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Failure identification in composite materials using Thermographics method

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A R T I C L E I N F O

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A B S T R A C T

This research gives an overview of an investigation into existing non-destructive testing (NDT) methods used to analyse composite materials. From the investigation and subsequent experimentation a new technique of failure identification in composite materials was developed. The new technique is a form of thermography whereby a temperature rise in a composite material during failure is detected via a thermal camera and a thermal image captured. By observing the thermal images captured of the event the location and the severity of the failure could be gained by only using the thermal images combined with a visual inspection to validate the results. By taking a thermal image and analysing the constituent red, green and blue colours that make up the image, the location of the defect could be pinpointed. This analysis method was developed using MATLAB® in order for the location of a defect to be found using only a thermal image of the composite during failure. The analysis showed that the information that yields the most accurate location of failure was the red part of the images.

1. Introduction

Composite materials are now widely used in industry as a standard material; this is often due to their low weight and high relative strength. Many components, machines and vehicles are now made from primarily composite materials. This combined with the higher cost of composite materials when compared to metals has led to the need for identifying defects within composite parts without damaging them, this allows for routine maintenance to be carried out on parts without affecting their working life. The simplest form of non-destructive testing (NDT) is a visual inspection of parts; this method does not often work for composite defect identification due to the main reinforcing structure being within the material. This means that more advanced NDT methods need to be employed to look within the parts for defects and failures.

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Typically non-destructive testing methods have been developed for use on metal, plastic and ceramic structures (Farley 1987) where used in many different applications such as fatigue crack (Fayro et.al 2001). Some of these existing methods can be used for composite material inspection such as vibro-thermography (Pieczonka et.al 2010) and (Holland 2011) however, not all NDT methods can be used in composite materials. The most common NDT methods used for composite testing are radiography and ultrasound testing; these have been used because the method of testing is non-invasive and requires no adaptation in order to be applied to composite materials. These NDT methods are either costly or the output data that is difficult to understand without vigorous data processing techniques or a skilled operator. Also, some of the simpler and cheaper NDT methods have yet to be used in composite defect identification. It was speculated that a new non-destructive testing method could be developed or currently used methods could be adapted for use specifically with composite materials. The ideal final outcome of this project is to have a non-destructive testing method that can be used in industry for the identification of defects within composite materials. During research it was deduced that active thermographic testing methods would be investigated further.

2. Active Thermography

2.1 Principles of active thermography

'Active thermography is defined as applying a stimulus to a target to cause the target to heat or cool in such a way as to allow characteristics of the target to be observed when viewed by thermal imagery' (Sharlon 2008).

The stimulus applied to a target or specimen can be theoretically anything that increases or decreases the temperature of the specimen (Haj-Ali et al. 2008), this could be directly heating, cooling the object or stressing it. This temperature change can be used to find certain characteristics of the specimen. Generally this temperature change is documented using a thermal imager and camera.

Active thermography can also be split into two types, simple and complex. The simple thermography approach is to apply heat to the specimen and document the change in temperature (ΔT) across its surface. The more complex method of active thermography usually involves looking at the temperature change over related to a changing variable (e.g. time or intensity of heating/cooling).

Simple active thermography methods are normally very quick and can gain repeatable results. More complex approaches can be costly and time consuming but can obtain more detailed information about the test specimen. Due to their cost and the increased time to run the tests complex methods are normally less repeatable than simple methods.

2.2 Lock-in thermography

The thermoelastic effect can be used to calculate the expected rise in temperature of a specimen under certain ideal conditions. If adiabatic conditions prevail it is equal to the sum of the principle stresses. By assuming that convection is negligible, external heat sources are independent, density and specific heat are material constants and that the material is isotropic from a heat conduction view then the total heat change equation can be seen in Eq.1.

$$\rho C(\Delta T) = S_{the}, \tag{1}$$

where ρ= Density, C= Specific heat, ΔT = Temperature variation and S_{the} = Thermoelastic energy. For a linear isotropic material, under plane stress, Eq. 2 can calculate the thermoelastic energy.

$$S_{the} = -\alpha T_0 \sigma, \tag{2}$$

where α= Thermal expansion coefficient, T_0= Original specimen temperature and σ= Sum of principle stresses. Lock-in thermography can also be used to find the depth and geometry of defects from the temperature distribution (Zoecke et al. 2010).

