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## AN ORIGINAL METHOD TO ESTIMATE LOCAL THERMOPHYSICAL PROPERTIES AND LATENT HEAT FROM THERMAL FIELD MEASUREMENT (TFM)

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### ABSTRACT:

This paper presents an original method: (i) to estimate thermophysical properties (heat capacity  $C$  and thermal conductivity  $k$ ) and (ii) to experimentally validate heat source estimations. The method, called Thermal Field Measurements (TFM), is based on infrared thermal observations during cooling experiments in a same experimental setup. Results obtained with this method are in good agreement with other results published in literature. Only the homogeneous case is presented in this paper but a 1D heterogeneous case will also be presented in the conference.

### 1. INTRODUCTION

Infrared thermography is now widely used in experimental mechanics. Heat sources associated to temperature variations are often estimated from the heat diffusion equation [1]. However, such estimation from experimental data is not easy. Firstly, the knowledge of the thermophysical properties (heat capacity and thermal conductivity) of the studied material is a key point to quantitatively estimate heat sources. Secondly, few studies refer to experimental validation of the heat sources estimation [2]. In this paper, an original method, called TFM (Thermal Field Measurement), is proposed to study these two points. Experiments are based on the observation of the simultaneous natural cooling of two samples, a 'studied' and a 'reference' sample.

In this abstract, after the experimental setup presentation, the study is restricted to the heat capacity  $C$  estimation. Results are obtained on a Vanadium sample and compared to those obtained by Differential Scanning Calorimetry (DSC) and to literature values. Then, the validation of heat source estimation in a homogeneous case is proposed. The heat sources due to martensitic transformation occurring in NiTi shape memory alloy are estimated with the TFM method and compared to the DSC result.

The thermal conductivity  $k$  estimation and the validation of heat source estimations in a 1D heterogeneous case will be presented during the oral presentation.

### 2. EXPERIMENTAL SETUP

The goal of the experimental setup is to observe natural cooling of two thin samples cut into strips. Initially, the two samples were in a first climatic chamber at the temperature  $T_{ini}$ . Then, they were simultaneously inserted in a chamber at the temperature  $T_0$ . An infrared camera measured the two samples temperature during the cooling through a transparent infrared window. To obtain a homogeneous cooling (homogeneous case), small samples were cut and maintained with insulating wires (Fig 1.a). To obtain axially heterogeneous cooling in the 1D case, samples were longer and maintained with a thermal mass (Fig 1.b).

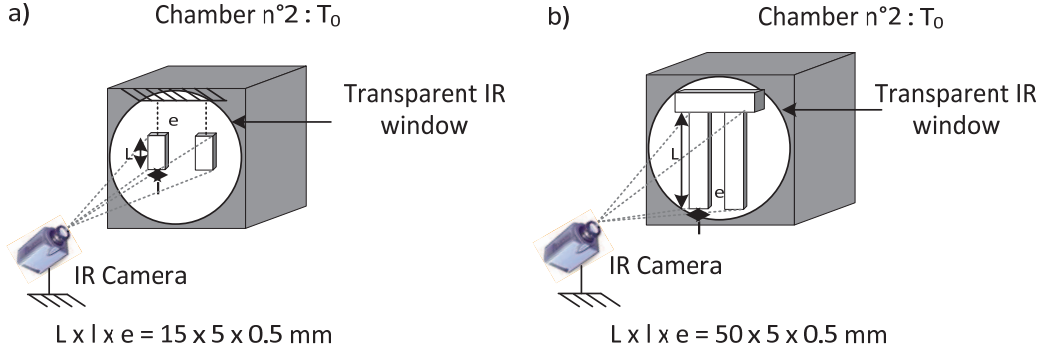


Figure 1: Experimental set-up proposed to obtain boundary conditions for (a) homogeneous and (b) heterogeneous cooling.

The first experimental configuration (Fig 1.a) allowed determining heat capacity of a materials and validating heat source estimation in a homogeneous case. The following results are obtained with this experimental configuration. The second configuration (Fig 1.b) allowed determining thermal conductivity of the material and validating heat source estimation in an axially heterogeneous case.

