CONTROL OF COMPOSITE FATIGUE DAMAGE EVOLUTION USING INFRARED THERMOGRAPHY AND THERMOELASTIC STRESS ANALYSIS

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ABSTRACT

It has been shown that as damage grows within a composite material during fatigue loading, there is a local temperature increase that can be measured with an infrared (IR) detector [1]. The possibility of controlling the rate of damage evolution during a test using infrared thermography (IRT) is investigated. To control damage evolution rate, the IR response (i.e. temperature change) associated with material damage must be defined and measured, before a control methodology can be developed.

Unlike the point or local monitoring achieved by strain gauges, IRT is a full-field technique which can be used to monitor the whole test specimen. The ability to monitor full-field is essential when considering unnotched composite specimens, where the damage initiation point is not known. The material damage type and the corresponding temperature evolution must be identified, characterised and quantified, before a control methodology can be developed. The specimen temperature evolution during damage progression is sufficient to be detected using IRT, however to identify the damage type further information is required. Therefore, during initial studies a technique known as thermoelastic stress analysis (TSA) [2] is applied to provide more data, to assist the identification of the damage type and link to the IRT measured temperature changes [3]. The thermoelastic response is proportional to stresses and enables the stress redistribution due to damage to be visualised and quantified. When capturing IR images during a fatigue test, it is also possible to post-process the images and apply TSA. The surface temperature captured in the IR images can then be directly compared with the damage type identified by the TSA to provide the specimen temperature change at which a certain damage type occurs.

The results of a series of tests conducted to establish the relationship between the recorded temperature change and damage condition in composite materials are described. Two types of glass reinforced epoxy specimens are studied with layup $(0, 90)_{3S}$ and $(+/-45)_{3S}$ under fatigue loading. A layup of $(0/90)_{3S}$ was prepared, from which on-axis specimens were used, generating progressive defects through the fatigue cycle, i.e. matrix cracking, longitudinal splitting, delamination and finally fibre breakage. The second type of specimens were cut at 45 ° to the fibre directions, in order to generate internal shear damage. The specimens were fatigue tested to failure under a sinusoidal, force-controlled loading, at a load ratio of R=0.1, during which the temperature was mapped and recorded. A comparison between the IRT and TSA results from the $(0/90)_{3S}$ specimen can be seen in Figures 1-4. Subsurface matrix cracking in the 90 ° plies, was seen from the first images taken at 1000 cycles. Figure 1, shows the more defined cracks at 20,000 cycles. Figure 2, has the first indication of longitudinal splitting of the surface 0 ° plies at 60,000 cycles. At 91,000 cycles, surface, 0 ° fibre breakage occurred and can be seen in Figure 3. Figure 4 represents the TSA response for a delamination, at 132,000 cycles.

It has been shown that IRT can be used to monitor some types of damage evolution in a composite material, allowing the temperature increase rate, or area increase rate to be controlled. It should be noted that the damage type was not detectable by IRT alone, requiring the use of TSA to reveal the damage state. Therefore the relationship between the IR data and the TSA needs to be established, with further investigations using X-ray computed tomography, to identify, characterise and quantify the damage type and its severity. A relationship will be established between the change in surface temperature and the damage type, using the temperature plots shown in Figures 1-4.

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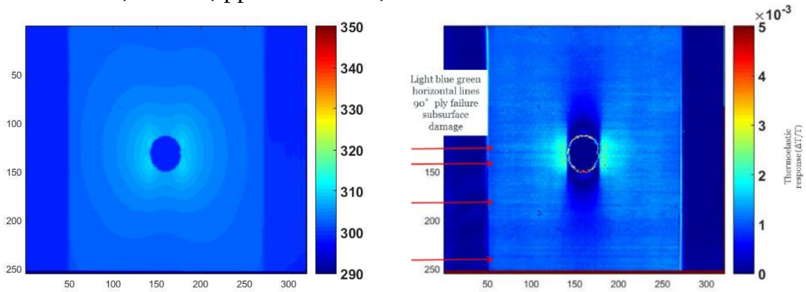

Figure 1. IRT response and TSA identification of matrix cracking at 20,000 cycles

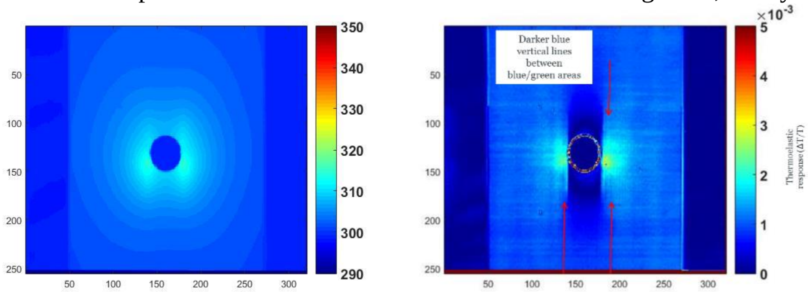

Figure 2. IRT response and TSA identification of longitudinal splitting at 60,000 cycles

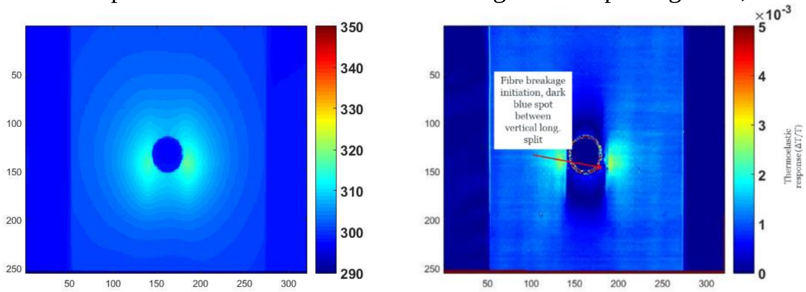

Figure 3. IRT response and TSA identification of fibre breakage at 91,000 cycles

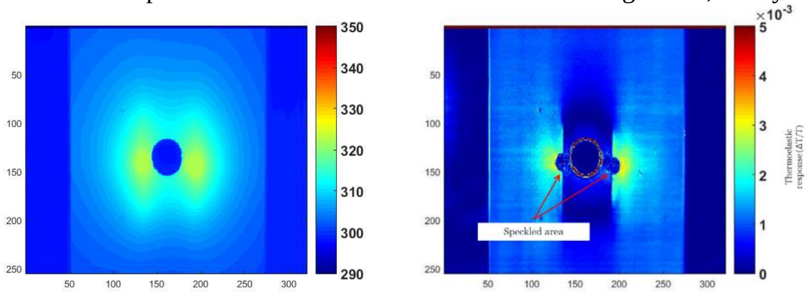

Figure 4. IRT response and TSA identification of delamination at 132,000 cycles