Cabability of the Thermoelastic Phase Analysis method for studying damage evolution of GFRP composites

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Abstract. Thermoelastic Stress Analysis represents a powerful instrument to investigate both the damage behaviour and fatigue characterisation of the materials, capable to reduce the experimental campaign from time and economic points of view.

In this work, in particular, Thermoealstic Phase Analysis method is adopted for determining damage evolution in GFRP plied-up composites in order to determine the behaviour of stitched yarns and bulk. Furtherly, the phase data provided by the method will be used for estimating endurance limit of the material.

Introduction

Based on InfraRed Thermography, the Thermoealstic Stress Analysis (TSA) is the well-known full-field, contactless, non-destructive technique which allows researchers to study the stress field of material undergoing dynamic loading by detecting surface radiometric temperature (thermoelastic effect) [1-4] in case adiabatic condition are achieved.

The potential of TSA is presented in [5], [6], for the identification of small size damaged areas in composites.

In the work of Emery [5], has been demonstrated that the inner damage mechanisms of material produce a redistribution of external strains/stresses with consequent stiffness degradation, while Palumbo et al [7] discussed the loss of adiabatic conditions in the through-the-thickness direction of GFRP composite, leading to a thermoelastic signal variation.

The aim of this work is to show the capability of Thermoelastic Phase Analysis method to:

• Study the damage behaviour of GFRP composite material

• Assess an estimation of the endurance limit of the GFRP material.

The loading procedure [8] provides the cyclic loading applied on three flat specimens sized according to Standard [9]. The setup for thermographic tests is represented in fig.1.

Figure1: Experimental set-up adopted for thermographic tests.

Methods, Results & Discussion. The model adopted for processing thermographic data in the frequency domain, is described by equation (1):

$$S_m(t)= S_0+ at+S_1\sin(\omega t+\varphi) \qquad (1)$$

where the term (S_0 + at) is the mean temperature growth in the test, ω is angular frequency of the imposed load, S1and φ are respectively the amplitude and phase of thermoelastic signal. IRTA® software integrates the Equation (1), provides φ parameter maps.

The analysis of phase shift involves the reduction of the thermographic scenario to a matrix of the gage length of sample, and, the extraction of the value of standard deviation (SDi) from each matrix.

Figure 2a represents the values of phase standard deviations (SDi) for a specimen in the three Sub-steps. The values are perfectly reproducible, this allows author to consider a fatigue test time reduced.

The phase maps for a sample at three stress levels, present an ordered pattern of horizontal stripes, figure 2b, that is, very likely related to the morphology of the fabric of the surface lamina. Generally, it was observed an increase of phase signal in correspondence of the stitched thermoplastic yarns used. Positive values of phase in correspondence of yarns owing to a possible through-the-thickness heat leakage between the stitches. This phenomenon generates high temperature gradients, hence a loss of adiabatic conditions.

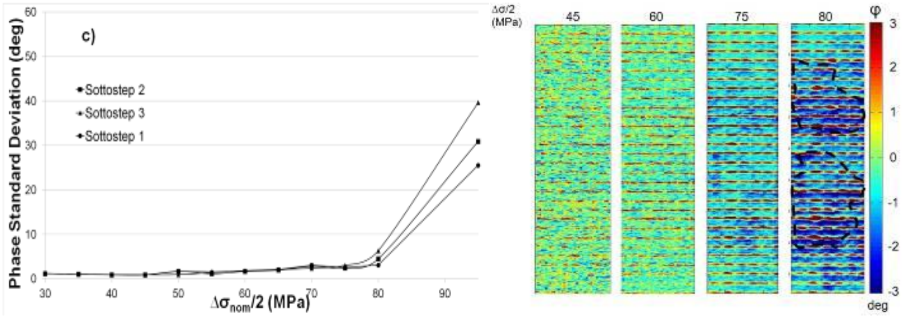

Figure 2: Sample 3: (a) Phase Standard Deviation parameter in three sub-steps, (b) phase maps.

To determine the endurance limit of the material, the slope of the standard deviation of phase data series has been calculated with a zero-threshold assumed as reference to evaluate data. The results are reported in Table 1. The reference value is 56.20 MPa (stress semi-amplitude) and refers to S-N curves (run-out limit of 2*10^6 cycles).

Phase Standard Deviation [MPa]			
Sample	Loading Sub-step1	Loading Sub-step2	Loading Sub-step3
1	50.00	50.00	50.00
2	55.00	55.00	55.00
3	45.00	45.00	46.67
4	55.00	50.00	51.67
5	60.00	55.00	56.67
Average	52.00 (std.dev 4.14)		

Table 1. Results of fatigue limit evaluation for each sample.

Conclusions. In this work, thermoelastic phase analysis as proposed as a method to study both fatigue behaviour and damage behaviour of GFRP composite materials. The main outcomes of the activities are:

- the capability of Standard Deviation of the phase signal as parameter to describe the fatigue damage in GFRP materials,
- the reproducibility of phase data curves sub-steps, which allows reducing testing time,
- the good agreement of phase data results with those provided by the conventional S-N curve.

Moreover, as demonstrated for metals phase signal provides local and more detailed information about the damaged areas.

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