Monitoring and characterising the infrared temperature evolution of metallic SENT specimens for test machine control

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Abstract

It has been shown that as damage grows within a material during fatigue loading, there is a local temperature increase that can be measured with an infrared (IR) detector. The possibility of controlling damage evolution during a fatigue test, by monitoring the evolution using infrared thermography (IRT), is investigated. The idea is to use the thermal response as a non-contact test machine control parameter, to achieve a constant damage evolution throughout the tests and establish better modes of failure. The approach of 'damage evolution control' is well established for crack propagation in metals. For example crack opening displacement (COD) gauges are a well-known approach to control fatigue crack growth [1, 2]. IRT is a full-field technique which can be used to monitor the whole test specimen and offers significant advantages over the local technique (such as strain or COD gauges) when examining composite materials, as the damage is not localized at a single point. To control the 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. Hence, to refine the monitoring and control methodology, metallic, single edge notch tensile (SENT) specimens, manufactured from 316L stainless steel were fatigue tested.

Two fatigue regimes were used: a constant load controlled waveform, and a stepped, decreasing load waveform. The stepped reduction in load was triggered at predefined change in the maximum displacement of the specimen. A FLIR SC5500 series photon detector was used in all tests, to monitor and record the specimen temperature evolution at 1000 cycle intervals throughout the test sequence. The temperature evolution in the neighbourhood of the crack was monitored and used to define the crack growth. Figure 1 shows that the specimen temperature evolution from IRT is sufficient to detect crack length evolution. It was also shown that the load reduction produced a measurable change in temperature hence indicating that that IRT may be used as a control parameter.

Thermoelastic stress analysis (TSA) [3] was applied, to assist in locating the crack tip and provide an independent measure of the stress intensity factor. The application of TSA allowed three methods to be used to locate the crack tip: the location of the maximum temperature in the IRT image (Figure 1), the maximum thermoelastic response ΔT (Figure 2), and the phase of the thermoelastic response (Figure 3). Figure 4 shows the crack length change plotted against the number of cycles and demonstrates clearly that the maximum temperature in the field can be used to monitor the crack advance. This means that the maximum temperature change can be used directly to control the test machine and it is not necessary to carry out the post processing required for TSA.

The photon detector used for TSA is expensive, hence a FLIR A655sc microbolometer, was trialled as it is an affordable alternative to a photon detector. This system was used to take readings from the back face of the specimens to compare the results with those from the photon detector. FLIR's ResearchIR™ software was used to control the microbolometer and record the test data. The ResearchIR™ software package incorporates software development kits (SDK) for LabVIEW and MATLAB, permitting rapid data filtering and processing.

The ability to monitor full-field is essential when considering unnotched specimens, where the damage initiation point is not known. The damage location and the corresponding temperature evolution must be identified, characterised and quantified, before a control methodology can be developed. A LabVIEW program, using FLIR's SDK, is currently under development. The program will locate the maximum temperature on a specimen, and monitor the change in temperature and location. The data is then processed into an Instron WaveMatrix™ compatible format to control the test parameters.

