# Application of Thermography for Assessment of Crack Propagation in Composites

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**ABSTRACT**
The use of infrared photon detectors for full-field measurement of surface temperature for damage assessment of composites is an ongoing field of research. This paper presents the preliminary work on the application of Telops Fast m3K infrared camera for strain energy release rate measurement in fibre failure of carbon fibre composites. The technique is shown for quasistatic loading of compact tension specimen and identifying the crack propagation and instantaneous crack lengths using local changes in temperature near the crack tip.

**Keywords:** Thermography, Composite, Fibre failure, Crack propagation

## INTRODUCTION

The application of full-field measurement techniques for composite material and structural characterization has been fuelled by the dramatic advances in digital and infrared camera technologies and computational power. These full-field techniques directly provide displacement, strain or temperature contours of the specimens under testing and enables the identification of strain concentrations and damage more accurately [1]. Infrared thermography (IRT) is one of the full-field measurement techniques for the measurement of the surface thermal field of a structure. IRT is based on the principle that electromagnetic radiation in the infrared spectrum (wavelength in the range of 0.75–1000 um) is emitted by all objects above absolute zero temperature and the surface temperature can be monitored using an infrared detector system. Various authors have used IR-thermography to identify damage in FRP materials. In addition to the change in material temperature due to a change in applied stress (thermoelastic effect), heat generation in composites can be due to various mechanisms such as fracture, damping caused by viscoelastic behaviour of the matrix or the frictional sliding between fibre-fibre and fibre-matrix interfaces. Libonati and Vergani [2] studied the damage evolution in GFRP under static loading conditions and showed that IR thermography is a powerful tool for damage analysis and the thermal maps and thermal profiles allowed the detection of defects, damage formation, and evolution. For instance, small amount of energy is dissipated during the formation of microcracks, which can be observed as small temperature increase in the thermal images, while fibre breakage causes large dissipation of energy and a corresponding local increase of temperature. However, the use of thermography for high strain rate applications is limited by the capabilities of the currently available IR detectors. Yuan and Wang [3] calculated the energy release rate in compression after impact tests and found that the thermographic technique was a reliable method. The study of heat source fields combined with micrographic observations was used to identify the matrix micro-cracking as the predominant damage phenomenon in crack tip during notch propagation tests [4]. However, Wang et al. [5] remarked that studying the crack propagation of brittle materials require a high frame rate capability to measure the crack front temperature as the crack propagation velocity can be as high as 200 m/s. The high acquisition rates (>10kHz) required to capture the phenomena in dynamic tests means reduced integration times which adversely affects the signal to noise ratio. In this paper, the strain-energy release rates associated with fibre failure was studied for carbon fibre composites (CFRP) using IR thermography of compact tension specimens. The calculation of strain energy release rate using the area method is based on relating the dissipated mechanical energy $\Delta U$ to the newly generated free surface area due to crack tip advancement $\Delta a$. It has been reported that there are inaccuracies in estimating the crack tip location using optical techniques [6]. Thatcher et al. [7] have shown the crack growth monitoring using Thermoelastic stress analysis in fatigue loading of stainless steel. This paper explores the suitability of thermography to accurately measure the crack extension in FRP composite sample for quasistatic loading.

## MATERIALS AND METHODS

The compact tension samples were tested according to the conditions presented in [6]. A schematic geometry of the specimen and the test setup is shown in Fig. 1.

