



Material enabled thermography

F. Pinto, F.Y. Maroun, M. Meo*

Department of Mechanical Engineering, University of Bath, UK

ARTICLE INFO

Article history:

Received 22 October 2013

Received in revised form

9 June 2014

Accepted 11 June 2014

Available online 19 June 2014

Keywords:

Thermography

Delamination

Composites

ABSTRACT

This paper is focused on the analysis of a novel structural health monitoring technique based on the inclusion of a thermoresistive network within the structure of a traditional CFRP laminate. By exploiting the thermoelectrical properties of shape memory alloys (SMA) it is possible to employ them as an embedded heat source to rapidly identify the presence of internal defects in composite structures by monitoring the time history of the superficial thermal contrast. The sensitivity of the methodology was evaluated by testing several samples characterised by embedded defects in different positions and with different sizes, together with an analysis of the effect of the position of the SMA grid and the intensity of the feeding current. The results obtained were compared with traditional NDT inspections such as ultrasonic C-Scan and Shearography and showed that material-enabled thermography is able to give results comparable with other techniques, saving inspection time and reducing the total costs of the analysis. In addition, because the only requirements for the test are the presence of an embedded heat source and simple electrical contacts, the inspection does not need any external heaters, therefore it is possible to rapidly monitor the health status of complex parts without dismounting them from the structure.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

The rapid development of composite materials during the last two decades has underlined the necessity for new materials characterised by improved mechanical properties in order to extend their fields of applications. However, one of the most severe disadvantages of composite structures is constituted by the weak interfacial strength between the laminae under compressive loads which makes them sensible to impact damage, thus leading to the generation of barely visible impact damage (BVID), microcracks and delaminations.

Over the past years, a considerable amount of research has been devoted to evaluate an effective solution to this issue, aimed towards the improvement of the impact resistance of composite structures [1–3]. According to the literature, this can be achieved following different approaches, depending on the typology of intervention on the material structure. A first approach consists in the modification of one of the components of the material in order to increase its specific properties, reducing its weaknesses, thus improving the compatibility between the different phases that form the composite structure. Strengthen mechanisms such as matrix toughening [4], interface toughening [5] and fibres surface modification [6] belong to this category as they operate

by increasing the properties of one or more existing phases within the material structure.

On the other hand, a different approach involves the hybridisation of the composite laminate through the embodiment of an additional engineered component characterised by specific functions, in order to exploit them to improve the impact resistance without affecting the other (desirable and needed) mechanical properties. Hybrid materials reinforced with several engineered phases (such as hollow fibres [7], single and multi-walled carbon nanotubes [8,9], graphene nanolayers and through-the-thickness reinforcements [2]) have been studied extensively during the last decade in order to evaluate how they can enhance the impact resistance of traditional laminates, showing good results in terms of energy absorption rate and structural vibrations damping.

Based on these considerations and following a similar methodology, impact properties can also be improved by embedding shape memory alloys (SMA) wires within a traditional laminate in order to exploit their unique properties (superelasticity [10] and shape memory effect [11]), to reduce the extent of the internal delamination caused by low velocity impacts. These particular properties rise from the transitions between two different crystalline structures (martensite and austenite) that can be activated by applying temperature gradients or loading the material with an external force.

Several studies have been focused on the analysis of the enhanced mechanical properties of SMA based composites, and a comprehensive review has been carried out by Angioni et al. [12].

* Corresponding author.

E-mail addresses: m.meo@bath.ac.uk, michele.meo@gmail.com (M. Meo).

However to this date, only few works have been focused on the possibility to exploit the presence of the internal network of SMA to enable additional non-structural functions for structural health monitoring (SHM).

Hideki et al. [13] demonstrated that SMA can be used to evaluate the amount of damage in a hybridised GFRP by measuring the variation of the electrical resistance of embedded NiTi wires. The correlation between strain and electrical resistance variation for strain sensing is also the main objective of the work made by Cui et al. [14] who demonstrated that for the purpose of strain sensing the material must be in its martensitic form so that this relationship is linear and independent from temperature. Localisation of the damaged areas and extent of the internal strain distribution was also evaluated by Oishi et al. [15] who analysed the acoustic emission signals generated from the austenite/martensite transformation.

Among the existing damage detection methods, active infrared thermography (IRT) represents one of the most promising non-destructive techniques, being able to detect subsurface defects for a wide variety of structural materials, including metals and composite media [16]. Contrary to passive thermography (which is based on the analysis of materials that are naturally at higher temperature than ambient), in the active approach an external stimulation is used to induce relevant temperature gradients that are recorded using an infrared camera, providing information regarding the integrity of structural components.

Indeed, as the presence of defects reduces locally the heat diffusion rate, when the surface temperature is analysed, damaged locations appears as areas of higher temperature than the rest of the sample [17,18]. As a consequence, the thermal contrast can be used to locate invisible defects embedded within the material and measure their extent. Thermography can detect cracks in Glass Fibre Reinforced Plastics (GFRP) composites and it has been also proved to give good results in detecting voids, inclusions, and impact damage in Carbon Fibre Reinforced Plastics (CFRP) laminates [19]. However, some cracks could pass as undetected in case they are aligned parallel to the direction of heat flow.