Acknowledgments

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References

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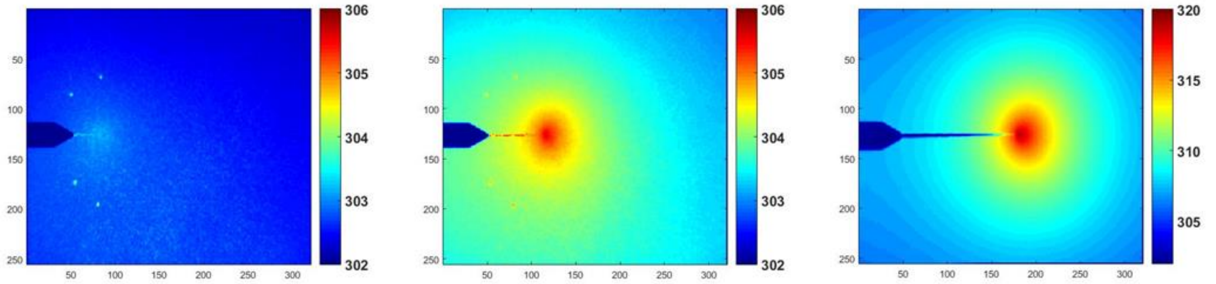
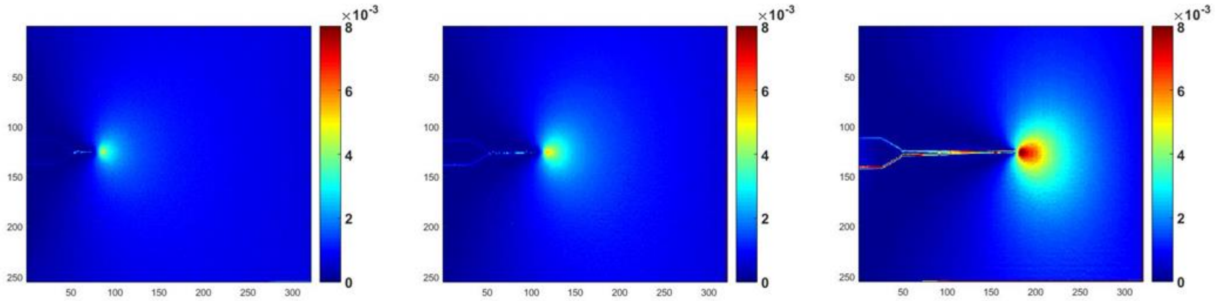


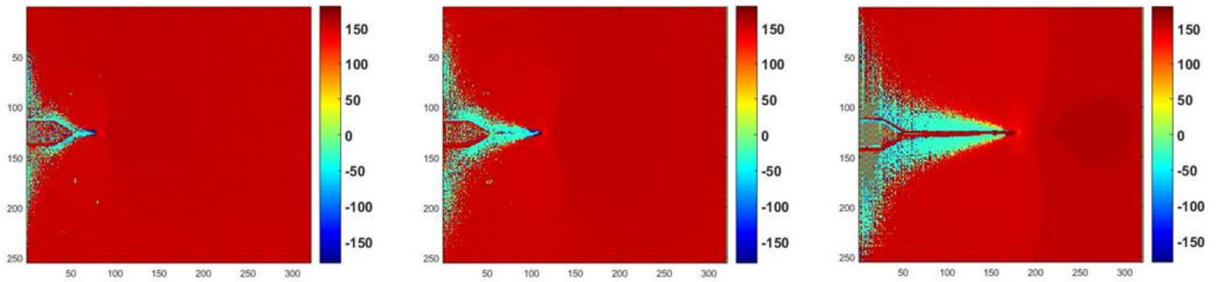
22,000 cycles 33,000 cycles 39,000 cycles

Figure 1. Specimen temperature evolution from IRT.



22,000 cycles 33,000 cycles 39,000 cycles

Figure 2. Thermoelastic response evolution (ΔT/T) from TSA.



22,000 cycles 33,000 cycles 39,000 cycles

Figure 3. Phase response evolution from TSA.

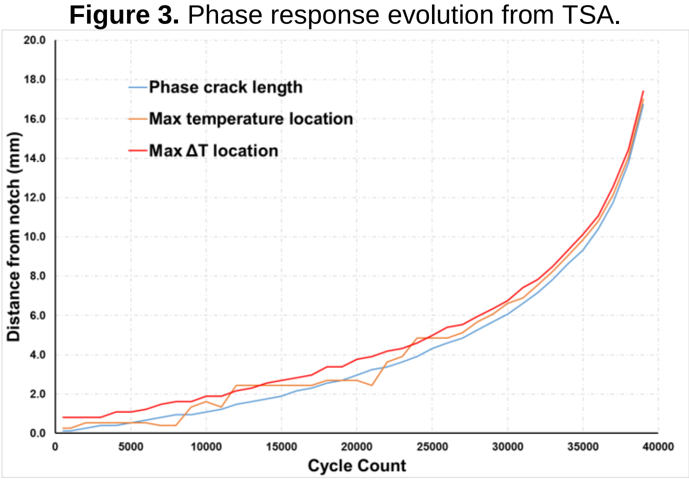


Figure 4. Crack tip location during constant load fatigue to failure.