2.3 Thermo-elastic stress analysis thermography (TSA)

This thermographic technique is classed as an active complex Infra-Red technique. The theory behind this is the thermoelastic affect, which states that an object will experience a change in temperature when placed under elastic adiabatic load. When an object is compressed there is an increase in temperature, when it is stretched the temperature decreases. Kelvin's relation, as seen in Eq. 3, can be used to approximate the temperature change.

$$\frac{\Delta T}{T_0} = -(\frac{\alpha}{\rho C})\sigma , \quad (3)$$

Typically during testing a sample is stressed in a cyclic pattern and the resulting thermal pattern is observed via thermal imaging techniques. This cyclic stressing can take form of a sinusoidal pressure change across the specimen's test surface. An example test diagram can be seen in Fig. 1. This type of testing is often used in the evaluation of materials and components during manufacture in the situ stage. During manufacture some components are pre-stressed to increase the components resistance to cracking. During this process the components can weaken leading to early failure of the component.

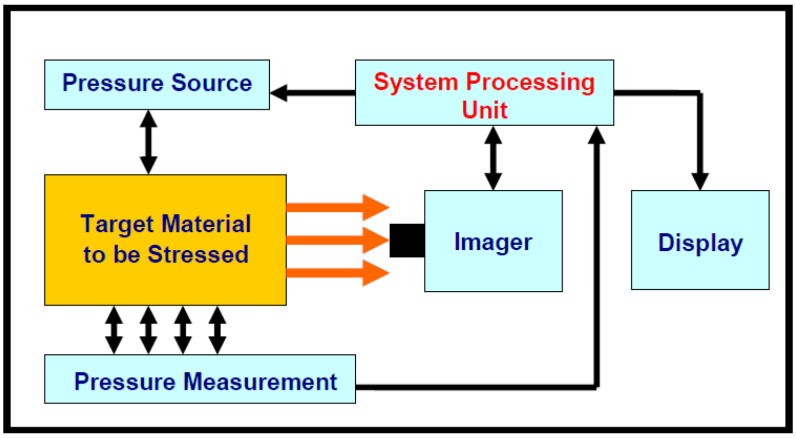


Fig. 1. Example of stress analysis test

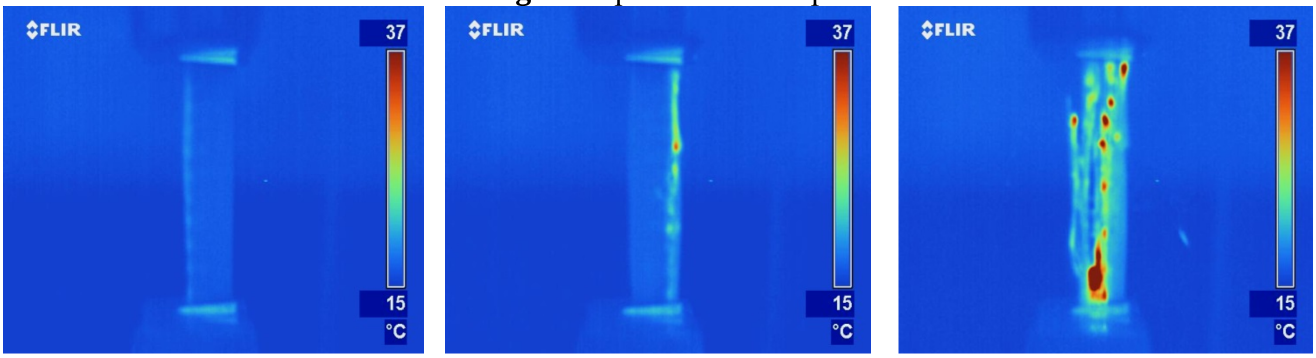
3. Initial testing

From the research into thermographic testing methods it was theorised that a composite part would heat up during failure. A small, uni-directional fibreglass composite samples, of width 20mm, height 80mm and thickness 1mm was strained using an automated tensile testing machine. The samples were tested to full destruction, meaning until it completely split in the horizontal axis, and a thermal camera was used to capture the temperature changes in the samples during their failure. The camera used for the testing was a FLIR system ThermaCAM P25. The testing setup can be seen in Fig. 2. Each sample was strained at a rate of 1mm/minute.

3.1. Test results

The thermal images of the sample upon failure can be seen in Fig. 3. It can be seen by looking at the images that there was indeed a temperature change in the sample upon failure. By looking at the thermal images captured and identifying the areas of heating on the actual sample, it was observed that the heating effect corresponded with the failure location. The failure location was easily identifiable in the composite structures as it was a single laminate (layered) structure.