The efficiency of the technique is strongly dependent on the way the thermal solicitation is given to the sample, being able to affect its feasibility and resolution. Indeed, according to the thermal stimulation, it is possible to identify three different kinds of thermographic inspection: pulses of light/heat in pulse thermography (PT), continuous heating (long pulse) in step heating thermography (SHT), and a sinusoidal heat wave in lock-in thermography (LT). Nonetheless, all the above mentioned techniques require the use external heat sources such as infrared radiators or high-power photographic flashes, which makes them unsuitable for in situ aerospace applications as they require each part to be dismantled from the structure in order to set-up the heaters and proceed with the inspection.

The aim of this work is the analysis of a novel technique based on the use of SMA hybrid composites for in-situ NDT/SHM analysis of aerospace structures. The method combines the multi-physical properties of SMA composites with the benefits of thermal analysis, being able to guarantee the autonomous inspection of complex parts without the needs for expensive external heating devices. Indeed, the heat wave generated by a current passing through the internal SMA network will be delayed due to the presence of an internal damage, causing a difference in the apparent temperature on the sample's surface that is detected and captured using a thermal IR-camera (see Fig. 1).

Samples characterised by different geometries were manufactured and investigated via in-situ thermography and the feasibility of the technique was analysed by detecting the presence of delaminations embedded at different depths and with different extents. A comparison with traditional NDT techniques such as C-Scan and

shearography was carried out in order to analyse the advantages and disadvantages of the material enabled thermography.

2. Samples manufacturing and experimental set-up

Different samples were manufactured in order to validate the material-enabled thermography as an appropriate technique to be used as an in situ NDT/SHM system. The samples were manufactured using different configurations of SMA network, damage dimensions and specimens geometry.

Sample I was manufactured by laying-up 10 layers of T700 UD carbon fibres prepreg (Airtech, UK) following a $[0^\circ, 90^\circ]_n$ stacking sequence. A network of 6 SMA wires was embedded between the third and fourth prepreg layers, with an inter-wire distance of 10 mm. In order to simulate the presence of an internal delamination, three squared Polytetrafluoroethylene (PTFE) patches characterised by different dimensions were included into the lamination sequence between the seventh and the eighth layers. As the presence of these patches locally hinders the reticulation of the polymeric chains during the curing reaction, the inclusion of Teflon inserts is a well-known technique to introduce artificial delaminations in a laminate structure, as reported in literature [20–22].

The dimensions of the patches used for Sample I are as follows: PTFE 1 ($20 \times 20 \text{ mm}^2$), PTFE 2 ($10 \times 10 \text{ mm}^2$) and PTFE 3 ($5 \times 5 \text{ mm}^2$). Fig. 2 shows a schematic layout of the sample.

The dependence of the position of the SMA network on the technique resolution was investigated by analysing the superficial response of the same PTFE patch recorded using two different SMA wires embedded at different depths within the laminate's thickness (Sample II) as heating source (Fig. 3).

Moreover, in order to analyse the effect on the thermal response of defects located at different positions along the z-axis, a third samples (labelled Sample III) was manufactured including two different PTFE patches in a 20 layers laminate. In particular, PTFE 1 was placed closer to the SMA network (between the 8th and 9th layers) while PTFE 2 was positioned closer to the top surface of the sample (between the 17th and 18th layers). Details of Sample III are presented in Fig. 4.

Because of the presence of an embedded heat source within the laminate's structure, one of the biggest advantages of SMA enabled thermography over the traditional techniques is that structures characterised by complex geometries can be easily scanned without dismantling them to expose their surfaces to the heaters. This was validated by manufacturing Sample IV in the shape of a wing leading edge section ($[0, 90]_{10}$) and using two squared PTFE patches ($10 \times 10 \text{ mm}^2$) embedded between the 17th and 18th layers as artificial defects (see Fig. 5).

Fig. 6 illustrates the experimental setup used to test the SMA enabled thermography. An electric current is passed through the wires for a period t of 3 s, heating up the samples via Joule effect. In order to guarantee an even distribution of the currents through the SMA network and a continuous thermal stimulation across the entire specimen, the wires were connected with a series of potentiometers on a circuit board fed through a power supply unit. Each SMA wire is plugged into a connector where a variable resistor regulates the amount of passing current. A series of switches determine the number of active SMA wires, depending on the resolution required from the test.

Thermal images were captured using an electrically cooled IR camera (CEDIP) with a resolution of 320×240 pixel (width $\times$ height), maximum frame rate up to 150 Hz and a temperature sensitivity of 30 mK. All tests were conducted at ambient settings (25 °C). Step Heating Thermography (SHT) was the adopted technique used

Download English Version:

<https://daneshyari.com/en/article/6758428>

Download Persian Version:

<https://daneshyari.com/article/6758428>

[Daneshyari.com](https://daneshyari.com)