In this study, pure Titanium was chosen as ‘reference’ material. Vanadium has been chosen as ‘studied’ material to validate the proposed thermophysical estimation method. Then, the ‘studied’ material has been changed for a Ti – 50.2 at. % Ni to validate the heat source estimation method. Samples were covered with high emissivity paint.

### 3. ESTIMATION OF HEAT CAPACITY

This part is studying the TFM method ability to estimate the heat capacity  $C$ . The cooling curves of the Titanium and Vanadium samples in a homogeneous case are plotted in Fig 2.a. The temperature of the two samples started from  $T_{ini}=48^{\circ}\text{C}$  and finished at  $T_0=3^{\circ}\text{C}$ .

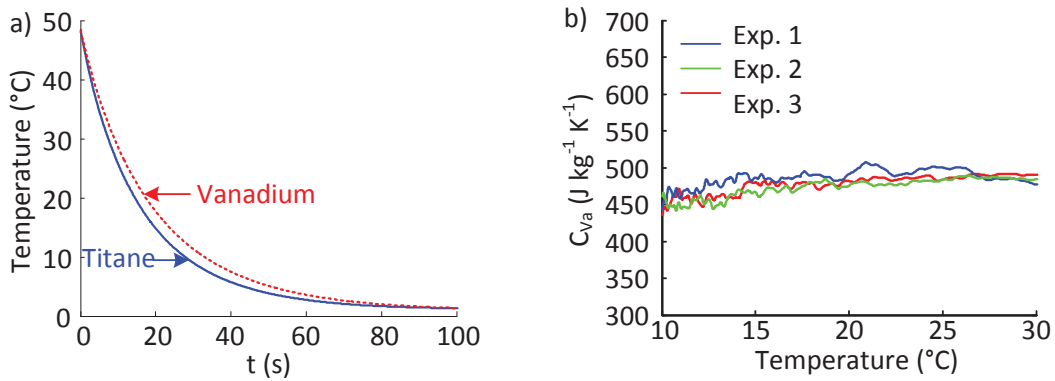


Figure 2: a) Homogeneous cooling curves of Titanium and Vanadium samples. b) Heat capacity of Vanadium estimated from TFM method.

The homogeneous heat diffusion equation [1, 2] can be expressed as:

$$C \frac{\partial T(t)}{\partial t} = \dot{q}(t) - \frac{f}{\rho e}, \quad (1)$$

where  $f$  is a “heat losses function”, including convection and radiation heat losses:

$$f = f_{conv} + f_{rad} = 2h(T - T_0) + 2\varepsilon\sigma(T^4 - T_0^4), \quad (2)$$

In this expression,  $h$  is the convection coefficient,  $T$  the sample temperature,  $\varepsilon$  the material emissivity and  $\sigma$  the Stephan-Boltzmann constant. The heat losses function  $f$  is independent of the material but is only dependent on the sample temperature and was estimated with the Titanium sample (‘reference’). Thus, as the heat sources were null during the experiments ( $\dot{q} = 0$ ), heat capacity of Vanadium (‘studied’ material) can be estimated by:

$$C_{Va} = \frac{\rho_{Ti} e_{Ti}}{\rho_{Va} e_{Va}} C_{Ti} \frac{\partial T_{Ti}}{\partial T_{Va}} \frac{\partial T_{Va}}{\partial t}. \quad (3)$$