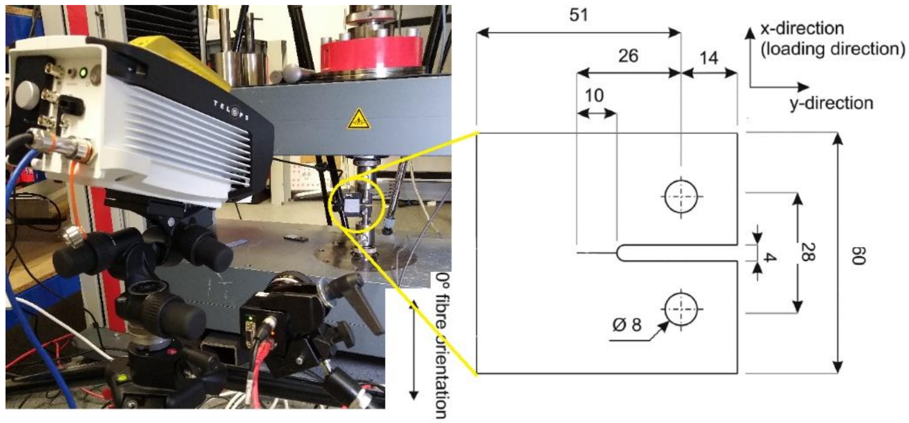


**Fig. 1** Test setup of Compact tension test for strain energy release rate measurement in fibre direction

Two different CFRP materials were chosen for the study: thermoset resin (epoxy) and thermoplastic matrix (PEEK). The carbon fibre epoxy composite was manufactured from 58 plies of Thinpreg 135 from North Thin Ply Technology while the thermoplastic composite was manufactured of 32 plies of CF-PEEK prepreg supplied by Solvay in a crossply [0/90] layup with additional 90 degree plies on the outer surface. A typical example of the force- displacement curve measured for quasistatic case of compact tension experiment from carbon fibre epoxy composite is shown in Fig.2. It can be seen that the curve exhibits a linear increase until reaching the peak after which a stepwise degradation of force can be observed for increasing values of opening displacement. The corresponding thermograms obtained from Telops FAST M3K photon detector camera capturing IR images at 10 Hz show hotspots at the location of the crack tip depicting crack propagation.

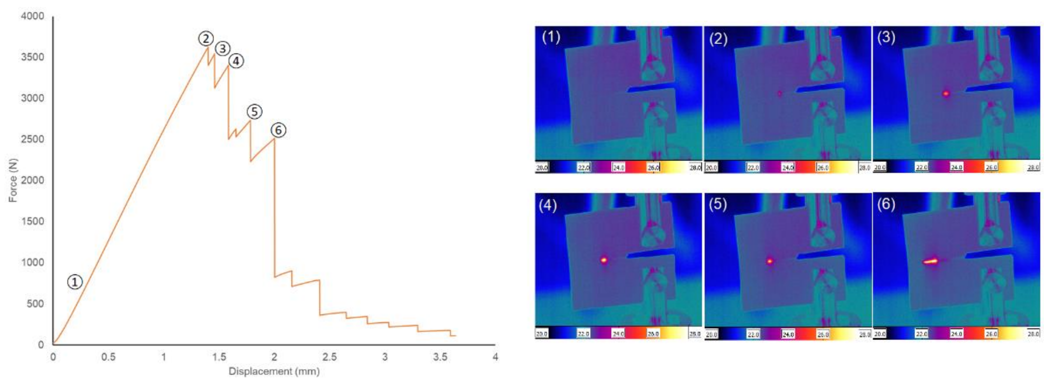


**Fig. 2** Force - displacement curve and surface temperature measurement showing hot spots at crack tip

**ANALYSIS**

The maximum temperature in the region of interest along the crack path was measured. A comparison of the change in temperature (ΔT) for the CF-epoxy composite and CF-PEEK composite is shown in Fig.3. In the linear elastic region before the crack propagation, there is a decrease in temperature (thermoelastic effect) followed by sharp peaks of temperature rise corresponding to crack propagation. It can be seen from the temperature history that the crack propagation is different for the thermoset and thermoplastic matrix. In the linear region, the cooling effect is more pronounced for the thermoplastic composite. The CF-epoxy composite shows slip-stick nature of the crack propagation which can be seen as distinctive peaks of large temperature increase while the PEEK composite showed a stable and continuous crack propagation and a smaller peak.

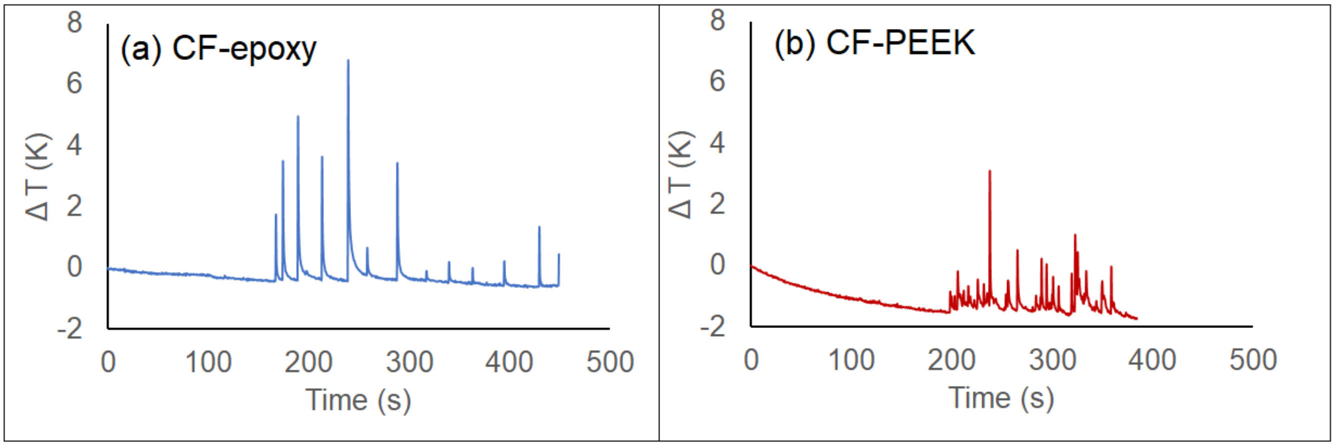


**Fig. 3** Comparison of change in max temperature for (a) CF-epoxy and (b) CF-PEEK composite

The location of the crack tip can be ascertained from the thermal maps. The frame number of the sharp peaks are identified and nondimensional ΔT/T maps are created by subtracting the peak image from the pixel by pixel average of the preceding 5 images. The crack extension for CF-epoxy composite shown in Fig. 4 can then be measured from the identified location of the hotspot.

