Towards developing a calibration technique to apply TSA with micro-bolometers

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Introduction

The Thermoelastic Stress Analysis (TSA) method is widely-known [1, 2] and usually performed with photon detectors to detect defects and damage and obtain the stress field. This paper presents the work performed on developing the TSA technique using micro-bolometers on homogeneous materials to replace expensive and common infrared (IR) photon detectors. There are examples of bolometers used in TSA [3-5] and they showed the need of applying corrections to obtain quantitative TSA measurements. This paper presents the development of a calibration technique for micro-bolometers in TSA to obtain accurate results. It was analysed for homogeneous materials, but it will be studied for composite materials.

Methodology

The TSA method consists of measuring changes of temperature with a thermal camera which occurs in an elastic solid due to change in stress or strain by applying cyclic loading. It is based on the thermoelastic effect that relates the thermal energy with the mechanical deformation of an elastic solid and it is reversible under adiabatic conditions. Lock-in process [6] is needed to extract the temperature change (ΔT) from a cyclic load and the temperature change is related to the sum of the change in the principal surface stress [4] by:

$$\Delta \mathrm{T} = -\frac{\mathrm{T}_0}{\rho \mathrm{C}_\mathrm{p}}(\alpha_1 \Delta\sigma 1 + \alpha_2 \Delta\sigma_2) \quad (1)$$

where ΔT is the temperature change, T_0 is the reference temperature, α is the coefficient of linear expansion, $\Delta\sigma$ is the change in stress in the principal directions 1 and 2, C_p is the specific heat capacity at constant pressure and ρ is the material density.

Two types of detectors are used: photon detector (FLIR SC5000), which converts the absorbed photons of energy into a change of the electronic energy distribution in an integration capacitator, and a bolometer (FLIR A655SC), which is a specific kind of thermal resistor (Vanadium Oxide - VOx) where the absorbed IR radiation changes rises the temperature of the sensor that is converted to an electrical signal by means of an electrical resistance [7]. The main difference between the photon detector and the bolometer is the time response, which depends on the integration time (10 - 20,000 µs) for the photon detector and the thermal time constant (8 ms) for the bolometer. The time response of the former is the same as the integration time, is instantaneous and variable, but, for the latter is at least 24 ms (3 x thermal time constant) to obtain an accurate result.

Results and Discussion

In this section, the study of the bolometer performance is presented. To do so, two specimens of aluminium and 316L stainless steel have been used. The thermoelastic constants [8, 9], dimensions and loading cases considered for both coupons are shown in Table 1. The TSA tests were performed by predicting three cases of temperature change ΔT i.e. 50, 80 and 100 mK.

Coupon	Thermoelastic constant (MPa^{-1})	Dimensions			Loading			
		Length (mm)	Width (mm)	Thickness (mm)	Mean (kN)	Amplitude 1 (kN)	Amplitude 2 (kN)	Amplitude 3 (kN)
Aluminium	$9.5\cdot10^{-6}$	50	150	6	2	0.81	1.30	1.62
316L stainless steel	$4.6\cdot10^{-6}$	237	30	2	3	1.12	1.79	2.24
					Predicted ΔT (mK)	**50**	**80**	**100**

Table 1 Samples description

Different tests were performed by changing the frame rate, loading amplitude and loading frequency to see the effect of each parameter on the measurement of the bolometer for TSA. Figure 1a shows the ratio between the measured over the predicted temperature change so that all the loading cases results can be compared. An attenuation in amplitude of the bolometer measurements is showing when the loading frequency rises. This is due to the thermal time constant [10], which is a property fixed by the sensor material and it determines the time the sensor needs to respond to a change in temperature. The attenuation only depends on the loading frequency, not on the frame rate, loading amplitude or material as seen in Figure 1a, the bolometer acts as a low-pass filter [11, 12]. Therefore, a calibration technique can be developed and it will only depend on the loading frequency. It has been obtained by dividing the temperature predicted over the temperature measured. By performing the natural logarithm of the calibration parameter as shown in Figure 1b and plotting it versus the loading frequency, the calibration is linear.

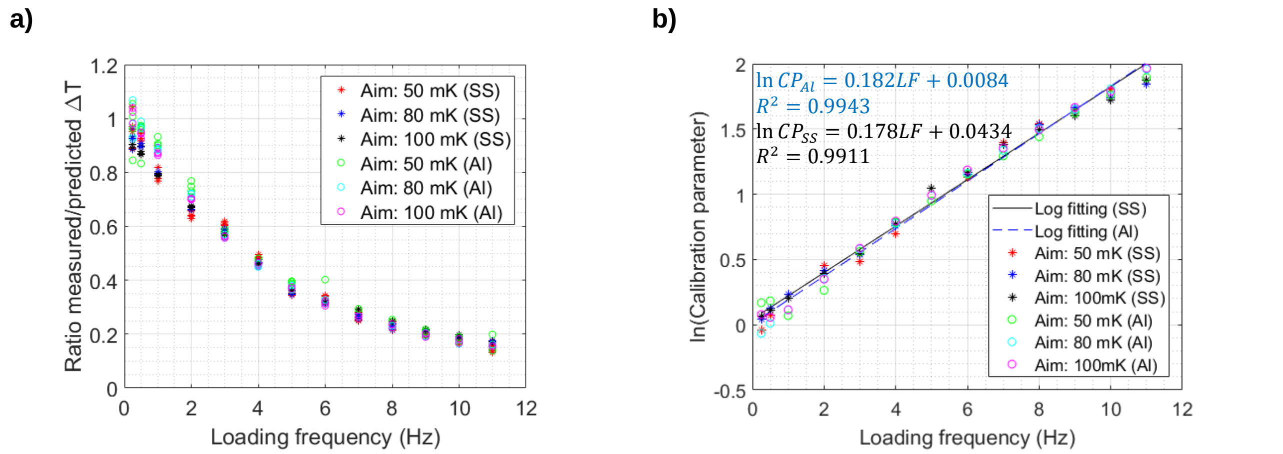

Figure 1 a) Temperature change normalised for all the experiments, b) Calibration technique for 50 Hz frame rate

Conclusions and Future Work

It has been seen that the bolometer acts as a low-pass filter by attenuating the amplitude when the loading frequency increases. The frame rate, loading amplitude and material do not affect the measurement of the temperature change. Therefore, a calibration technique is introduced and it only depends on the loading frequency. The natural logarithm of the calibration parameter versus the loading frequency is linear. This technique will be validated for composite materials. Tests considering unidirectional specimens will be performed following the same procedure as the tests with aluminium and stainless steel samples.

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