Fig. 2. Experimental setup



(a) (b) (c)

Fig. 3. Thermal images upon failure

4. Further testing

The previous test proved that there is indeed a heating induced in a composite sample when failure occurs. However the samples used were identical and simplistic in their structure, being only made from single layer uni-directional fibres. The second set of thermal testing tested five different fibreglass samples of varying internal structure. The differences in the samples are described in Table 1 and the internal structure of the different samples can be seen in Fig. 4. The testing method was exactly the same as previously with the setup seen in Fig. 2.

Table 1
Sample characteristics

Sample number	Width (mm)	Height (mm)	Sample characteristics Thickness(mm)	Structure
Sample 1	24	170	0.6	Random cut fiber
Sample 2	25	160	0.6	Fine multi-directional
Sample 3	25	135	1	Medium multi- directional
Sample 4	27	120	1.2	Large multi- directional
Sample 5	26	255	2.3	Triple layer uni-directional

Fig. 4. Sample structure, descending order, sample 1, 2, 3, 4 and 5

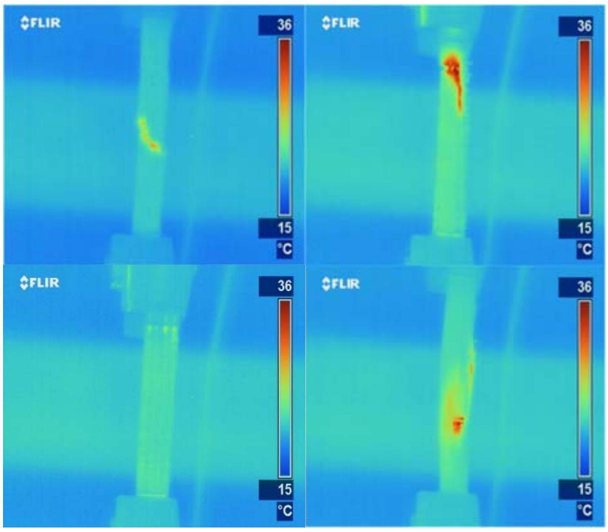


Fig. 5. Testing results, top left: sample 1, top right: sample 3, bottom left: sample 4, bottom right: sample 5

4.1. Results

Again, as with the previous thermal testing, thermal emissions were detected from the sample upon failure. Sample 2 did not yield any useable results upon failure however all other samples did. The captured thermal images of said samples can be seen in Fig. 5.

5. Result analysis

A main problem highlighted earlier was that NDT methods often need skilled operators to make sense of the data created. This issue has not been addressed here. In order to solve this problem, the numerical package MATLAB® was employed to split the image data into the component parts and analyse these parts. A computer recognises an image as a series of pixels, each pixel is actually a series of numerical values depicting the amount of red, blue and green colour that is in the image. Thus, a complete image is actually a three deep matrix. By splitting this 3D matrix into three separate 2D matrices the images could be analysed in terms of its red, green and blue colours. A split thermal image can be seen in Fig. 6.