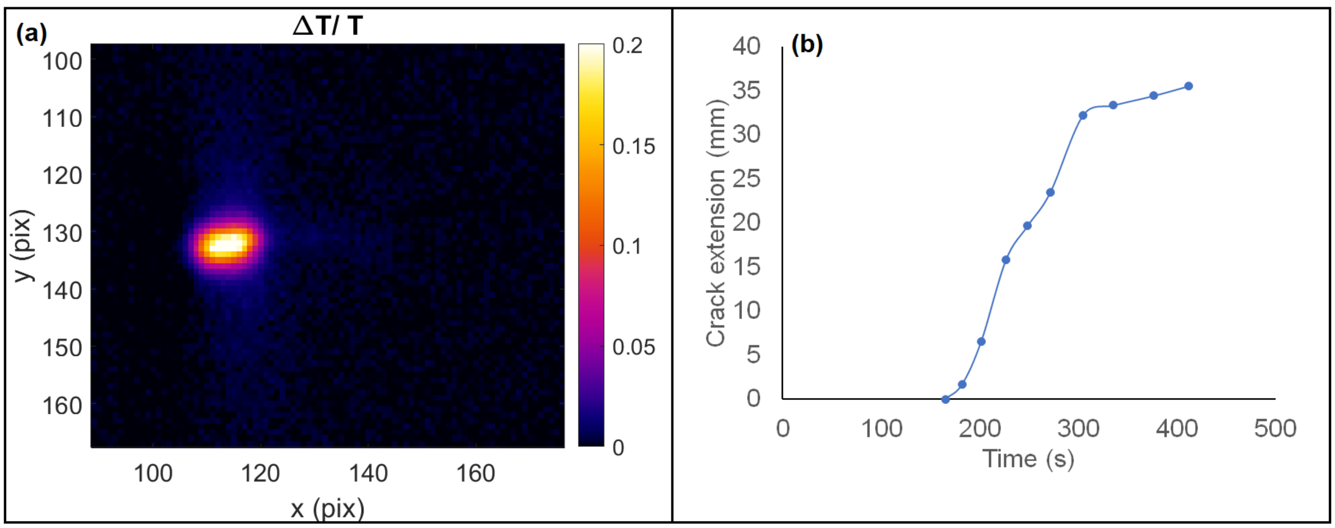


**Fig. 4** (a) Location of crack tip from normalised temperature maps and (b) crack extension

## CONCLUSION

The paper presents a preliminary study of the use of thermography for crack propagation analysis in compact tension specimen loaded quasistatically to show the feasibility of the technique. A combination of the crack extension measured from thermography and obtained from DIC will provide more accurate strain energy release rate measurement. Future study will utilise the high speed image acquisition capability of the Telops camera to study the crack propagation for dynamic case.

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## REFERENCES

[1] Grédiac M. The use of full-field measurement methods in composite material characterization: Interest and limitations. Compos Part A Appl Sci Manuf 2004;35:751–61. https://doi.org/10.1016/j.compositesa.2004.01.019.

[2] Libonati F, Vergani L. Damage assessment of composite materials by means of thermographic analyses. Compos Part B Eng 2013;50:82–90. https://doi.org/10.1016/j.compositesb.2013.01.012.

[3] Yuan Y, Wang S. Measurement of the energy release rate of compressive failure in composites by combining infrared thermography and digital image correlation. Compos Part A Appl Sci Manuf 2019;122:59–66. https://doi.org/10.1016/j.compositesa.2019.04.022.
[4] Lisle T, Pastor ML, Bouvet C, Margueres P. Damage of woven composite under translaminar cracking tests using infrared thermography. Compos Struct 2017;161:275–86. https://doi.org/10.1016/j.compstruct.2016.11.030.
[5] Wang W, Dulieu-Barton JM, Thomsen OT. A Methodology for Characterizing the Interfacial Fracture Toughness of Sandwich Structures using High Speed Infrared Thermography. Exp Mech 2016:121–32. https://doi.org/10.1007/s11340-015-0023-3.
[6] Hoffmann J, Cui H, Petrinic N. Determination of the strain-energy release rate of a composite laminate under high-rate tensile deformation in fi bre direction. Compos Sci Technol 2018;164:110–9. https://doi.org/10.1016/j.compscitech.2018.05.034.
[7] Thatcher JE, Crump DA, Devivier C, Bailey PB, Dulieu-Barton JM. Low cost infrared thermography for automated crack monitoring in fatigue testing. Optics and Lasers in Engineering. 2020 Mar 1;126:105914.