Digital Imaging Correlation for Strain Control during Fatigue Cycling

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Abstract

Strain controlled fatigue testing is used to characterise the behaviour of material and components subject to thermal strains and cycling, for example, in high temperature reactor plants. Conventionally such testing uses an extensometer with a pair of ceramic probes pressed against the test specimen. Limitations of this approach include: potentially imparting surface damage and limiting the data generated from specimens with different properties, e.g. weldments. For these reasons, the present study evaluates the potential for using the non-contacting digital image correlation (DIC) strain measurement on standard low cycle fatigue (LCF) specimens.

Developments of the DIC approach involved improving the DIC processing speeds, mounting the optical camera system, and enhancing surface patterning (speckle-pattern) for localised strain measurement. The experimental setup is shown in figure 1 below. For speckle pattern development, parameters were developed to try to attain a speckle size of 10um, which would make each speckle about 3-5 pixels at the chosen magnification. A black Urethane based high temperature paint was tailored to the right consistency by using a thinning agent. This was to avoid the nozzle of the spray gun becoming blocked and losing control of the speckle size. A base coat of white paint was applied to the specimen surface before the black urethane paint was applied using an airbrush, with various compressor pressures trialled to find the optimal conditions for application and to create a trackable speckle pattern.

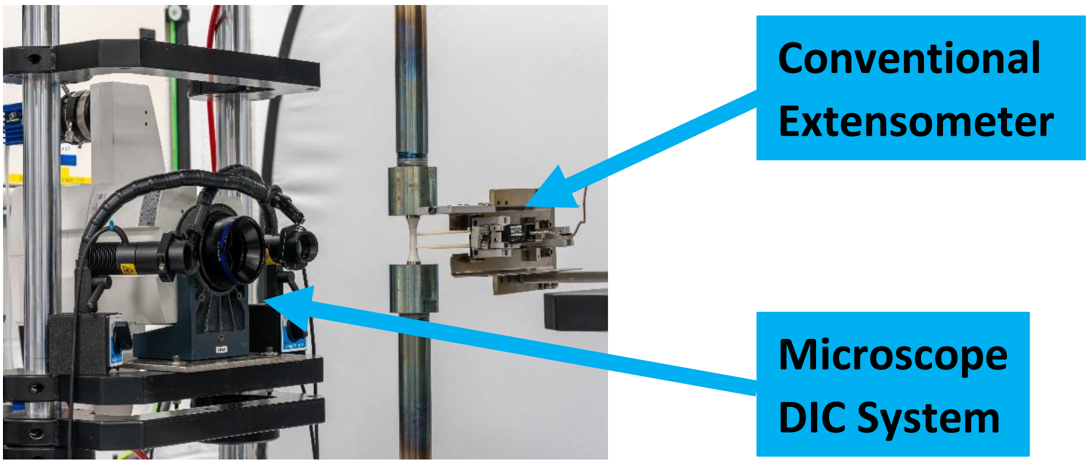

Figure 1: Experimental setup including the dual camera binocular microscope to capture images for DIC strain monitoring and conventional extensometer mount 180° from cameras

To understand the capability and accuracy of the DIC system, trials were conducted with the applied strain controlled by the conventional side-loaded extensometer and the DIC strain output was utilised for monitoring purposes. After the DIC output was optimised, subsequent trials focused on enabling the fatigue test equipment to receive the strain input from the DIC rather than extensometer output. All fatigue testing was carried out at room temperature with a target strain rate of 0.025%/s and a strain range of +/-0.3%. The conventional extensometer and test arrangement was consistent with the BS ISO 7270:2006

Initial trials used conventional extensometer controlled with DIC monitoring. It was successfully demonstrated that the DIC could maintain monitoring for at least 9000 cycles without loss of tracking. An example of the peak cyclic strains measured by the conventional extensometer and DIC are compared in figure 2. The diversion of the DIC strain measurements at cycle 2500 correlate with a crack developing within the test specimen. The stress vs strain hysteresis loops showed good correlation in the form of the loops, although some small discrepancies in the absolute strain measurements were found. These measured strain discrepancies require further calibration development for the DIC system.

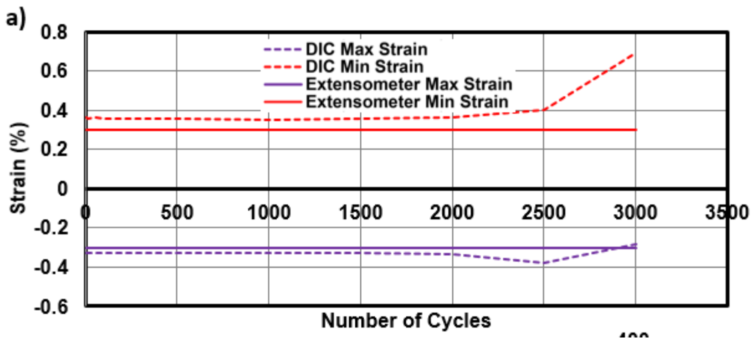

Figure 2 A trial where the specimen was taken to failure here a) plots the maximum and minimum strain vs number of cycles

Following growing confidence with the DIC strain monitoring, the control method for the load frame was changed to the DIC. The first step was to undertake increasing monotonic strain levels at slower strain rates prior to moving to cycling. Early fatigue cycles were performed at lower strain ranges and slower strain rates to gain confidence of the compatibility of the DIC control with the load frame. The strain ranges were increased and faster rates were used until the frame was performing the same loading conditions as the monitoring trials i.e. +/- 0.3% at 0.025%/s.

DIC control of fatigue cycling of a standard LCF test specimen was successfully achieved at room temperature, and up to 1000 fatigue cycles were undertaken in this control mode. Figure 3 shows the hysteresis loop responses from the conventional extensometer and the DIC. There is good correlation in the response from both of them, although the conventional extensometer shows some slight discrepancies at the reversal maximum and minimum strains.

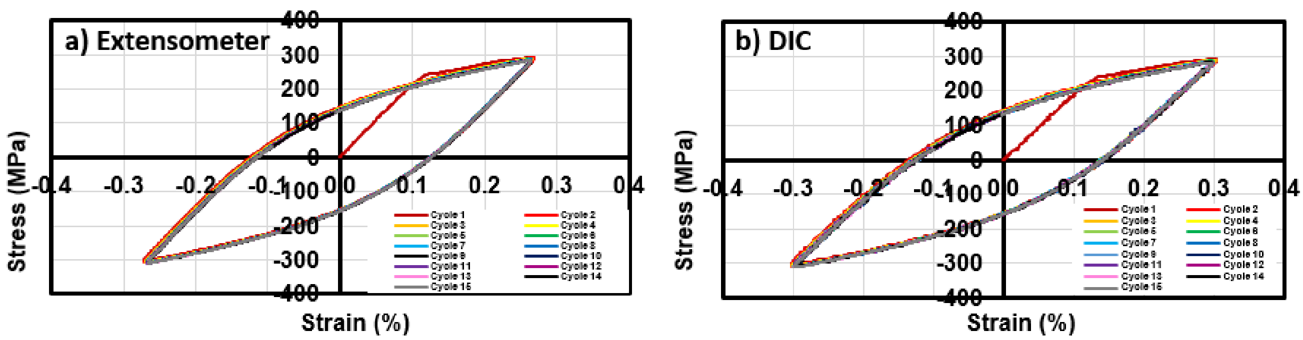

Figure 3 Outputs from a DIC controlled room temperature trial where, a, b) detail the stress vs strain response from the extensometer and DIC output respectively.