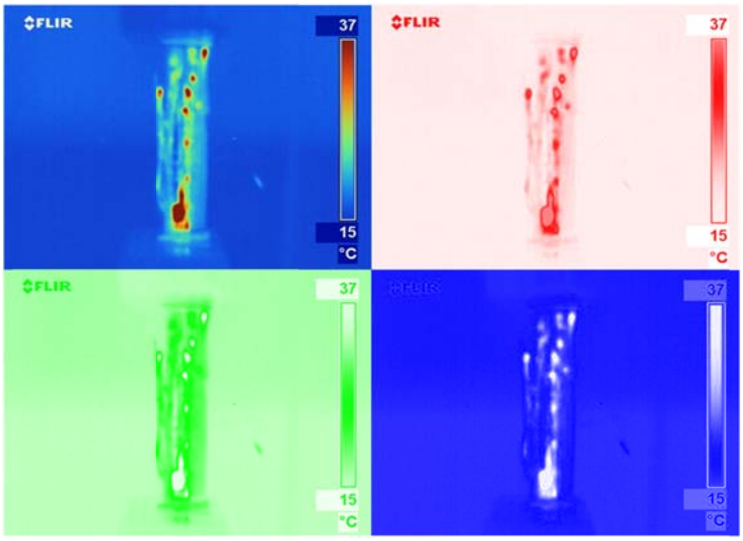


Fig. 6. Separated thermal image

It was found that the highest value in the red matrix was the location of the failure within the composite structure. To prove the location on the image was correct, the location of defect was physically measured on a printed thermal image. The distances given by both the program and the measured, real image were compared. A graph of this can be seen in Fig. 7. Now knowing that MATLAB® provides results equal to that of reality, the program was altered to give the location of the defect as a real world distance on the sample, i.e. the defect location vertically and horizontally from the point of origin (taken as the top left of the sample). This means that the output from the system does not require specialist training to comprehend.

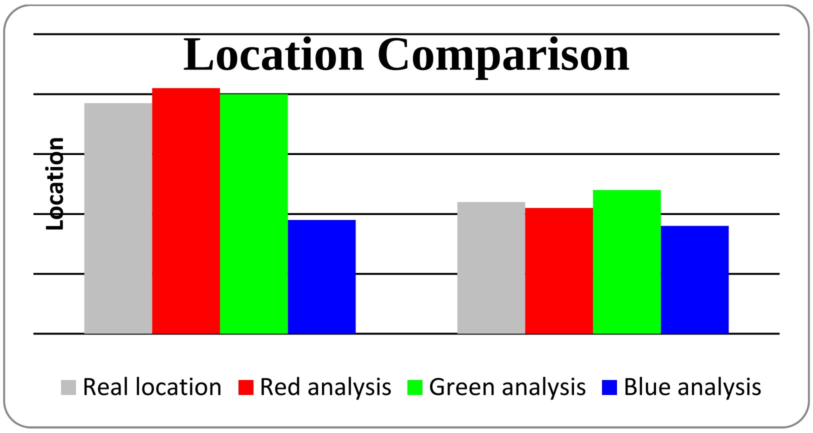


Fig. 7. Location comparison

6. Conclusion

In this research it has been demonstrated that by using thermal imaging and MATLAB® code it is possible to identify and locate a defect within a composite material as the failure occurs. This was done by taking a thermal image, breaking it down into its component red, green and blue parts, and identifying the location of maximum colour saturation in the red matrix. This maximum red colour corresponds directly to the location of heating the in thermal image and therefore the location of the defect. When looking back at the original aims at the start of the project we can see that we have succeeded in all aspects. We have produced a comprehensive methodology for detecting defects. This method is also applicable to an automated system as the thermal images are processed entirely by the created MATLAB® code to produce the defect location.

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