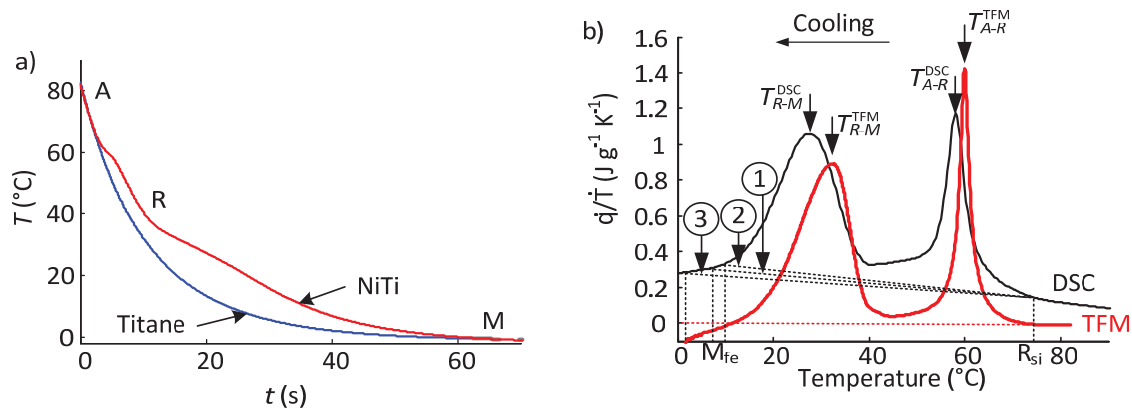
In this equation, the temporal derivatives are estimated at the same temperature.

Results obtained from the TFM method, for three different experiments, are plotted in Fig. 2.b. Heat capacity of Vanadium was estimated to  $C_{Va}^{TFM}=480 \pm 30 \text{ J kg}^{-1} \text{ K}^{-1}$  with the TFM method which is in good agreement with those

obtained from classical DSC on the same material  $C_{Va}^{DSC}=480\pm 40 \text{ J kg}^{-1} \text{ K}^{-1}$ , and from the literature results  $C_{Va}^{lit}=480 - 520 \text{ J kg}^{-1} \text{ K}^{-1}$ .

#### 4. VALIDATION OF THE HEAT SOURCES METHOD

This part presents an experimental validation of the heat source estimation proposed in [1] and partially presented in [2]. Figure 3.a shows the cooling curves of the Titanium and NiTi sample. The temperature of the two samples started from  $T_{ini}=80^\circ\text{C}$  and finished at  $T_0=1^\circ\text{C}$ . In the NiTi curves, two bumps, due to exothermic transformation from Austenite to R-phase to Martensite were observed.



Figure

3: a) Homogeneous cooling curves of Titanium and NiTi samples. b) Ratio  $\left(\frac{\dot{q}}{\dot{T}}\right)$  obtained with TFM method and DSC.

Once again, the Titanium sample was used to estimate the heat loss function during the experiment. Heat sources  $\dot{q}$ , generated by the NiTi, were estimated from the NiTi curve. Heat sources were divided by  $\dot{T}$  so that the results are independent from the cooling rate. Finally, the  $\frac{\dot{q}}{\dot{T}}$  ratio is plotted as a function of the temperature in Fig. 3.b. The  $\frac{\dot{q}}{\dot{T}}$  ratios obtained either by TFM or by DSC (which is the classical method to estimate heat or cooling rate during martensitic transformation) are compared. The two techniques are quantitatively in good agreement. Transformation temperatures ranges are similar with the two techniques. Peak temperature  $T_{A-R}$  and  $T_{R-M}$ , obtained with the two techniques, are almost identical. The difference can be explained by the accuracy of the IR camera,  $\pm 2^\circ\text{C}$ , and by DSC inertia [3]. Amplitude of the peaks with the two techniques is quantitatively in good agreement. The TFM technique is thus validated in the 0D thermal approach in the case of heat source estimations.

#### 5. CONCLUSION

The TFM method proposed is based on the observation of the simultaneous cooling of two samples. Firstly, in a homogeneous case, the TFM has been proved able to provide a measurement of the material heat capacity  $C$ : this method was used to study Vanadium heat capacity. Results obtained from TFM techniques are in good agreement with those obtained by classical DSC and those given in the literature. Secondly, the TFM technique also allows validating experimentally heat source estimation. Heat sources released by a NiTi sample during cooling have been estimated and are in good agreement with those obtained by DSC.

Adapted to an axially thermally heterogeneous case, the TFM method also allows to estimate material thermal conductivity  $k$  and to experimentally validate heat source estimation when conductivity occurs in the material. This last part will be presented during the oral presentation.

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