Figure 8 shows equally a weld having strictly the same thermophysical characteristics as the tube welding. We can note also that there is no contrast in the thermographical image, the temperature is uniform throughout the structure surface which may be translated as an homogeneity of this structure.

The same results are obtained by the curves of the spatial variation of the temperature along an axis passing through the surface pipe from end to end through the weld zone, Figure (9).

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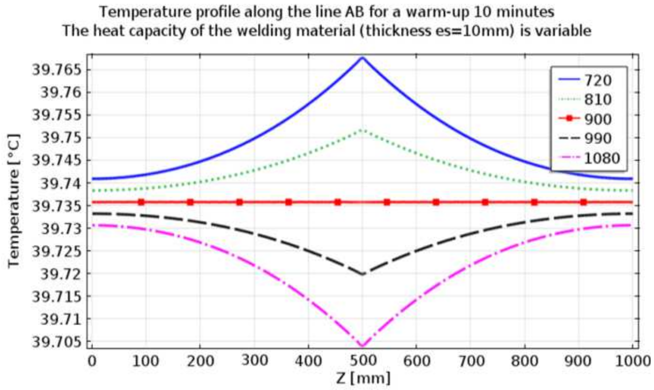

Fig. 9. *Temperature profile along the surface line AB for a warm-up 10min for 5 different values of heat capacity C_p: 720 – 810 – 900 – 990 and 1080 J/(kg.K)*

4.3 Effect of the thickness of the welding material

4.3.1 Thermophysical characteristics

The following table (Table 3) shows the thermophysical parameters used in this part.

Table 3. *The considered thermophysical parameters*

	Thermal conductivity k [W/m.K]	Density [Kg/m^3]	Heat capacity at constant pressure [J/Kg.K]
The aluminum tube	237	2700	900
The welding material	kal x (1+βx10%)	2700	Cpal x (1+βx10%)

4.3.2 Digital resolution

To illustrate the effect of the thickness of the welding material on the tube surface temperature, three different values of thickness e_s of the welding m aterial are chosen: 10 mm, 15 mm and 20 mm. The obtained temperature profile curves, figure 14, show that the more the thickness e_s of the welding material increases, the more the external surface temperature increases and the more the disturbed area temperature increases and vice versa.

But this time the temperature varies significantly and can reach for the studied cases the value of 0.3 degrees.

The obtained temperature profile curves, figure 15, show that the more the thickness e_s of the welding material increases, the more the external surface temperature decreases and vice versa. The detectability of the welded part becomes easier for a greater temperature difference between the healthy and the welded areas, which shows the greatest thickness welding.

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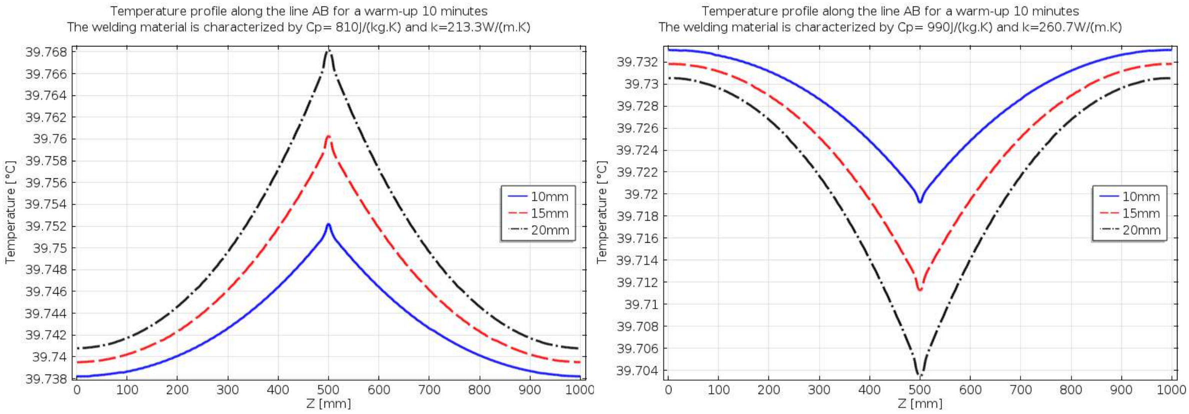

a) b)

Fig. 10.*Temperature profile along the surface line AB for a warm-up 10min*
a): *Effect of the thickness e_s (20mm, 15mm and 10mm) of the welding material C_p=810J/(kg.K) and k=213.3W/(m.K)*
b): *Effect of the thickness e_s (20mm, 15mm and 10mm) of the welding material C_p=990J/(kg.K) and k=260.7W/(m.K), for a warm-up 10min*

5. Conclusion

In this paper, we studied the evolution of the temperature on an aluminum tube welded in relation to several parameters (the effect of the thermal conductivity, the effect of the heat capacity and the effect of the thickness of welding material), this allows us to draw the following conclusions:

- The detectability of the part of the welding material becomes easier for a greater (or smaller) thermal conductivity of the welding material compared to that of the aluminum tube.
- The detectability of the part of the welding material becomes easier for a greater (or smaller) heat capacity of the welding material compared to that the aluminum tube.
- The detectability of the welded part becomes easier for a greater temperature difference between the healthy and the welded areas, which shows the greatest thickness welding.

REFERENCES

[1] J. Williams, S. Mansouri, S. Lee, Br. J. NDT(1980) 113-118.
[2] S. Belattar, Thèse de doctorat, juillet 1992, Faculté des Sciences II, Casablanca (Maroc).

[3] Krapez, J. C. Contribution à la caractérisation des défauts de type délaminage ou cavité par thermographie stimulée(Doctoral dissertation, PhD. Thesis, Ecole Centrale de Paris, (1991). Châtenay-Malabry, France).

[4] Procédés de soudage, Principes généraux et critères de choix Par Roland CAZES, Techniques de l'Ingénieur, traité Génie mécanique. http://www.techniques-ingenieur.fr/base-documentaire/mecanique-th7/assemblage-des-materiaux-par-souda
[5] Connaissances des aéronefs, Brevet d'initiation aéronautique. http://www2.ac-lille.fr/ciras/BIA/Cours_BIA/Connaisance_aeronefs/Connaissance_des_aeronefs
[6] Méthode des éléments finis, Hervé Oudin, Ecole Centrale Nantes, France, 28/09/2008
[7] Méthode des éléments finis, MEF, HERVÉ OUDIN. https://meefi.pedagogie.ec-nantes.fr/meef/pdf/poly-MEEFI.pdf
[8] H. S. Carslaw, J. C. Jaeger, "Conduction of heat in solids", 2nd Ed. 1959 (Oxford: Clarendon).